Review

Assessment of intraoral scanning technology for multiple implant impressions – A systematic review and meta-analysis

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Abstract

Background: Intraoral scanner (IOS) is a medical device used for capturing direct optical impressions and composed of a handheld camera (hardware), a computer and software. Digital impressions by intraoral scanning have become an increasingly popular alternative to conventional impressions. The aim of this systematic review is to assess the studies regarding the various available technologies for IOS and evaluate the most accurate IOS system for cases with multiple implants and identify the factors that can influence its accuracy.

Materials and Methods: A comprehensive electronic search was done in online databases, 'Pubmed', 'Google Scholar' and 'Cochrane' based on pre-determined eligibility criteria. In-vitro studies, In-vivo studies and Randomized controlled trials assessing the accuracy of intra-oral scanner technology were selected after thorough screening. The search strategy covered all studies published until February 2019 and yielded a total of 11 articles out of which 8 studies were determined to fulfil the inclusion criteria and were selected for this review. Data extraction from the included studies was conducted by the primary author and reviewed by the second author.

Results: The information collected included sample size and population, study design, intervention, scanning methods, comparisons and outcome measures. 5 out of 8 included studies compared the distance deviation of the acquired scans from the true values while the remaining 3 studies gave trueness and precision values as the outcome variables. A forest plot on scanner precision displayed slightly higher precision levels in the TRIOS scanner compared to the other intraoral scanners.

Conclusion: Despite the limitations this study, it can be concluded that active wavefront sampling is more accurate than the other intraoral scanning technology employed by commercial scanners.

Keywords: Accuracy, active wavefront sampling, confocal microscopy, multiple implant digital impression, optical triangulation, precision, trueness

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INTRODUCTION

Making an accurate implant impression is a crucial step in fabricating an implant-supported prosthesis.[1,2] There are two methods to make an impression-conventional methods which use elastomeric impression material to record implant position through physical copings and

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digital implant impressions which use optical methods. Irrespective of the method, the objective is to transfer the intraoral position of dental implants to a working cast or a virtual model.[2] Although the conventional impression has been routine in clinical practice for many decades, it is associated with many problems such as material preparation, distortion of impression, technique sensitivity, time-consuming, and patient discomfort.[3,4]

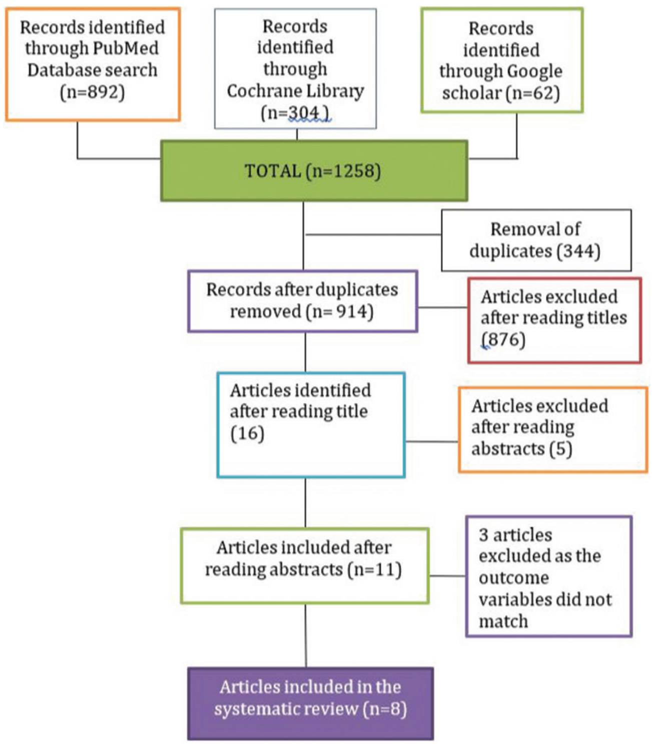
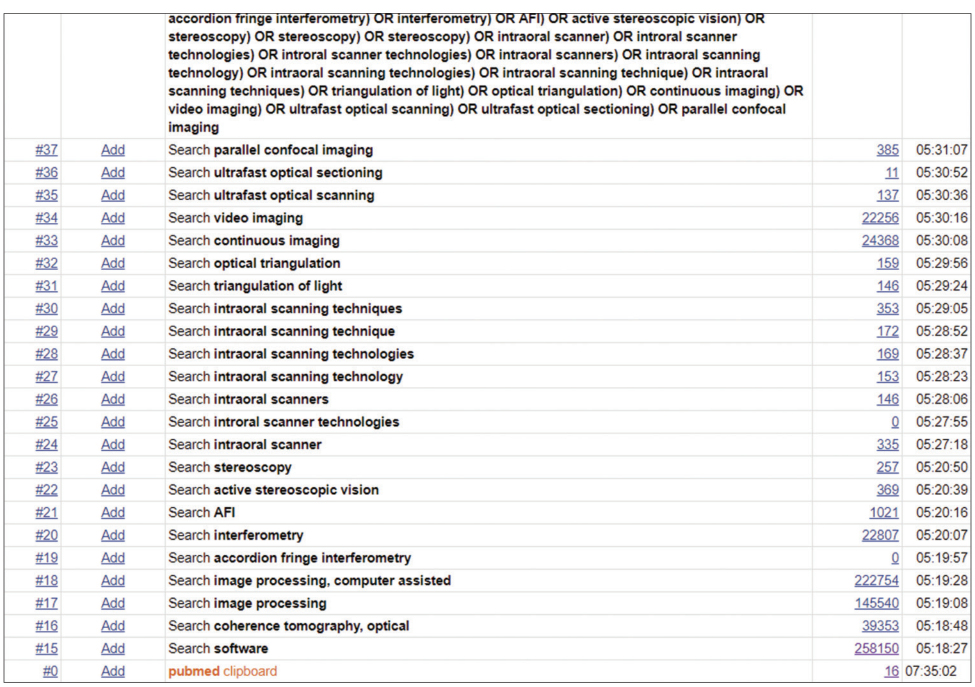


Figure 1: Flowchart of methodology (Prisma chart)

Digital impressions by intraoral scanning have become an increasingly popular alternative to conventional impressions.[5] They are a new method for acquiring implant positions and may replace conventional implant impressions and stone cast production.[6] Intraoral scanners (IOSs) help in overcoming the mistakes that occur during the conventional impression techniques since no laboratory procedures are involved, and a digital file can be transferred directly into a digital workflow.[3,7] Furthermore, IOS impressions help in decreasing the chairside time, enhance patient comfort, and allow for immediately visualizing the adequacy of the impression.[8,9]

IOS is a medical device used for capturing direct optical impressions composed of a handheld camera (hardware), a computer and a software.[10] The goal of an IOS is to record with precision the three-dimensional (3D) geometry of an object by projecting a light source onto the object to be scanned.[3,11] The images captured by imaging sensors are processed by the scanning software, which generates point clouds which are triangulated by the same software, creating a 3D-surface virtual model.[5] An increasing number of optical IOSs have been witnessed in the last decade.[12] These IOSs are based on different technologies, the choice of which may impact quality of clinical outcome.[6,11]



		accordion fringe interferometry) OR interferometry) OR AFI) OR active stereoscopic vision) OR stereoscopy) OR stereoscopy) OR stereoscopy) OR intraoral scanner) OR introral scanner technologies) OR introral scanner technologies) OR intraoral scanners) OR intraoral scanning technology) OR intraoral scanning technologies) OR intraoral scanning technique) OR intraoral scanning techniques) OR triangulation of light) OR optical triangulation) OR continuous imaging) OR video imaging) OR ultrafast optical scanning) OR ultrafast optical sectioning) OR parallel confocal imaging		
#37	Add	Search **parallel confocal imaging**	385	05:31:07
#36	Add	Search **ultrafast optical sectioning**	11	05:30:52
#35	Add	Search **ultrafast optical scanning**	137	05:30:36
#34	Add	Search **video imaging**	22256	05:30:16
#33	Add	Search **continuous imaging**	24368	05:30:08
#32	Add	Search **optical triangulation**	159	05:29:56
#31	Add	Search **triangulation of light**	146	05:29:24
#30	Add	Search **intraoral scanning techniques**	353	05:29:05
#29	Add	Search **intraoral scanning technique**	172	05:28:52
#28	Add	Search **intraoral scanning technologies**	169	05:28:37
#27	Add	Search **intraoral scanning technology**	153	05:28:23
#26	Add	Search **intraoral scanners**	146	05:28:06
#25	Add	Search **introral scanner technologies**	0	05:27:55
#24	Add	Search **intraoral scanner**	335	05:27:18
#23	Add	Search **stereoscopy**	257	05:20:50
#22	Add	Search **active stereoscopic vision**	369	05:20:39
#21	Add	Search **AFI**	1021	05:20:16
#20	Add	Search **interferometry**	22807	05:20:07
#19	Add	Search **accordion fringe interferometry**	0	05:19:57
#18	Add	Search **image processing, computer assisted**	222754	05:19:28
#17	Add	Search **image processing**	145540	05:19:08
#16	Add	Search **coherence tomography, optical**	39353	05:18:48
#15	Add	Search **software**	258150	05:18:27
#0	Add	**pubmed** clipboard	16	07:35:02

Figure 2: PubMed search showing terms for intervention

#57	Add	Search ((((((((((((((((dental implant) OR dental implants) OR dental implantation) OR maxilla) OR mandible) OR mouth) OR dental impression techniques) OR dental impression technique) OR digital implant impressions) OR digital implant impression) OR dental prosthesis, implant-supported) OR mouth, edentulous) OR multi unit implant impression) OR jaw, edentulous) OR implant, dental) OR implants, dental) OR dental models	490571	05:39:16
#56	Add	Search **dental models**	34519	05:38:07
#55	Add	Search **implants, dental**	36844	05:37:57
#54	Add	Search **implant, dental**	44306	05:37:47
#53	Add	Search **jaw, edentulous**	8949	05:37:31
#52	Add	Search **multi unit implant impression**	15	05:37:20
#51	Add	Search **mouth rehabilitation**	4995	05:37:08
#50	Add	Search **mouth, edentulous**	12210	05:36:59
#49	Add	Search **dental prosthesis, implant-supported**	8982	05:36:10
#48	Add	Search **digital implant impression**	184	05:35:50
#47	Add	Search **digital implant impressions**	126	05:35:34
#46	Add	Search **dental impression technique**	6639	05:35:21
#45	Add	Search **dental impression techniques**	6873	05:35:10
#44	Add	Search **mouth**	376226	05:34:46
#43	Add	Search **mandible**	72825	05:34:40
#42	Add	Search **maxilla**	39570	05:34:34
#41	Add	Search **dental implantation**	24187	05:34:26
#40	Add	Search **dental implants**	36844	05:34:17
#39	Add	Search **dental implant**	44306	05:34:10
#38	Add	Search **(((((((((((((((((((((((((((((((((((((((optical coherence tomography) OR microscopy, confocal) OR confocal mircroscopy) OR confocal microscopies) OR microscopies, confocal) OR confocal laser scanning microscopy) OR laser scanning confocal microscopy) OR microscopy,confocal,laser scnning) OR active wavefront sampling) OR AWS) OR stereophotogrammetry) OR stereophotogrammetries) OR tomography, optical coherence) OR OCT tomography) OR software) OR coherence tomography, optical) OR image processing) OR image processing, computer assisted) OR accordion fringe interferometry) OR interferometry) OR AFI) OR active stereoscopic vision) OR stereoscopy) OR stereoscopy) OR stereoscopy) OR intraoral scanner) OR introral scanner technologies) OR introral scanner technologies) OR intraoral scanners) OR intraoral scanning technology) OR intraoral scanning technologies) OR intraoral scanning technique) OR intraoral scanning techniques) OR triangulation of light) OR optical triangulation) OR continuous imaging) OR video imaging) OR ultrafast optical scanning) OR ultrafast optical sectioning) OR parallel confocal imaging**	692618	05:33:56
#37	Add	Search **parallel confocal imaging**	385	05:31:07

Figure 3: PubMed search showing terms for population and intervention

		digital implant impressions) OR digital implant impression) OR dental prosthesis, implant-supported) OR mouth, edentulous) OR multi unit implant impression) OR jaw, edentulous) OR implant, dental) OR implants, dental) OR dental models)) AND ((((((((((((((((((data accuracy) OR reproducibility of results) OR measurement accuracies, dimensional) OR accuracy, dimensional measurement) OR accuracies dimensional measurement) OR speed) OR time) OR trueness) OR precision) OR accuracy) OR trueness) OR data accuracies) OR dimensional measurement accuracies) OR dimensional measurement accuracy) OR accuracies, data) OR gap) OR accuarcy, data) OR discrepency) OR misfit)		
#76	Add	Search **((((((((((((((((((data accuracy) OR reproducibility of results) OR measurement accuracies, dimensional) OR accuracy, dimensional measurement) OR accuracies dimensional measurement) OR speed) OR time) OR trueness) OR precision) OR accuracy) OR trueness) OR data accuracies) OR dimensional measurement accuracies) OR dimensional measurement accuracy) OR accuracies, data) OR gap) OR accuarcy, data) OR discrepency) OR misfit**	4741591	05:44:11
#75	Add	Search **misfit**	1438	05:42:24
#74	Add	Search **discrepency**	24	05:42:15
#73	Add	Search **gap**	131851	05:42:07
#72	Add	Search **accuarcy, data**	1	05:42:01
#71	Add	Search **accuracies, data**	117817	05:41:38
#70	Add	Search **dimensional measurement accuracy**	3661	05:41:29
#69	Add	Search **dimensional measurement accuracies**	3695	05:41:20
#68	Add	Search **data accuracies**	117817	05:41:05
#67	Add	Search **accuracy**	358579	05:40:56
#66	Add	Search **trueness**	1087	05:40:49
#65	Add	Search **precision**	136350	05:40:43
#64	Add	Search **time**	3922987	05:40:34
#63	Add	Search **speed**	190764	05:40:28
#62	Add	Search **accuracies dimensional measurement**	77	05:40:22
#61	Add	Search **accuracy, dimensional measurement**	3661	05:40:12
#60	Add	Search **measurement accuracies, dimensional**	3695	05:39:52
#59	Add	Search **reproducibility of results**	392768	05:39:44
#58	Add	Search **data accuracy**	116085	05:39:31
#57	Add	Search **((((((((((((((((dental implant) OR dental implants) OR dental implantation) OR maxilla) OR mandible) OR mouth) OR dental impression techniques) OR dental impression technique) OR digital implant impressions) OR digital implant impression) OR dental prosthesis, implant-supported) OR mouth, edentulous) OR multi unit implant impression) OR jaw, edentulous) OR implant, dental) OR implants, dental) OR dental models**	490571	05:39:16
#56	Add	Search **dental models**	34519	05:38:07
#55	Add	Search **implants, dental**	36844	05:37:57

Figure 4: PubMed search showing terms for outcome and OR boolein for population

Various IOS differ in the distance to object technologies which are as follows:

1. Optical triangulation – Position of a point of a triangle (the object) can be calculated using the positions and angles of two points of view[7]
2. Confocal microscopy – Acquisition of focused and defocused images from selected depths. This technology can detect the sharpness area of the image

		accuarcy, data) OR gap) OR misfit) OR discrepancy)		
#80	Add	Search (((((((((((((((data accuracy) OR reproducibility of results) OR measurement accuracies, dimensional) OR accuracy, dimensional measurement) OR accuracies dimensional measurement) OR precision) OR trueness) OR accuracy) OR data accuracies) OR dimensional measurement accuracies) OR dimensional measurement accuracy) OR accuracies, data) OR accuarcy, data) OR gap) OR misfit) OR discrepancy	948734	06:08:13
#79	Add	Search ((((((((((((dental implant) OR dental implants) OR dental implantation) OR dental impression techniques) OR digital implant impressions) OR digital implant impression) OR dental prosthesis, implant-supported) OR multi unit implant impression) OR implant, dental) OR implants, dental) OR dental models) OR scan body) OR scan bodies) OR multiple implant impression	109839	06:06:07
#78	Add	Search (((((((((((((((((((((((optical coherence tomography) OR confocal mircroscopy) OR confocal microscopies) OR confocal laser scanning microscopy) OR active wavefront sampling) OR AWS) OR stereophotogrammetry) OR stereophotogrammetries) OR coherence tomography, optical) OR image processing) OR accordion fringe interferometry) OR interferometry) OR AFI) OR active stereoscopic vision) OR stereoscopy) OR intraoral scanner) OR introral scanner technologies) OR optical triangulation) OR triangulation of light) OR intraoral scanning techniques) OR intraoral scanning technique) OR continuous imaging) OR video imaging) OR ultrafast optical scanning) OR parallel confocal imaging	331791	06:03:23
#77	Add	Search ((optical coherence tomography) OR microscopy, confocal) OR confocal mircroscopy) OR confocal microscopies) OR microscopies, confocal) OR confocal laser scanning microscopy) OR laser scanning confocal microscopy) OR microscopy,confocal,laser scnning) OR active wavefront sampling) OR AWS) OR stereophotogrammetry) OR stereophotogrammetries) OR tomography, optical coherence) OR OCT tomography) OR software) OR coherence tomography, optical) OR image processing) OR image processing, computer assisted) OR accordion fringe interferometry) OR interferometry) OR AFI) OR active stereoscopic vision) OR stereoscopy) OR stereoscopy) OR stereoscopy) OR intraoral scanner) OR introral scanner technologies) OR introral scanner technologies) OR intraoral scanners) OR intraoral scanning technology) OR intraoral scanning technologies) OR intraoral scanning technique) OR intraoral scanning techniques) OR triangulation of light) OR optical triangulation) OR continuous imaging) OR video imaging) OR ultrafast optical scanning) OR ultrafast optical sectioning) OR parallel confocal imaging)) AND (((((((((((((((((dental implant) OR dental implants) OR dental implantation) OR maxilla) OR mandible) OR mouth) OR dental impression techniques) OR dental impression technique) OR digital implant impressions) OR digital implant impression) OR dental prosthesis, implant-supported) OR mouth, edentulous) OR multi unit implant impression) OR jaw, edentulous) OR implant, dental) OR implants, dental) OR dental models)) AND ((((((((((((((((((data accuracy) OR reproducibility of results) OR measurement accuracies, dimensional) OR accuracy, dimensional measurement) OR accuracies dimensional measurement) OR speed) OR time) OR trueness) OR precision) OR accuracy) OR trueness) OR data accuracies) OR dimensional measurement accuracies) OR dimensional measurement accuracy) OR accuracies, data) OR gap) OR accuarcy, data) OR discrepency) OR misfit)	8005	05:44:35
#76	Add	Search (((((((((((((((((data accuracy) OR reproducibility of results) OR measurement accuracies,	4741591	05:44:11

Figure 5: PubMed search showing AND boolein for population, intervention and outcome

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Search	Add to builder	Query	Items found	Time
#82	Add	Search (((((((((((((((((((((((((optical coherence tomography) OR confocal mircroscopy) OR confocal microscopies) OR confocal laser scanning microscopy) OR active wavefront sampling) OR AWS) OR stereophotogrammetry) OR stereophotogrammetries) OR coherence tomography, optical) OR image processing) OR accordion fringe interferometry) OR interferometry) OR AFI) OR active stereoscopic vision) OR stereoscopy) OR intraoral scanner) OR introral scanner technologies) OR optical triangulation) OR triangulation of light) OR intraoral scanning techniques) OR intraoral scanning technique) OR continuous imaging) OR video imaging) OR ultrafast optical scanning) OR parallel confocal imaging)) AND ((((((((((((dental implant) OR dental implants) OR dental implantation) OR dental impression techniques) OR digital implant impressions) OR digital implant impression) OR dental prosthesis, implant-supported) OR multi unit implant impression) OR implant, dental) OR implants, dental) OR dental models) OR scan body) OR scan bodies) OR multiple implant impression)) AND (((((((((((((((data accuracy) OR reproducibility of results) OR measurement accuracies, dimensional) OR accuracy, dimensional measurement) OR accuracies dimensional measurement) OR precision) OR trueness) OR accuracy) OR data accuracies) OR dimensional measurement accuracies) OR dimensional measurement accuracy) OR accuracies, data) OR accuarcy, data) OR gap) OR misfit) OR discrepancy) Sort by: **Best Match** Filters: **published in the last 5 years**	892	07:31:55
#81	Add	Search (((((((((((((((((((((((((optical coherence tomography) OR confocal mircroscopy) OR confocal microscopies) OR confocal laser scanning microscopy) OR active wavefront sampling) OR AWS) OR stereophotogrammetry) OR stereophotogrammetries) OR coherence tomography, optical) OR image processing) OR accordion fringe interferometry) OR interferometry) OR AFI) OR active stereoscopic vision) OR stereoscopy) OR intraoral scanner) OR introral scanner technologies) OR optical triangulation) OR triangulation of light) OR intraoral scanning techniques) OR intraoral scanning technique) OR continuous imaging) OR video imaging) OR ultrafast optical scanning) OR parallel confocal imaging)) AND ((((((((((((dental implant) OR dental implants) OR dental implantation) OR dental impression techniques) OR digital implant impressions) OR digital implant impression) OR dental prosthesis, implant-supported) OR multi unit implant impression) OR implant, dental) OR implants, dental) OR dental models) OR scan body) OR scan bodies) OR multiple implant impression)) AND (((((((((((((((data accuracy) OR reproducibility of results) OR measurement accuracies, dimensional) OR accuracy, dimensional measurement) OR accuracies dimensional measurement) OR precision) OR trueness) OR accuracy) OR data accuracies) OR dimensional measurement accuracies) OR dimensional measurement accuracy) OR accuracies, data) OR accuarcy, data) OR gap) OR misfit) OR discrepancy)	1527	06:10:43
#80	Add	Search (((((((((((((((data accuracy) OR reproducibility of results) OR measurement accuracies, dimensional) OR accuracy, dimensional measurement) OR accuracies dimensional measurement) OR precision) OR trueness) OR accuracy) OR data accuracies) OR dimensional measurement accuracies) OR dimensional measurement accuracy) OR accuracies, data) OR accuarcy, data) OR	948734	06:08:13

Figure 6: PubMed search showing final articles after using 5 years filter

to infer distance to the object that is correlated to the focal length of the lens[13]

3. Active Wavefront Sampling (AWS) – Distance and depth information are derived and calculated from the pattern produced by each point formed by the rotating module around the optical axis[14]
4. Stereophotogrammetry – Estimates all coordinates (x, y, and z) only through an algorithmic analysis

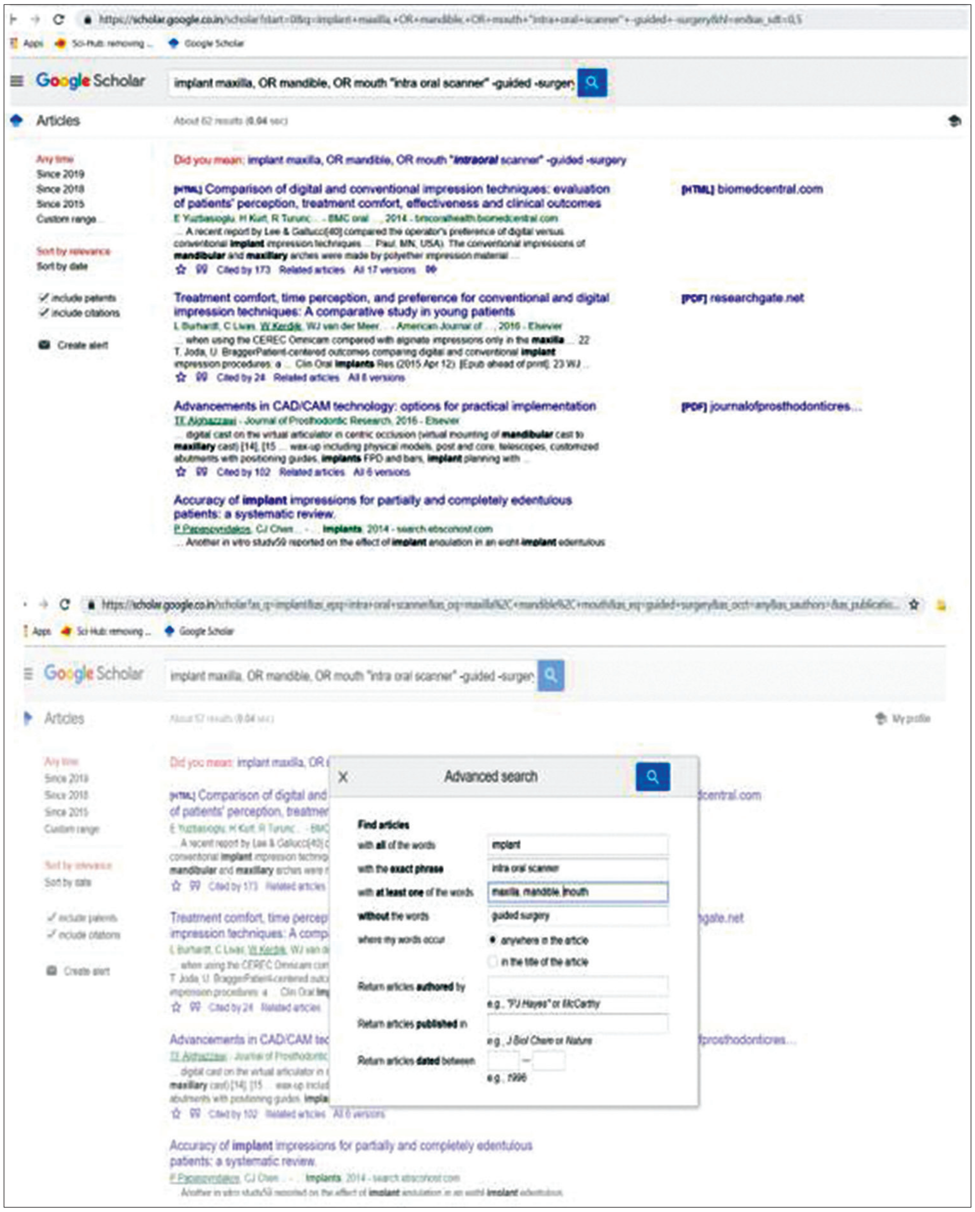

Figure 7: Electronic search using Google Scholar

of images, it relies on software and passive light projection.[15]

These IOS technologies have their share of clinical impact and pitfalls, which include powdering the surfaces, learning the art of handling the IOS, scanning path to be followed, understanding the tracking and software system.[10] Different IOS work on different technologies, and some systems even combine two or more methods to get more accurate scans. The assessment of the accuracy of the impression made by IOS is done by measuring the trueness and precision.[7] The purpose of this systematic review is to assess the studies regarding the various available technologies for IOS and evaluate the most accurate IOS system for scanning multiple implants and identify factors that can influence its accuracy.

Aim

This systematic review aims to assess various available intraoral scanning methods for multiple implant impressions and evaluate their accuracy.

MATERIALS AND METHODS

Structured question

Which is the most explicit intraoral scanning technology for multiple implant impressions in terms of accuracy and precision?

PICO (Population, Intervention, Comparison, and Outcomes)

- P – Multiple implants
- I – Intraoral scanning methods
- C – Nil
- O – Accuracy, trueness, and precision of impression and time taken to make the impression.

Outcome variables

The outcomes of interest in this systematic review are

- 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: Closeness of measured values between the independent results of the measurement obtained under specific conditions. It measures the repeatability and reproducibility of the results (Measured by difference in distance deviation, implant angulation and depth in μm)
- Trueness: Trueness is closeness of agreement between the mean obtained from repeated measurements and a true value. It depends on the repeatability of the results (Measured by difference in distance deviation, implant angulation and depth in μm)
- Speed: Amount of time taken to complete the full mouth scan.

Literature search protocol

Publications of interest within the scope of this focused systematic review were searched in

- The electronic database National Library of Medicine (MEDLINE/PubMed)
- Google Scholar
- Cochrane library
- Web of Science
- EMBASE
- Scopus.

The search was limited to the past 5 years. There were no restrictions or filters applied for the type of literature. A hand search was carried, but no additional articles apart from the electronic search were identified.

Search terms

P – Dental implant, dental implants, implants, dental, implant, dental prosthesis, implant-supported, mouth, maxilla, mandible, dental impression technique, humans, dental implant impressions, dental implant impression, dental implantation, jaw, edentulous, multi-unit implant impression, mouth edentulous, and mouth rehabilitation.

I – Intraoral scanning technologies, intraoral scanning technology, intraoral scanning technique, intraoral scanning techniques, IOSs, IOS, confocal microscopy, confocal microscopies, confocal laser scanning microscopies, stereophotogrammetry, stereophotogrammetries, optical coherence tomography, software, image processing, video imaging, continuous imaging, ultrafast optical sectioning, ultrafast optical scanning, parallel confocal microscopy, triangulation of light, optical triangulation, accordion fringe interferometry, interferometry, and active stereoscopic vision.

O – Accuracy, accuracies, data accuracy, data accuracies, dimensional measurement accuracy, dimensional measurement accuracies, speed, time, trueness, precision, reproducibility of data, repeatability of data, discrepancy, misfit, gap.

Article eligibility criteria

Inclusion criteria

- Experimental and clinical studies, *in vitro* and *in vivo* studies
- Studies using any one or multiple IOSs
- Articles having outcome measures as accuracy, trueness, or precision
- Studies using digital impressions of multiple implants in edentulous arches.

Exclusion criteria

- Animal studies
- Studies involving single implant restorations
- Studies involving partially edentulous arches
- Case reports, reviews, systematic reviews
- Studies comparing digital and conventional methods for scanning.

Article selection

Search results

A total of 1258 articles were obtained using keywords in a Boolean search operator in the PubMed search engine. Duplicates were removed, and the remaining articles were subjected to a title analysis which yielded a total of 16. Further analysis of the articles' abstracts leads to an exclusion of five articles. The remaining 11 articles were subjected to full-text analysis which yielded a total of 8 articles [Figures 1-8].

Search strategy

Data extraction

The data of the selected studies were extracted using customized data abstraction tables. Information extracted from each study included the following [Tables 1-6]:

- Author and year

- Study design
- Specimen
- Scanning technique
- Scanner
- Implant site and number
- Implant angulation used
- Depth of implant
- Outcome variables
- Sample size
- Scanned surface treatment
- Significance
- Operator.

RESULTS

Meta-analysis was planned between two studies namely Stefen *et al*., 2016 and Mario *et al*., 2017 as both these studies had a similar methodology, outcome variables and comparison between CEREC Omnicam and Trios 3.

The cumulative results of the meta-analysis display a mild superiority in terms of accuracy for the Trios 3 scanner (AWS) over CEREC Omnicam. Figure 9 shows the meta-analysis of articles comparing the precision of Trios 3 and CEREC Omnicam, and Figure 10 shows a comparison of trueness between the two. Precision of included studies has low heterogeneity (I^2) while the trueness plot is observed to possess high heterogeneity. The overall effect of the consolidated meta-analysis favors the Trios 3 IOS ($z = 3.53$).

DISCUSSION

Conventionally, multiple implant impressions are obtained from either direct (open tray/splinted impression) or indirect (closed tray/unsplinted impression) techniques.[16] These impressions made from the impression materials have been gold standard for multiple implant impressions for decades.[17,18] These impressions are time-consuming,

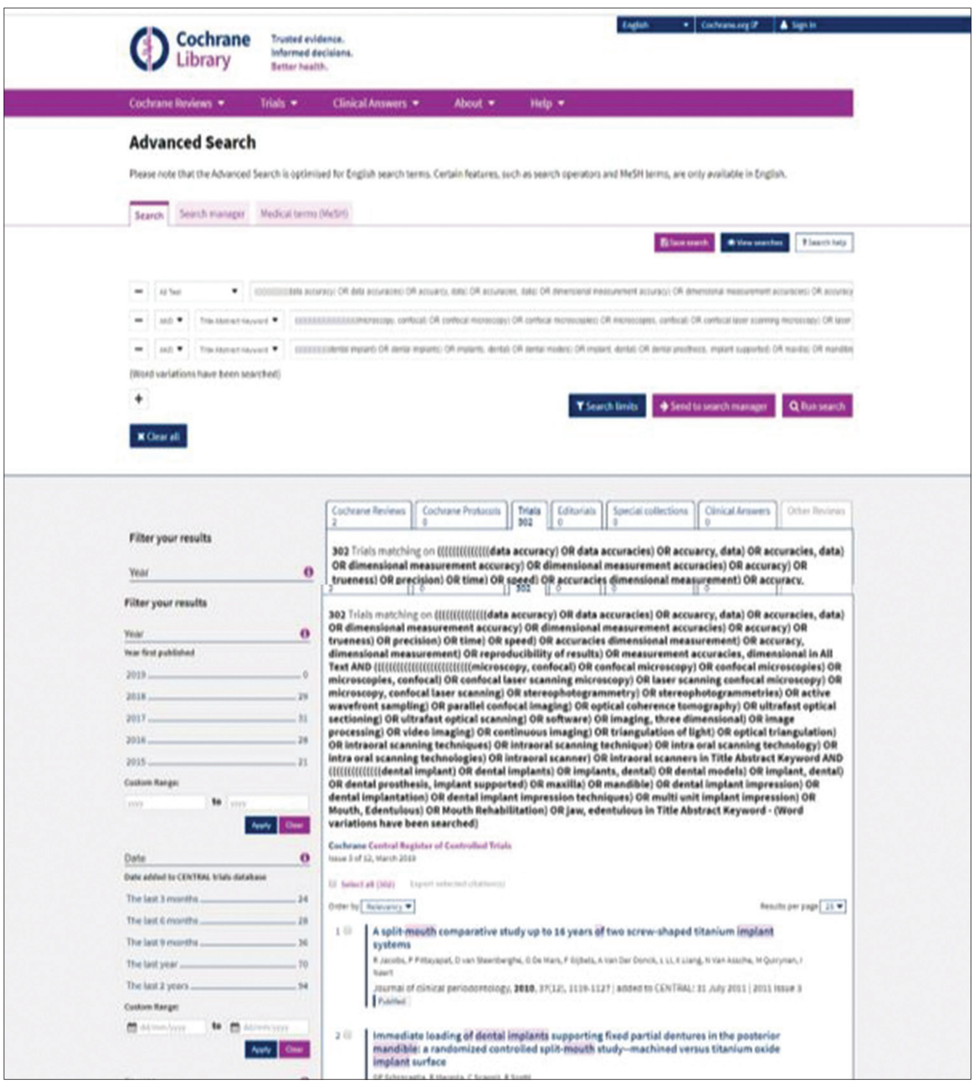

Figure 8: Cochrane search resulted in 2 systematic reviews and 302 trials

Forest plot

Study or Subgroup	Trios Mean	Trios SD	Trios Total	Cerec omnicam Mean	Cerec omnicam SD	Cerec omnicam Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Mario et al 2017	0.031	0.009	5	0.057	0.009	5	20.9%	−2.61 [−4.53, −0.69]
stephan et al 2016	0.033	0.012	10	0.059	0.024	10	79.1%	−1.31 [−2.30, −0.33]
Total (95% CI)			**15**			**15**	**100.0%**	**−1.58 [−2.46, −0.71]**

Heterogeneity: $Chi^2 = 1.38$, df = 1 (P = 0.24); $I^2 = 28\%$
Test for overall effect: Z = 3.53 (P = 0.0004)

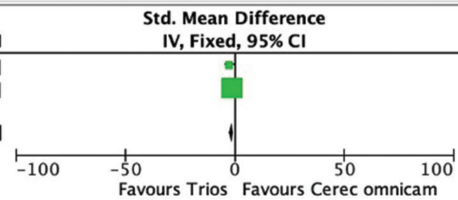

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Figure 9: Precision

Study or Subgroup	Trios Mean	Trios SD	Trios Total	Cerec omnicam Mean	Cerec omnicam SD	Cerec omnicam Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Mario et al 2017	0.067	0.006	5	0.066	0.003	5	43.3%	0.19 [−1.05, 1.43]
stephan et al 2016	0.028	0.007	10	0.061	0.023	10	56.7%	−1.86 [−2.95, −0.77]
Total (95% CI)			**15**			**15**	**100.0%**	**−0.97 [−1.79, −0.15]**

Heterogeneity: $Chi^2 = 5.91$, df = 1 (P = 0.02); $I^2 = 83\%$
Test for overall effect: Z = 2.33 (P = 0.02)

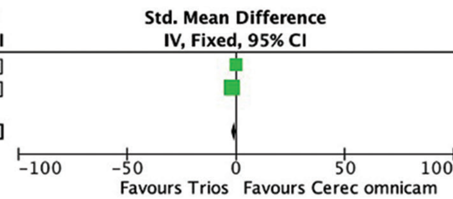

Figure 10: Trueness

messy, and technique sensitive. They lead to many errors and discrepancies in the cast models due to material properties, method of impression making, and laboratory procedures. They are also considered to be uncomfortable for the patients due to various factors such as smell of the material, amount of the material, size of the tray, and the intraoral setting time of the material.[17]

The digital revolution has engulfed the dental profession through the introduction of digital impressions through IOSs.[19,20] The optical impressions are considered to be relatively more comfortable for the patient and easier and convenient to take for the clinician.[13,21,22] They are rapidly overtaking the conventional methods, with the latter likely to disappear in the next few years.[19] The last decade has seen an increasing number of optical IOSs, and these are based on different technologies.[11]

An IOS is a medical device which takes an optical impression of teeth and implants, using a beam of light.[23,24] Irrespective of the type of imaging technology used by IOS, all cameras require the projection of light. This beam of light is then recorded as individual images or video and compiled by the software after recognition of the POI (points of interest). The first two coordinates (x and y) of each point are evaluated on the image, and the third coordinate (*z*) is then calculated depending on the distance to object technologies of each camera.[10] The distance to object technologies is based on principles of optical triangulation, AWS, confocal microscopy, stereophotogrammetry, accordion fringe interferometry or video imaging.

The commercially available scanners based on optical triangulation are CEREC Bluecam; AWS-Lava COS and TrueDef; Confocal microscopy-Trios 3, Trios 3 Mono, iTero, 3D Progress; Video imaging-CS 3600. A few commercial scanners like CEREC Omnicam employ a combination of optical triangulation and confocal microscopy technology.[5,7]

The fact that IOS can be a reliable tool for making impressions of single and multiple abutments in patients have been proved by several studies.[25-27] However, there is no systematic review compiling the results of these studies based on the technology used in the scanner. This systematic review aims to assess the various technologies used for IOS and the clinical factors affecting it.

In this systematic review, a total of eight *in vitro* studies were evaluated. All the eight studies evaluated the accuracy of the digital impression of the multiple implant casts. They compared the distance deviation in length and angle between the implant scan bodies of the acquired standard tessellation language files from the scanned models to the true values of the master model obtained using an industrial 3D coordinated measurement machine whose accuracy was certified by the National Entity of Accreditation. Five out of eight studies gave the distance deviations from true values and compared the underlying technology by the average error values. The remaining three studies described the trueness and precision of the scanner used.

The average error values obtained for the complete arch multiple implant digital impression from the five included studies were as follows: Lava COS - 45.02 ± 37.31 μm, Cerec

Table 1: Characteristics and summary of included studies

Author and years	Study design	Specimen	Scanning technique	Scanner	Implant site and number	Angulation of implant (°)	Depth of implant (mm)	Scanning method	Sample size	Scanned surface treatment	Operators
Beatriz Gimenez *et al*., 2013	*In vitro*	Edentulous resin model	AWS	Lava COS	12, 22 15, 25 17, 27 6	0, 0 30 distal, 30 mesial 0, 0	4, 2 0, 0 0, 0	Continuous circular scan	50 per group	Application of titanium dioxide powder	4 Group 1-2 experienced Group 2-2 inexperienced
Beatriz Gimenez *et al*., 2015	*In vitro*	Edentulous resin model	Optical triangulation	CEREC bluecam	12, 22 15, 25 17, 27 6	0, 0 30 distal, 30 mesial 0, 0	4, 2 0, 0 0, 0	Continuous scans parallel to the arch	50 per group	-	4 Group 1-2 experienced Group 2-2 inexperienced
Beatriz Gimenez *et al*., 2014	*In vitro*	Edentulous resin model	Parallel confocal laser technology	iTero	12, 22 15, 25 17, 27 6	0, 0 30 distal, 30 mesial 0, 0	4, 2 0, 0 0, 0	BOP	50 per group	Nil	4 Group 1-2 experienced Group 2-2 inexperienced
Beatriz Gimenez *et al*., 2015	*In vitro*	Edentulous resin model	Confocal microscopy	3D progress ZFX intrascan	12, 22 15, 25 17, 27	0, 0 30 distal, 30 mesial 0, 0	4, 2 0, 0 0, 0	Continuous around scan bodies	50 per group	Nil	4 Group 1-2 experienced Group 2-2 inexperienced
Beatriz Gimenez *et al*., 2015	*In vitro*	Edentulous resin model	AWS	True definition	12, 22 15, 25 17, 27 6	0, 0 30 distal, 30 mesial 0, 0	4, 2 0, 0 0, 0	-	50 per group	-	4 Group 1-2 experienced Group 2-2 inexperienced
Stefan *et al*., 2016	*In vitro*	Acrylic edentulous mandible model	AWS AWS Active triangulation confocal microscopy	Lava COS True definition CEREC omnicam Trios	36, 46 34, 44 32, 42 6	-	-		10 per group	Light powder dusting Light powder dusting Nil Nil	-
Hussam *et al*., 2018	*In vitro*	Edentulous stone model with core structure of tungsten	Confocal microscopy Confocal microscopy Parallel confocal microscopy	Trios 3 Trios 3 mono iTero	12, 22, 23, 25, 15 5	Nonparallel positions	-	BOP BOP Zigzag movement	30 per group	Nil Nil Nil	1 experienced
Mario Imburgia *et al*., 2017	*In vitro*	2 models: Stone model of partially edentulous maxilla Stone model of edentulous maxilla	Active speed 3D video Confocal microscopy and ultrafast Optical scanning Optical triangulation and confocal Microscopy AWS 3D video technology	CS 3600 Trios 3 CEREC omnicam True definition	23, 24, 26 3 11, 21 14, 24 16, 26 6	-	-	-	5 per group	Nil Nil Nil Powder dust	1 experienced

AWS: Active wavefront sampling, 3D: Three-dimensional, BOP: Buccal-occlusal-palatal

Bluecam - 44.10 ± 48.5 μm, iTero - 32 ± 216.1 μm, ZFX Intrascan - 150.6 ± 1080.3 μm, 3D Progress - 497.4 ± 1346.0 μm and TrueDef - 26.47 ± 50.56 μm. According to these results, AWS technology gives the least error values followed by confocal microscopy and then optical triangulation. The distance deviation increases with the amount of overlaps taken and also from the first quadrant to the second, with the first scanned quadrant being significantly more accurate than the second.[28,29]

The remaining three studies by Stefan *et al.* in 2016, Hussam *et al*., in 2018, and Imburgia *et al.* in 2017, compared the trueness and precision of the IOSs. Trueness refers to the closeness of agreement between the expectation of a test result and a true value.[5,27,30] Precision is defined as the closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same objects under specified conditions.[5,27,30] Ideally, an IOS should have high trueness value, i.e., it should be able to match reality as closely as possible and also high precision value which indicates its repeatability.[31] According to Hussam *et al*., none of the technologies reached the required trueness and precision values and were considered unreliable for multiple implant impression. According to Stefan *et al*., AWS showed higher trueness and precision compared to confocal microscopy and optical triangulation.

Table 2: Outcome variables of 5 included studies

	Beatriz Gimenez *et al.*, 2013	Beatriz Gimenez *et al.*, 2015	Beatriz Gimenez *et al.*, 2014	Beatriz Gimenez *et al.*, 2015		Beatriz Gimenez *et al.*, 2015
				ZFX intrscan	3D progress	
Distance deviation (µm)						
Group 1	−29.39±5.49	−28.49±26.91	−14.3±25.6	−32.7±111.1	28.8±94	5.83±12.61
Group 2	−33.35±15.64	−22.46±30.92	−16.2±34.6	−157±292	9.3±29.5	9.86±21.62
Group 3	−45.02±37.31	−107.25±68.65	−27.9±61.6	−142.8±487.7	164.5±526.3	10.05±18.84
Group 4	−11.02±28.12	116.84±94.23	−23.1±148.0	−216.7±836.6	484.6±1057.3	−14.07±33.26
Group 5	−35.28±22.19	−123.09±138.31	−32.0±216.1	−150.6±1080.3	497.4±1346	−26.97±50.56
Implant angulation (µm)						
Angled	−20.2±21.9	−72.7±81.7	–	−125±596	257±776	0.12°±0.05°
Straight	−37.9±26.2	−84.3±99.9	–	−150±693	224±854	0.31°±0.11°
Implant depth (µm)						
Deep	−34.33±18.7	−89.47±105.59	−27.9±61.64	−150±397	87±403	–
Normal	−28.3±29.8	−107.25±68.65	−23.1±149.48	−133±782	337±997	–
Operator experience (µm)						
Experienced	−30.8±25.9	−85.4±98.9	–	−179±601	249±702	–
Inexperienced	13.3±51.2	−47.3±75.7	–	−101±705	224±930	–
Average error	−42.02±37.31	−44.10±48.5	−32±216.1	−150.6±1080.3	497.4±1346.0	−29.97±50.56

3D: Three-dimensional

Table 3: Outcome variables of 3 included studies

Author and years	Scanning technology	Scanner	Trueness (µm)	Precision (µm)
Stefan *et al.*, 2016	AWS	Lava COS	112±25	66±25
	AWS	True definition	35±12	30±11
	Confocal microscopy	Trios	28±7	33±12
	Active triangulation	CEREC omnicam	61±23	59±24
Hussam *et al.*, 2018	Confocal microscopy	Trios 3	−38	124
	Confocal microscopy	Trios 3 mono	−20	86
	Parallel confocal microscopy	iTero	−35	78
Mario Imburgia *et al.*, 2017	Active speed 3D video	CS 3600	60.6±11.7	65.5±16.7
	Confocal microscopy and ultrafast optical scanning	Trios 3	67.2±6.9	31.5±9.1
	Optical triangulation and confocal microscopy	CEREC omnicam	66.4±3.9	57.2±9.1
	Active wavefrontsampling 3D video technology	True definition	106.4±23.1	75.3±43.8

AWS: Active wavefront sampling, 3D: Three-dimensional

Table 4: Enlists the groups of studies based on parameters assessesing outcome

Type of parameter	Total number of studies
Accuracy	5
Precision	3
Trueness	3
Operator experience	6
Implant depth and angulation	7

According to Mario *et al.*, AWS had significantly higher precision and trueness values compared to the others which were almost at similar values. The meta-analysis performed between Trios 3 and CEREC Omnicam for Stefan *et al.* and Mario *et al.* studies favored Trios 3 scanner for better trueness and precision.

There are certain clinical impacts and concerns of digital impressions, especially when it involves full arch implant scanning.[31] For digital implant impressions, scan bodies are required which are available separately for every implant size and system which adds to the expense of the impression. The studies included in the review were *in vitro* studies where research was performed on models. Clinically, the oral environment consists of saliva, humidity, limited mouth opening and also patient anxiety levels adds to the difficulty of impression making.[4] Secondary outcome variables such as operator experience, implant angulation and depth, scanning technique were also included in the studies by Beatriz Gimenez *et al.*

Operator experience influences the accuracy of the digital impressions. The accuracy of impressions is better with experienced operator compared to the inexperienced one. However, the inexperienced operators improve the accuracy with the increased number of trials.[22] Contrary to this study another study concluded that the performance of the operator is not necessarily dependent on experience.[32] However, the author was keen to note that expertise even at the lack of experience, is definitely crucial to the accuracy of digital impression.[32]

Implant angulation and depth affect the accuracy of the impression taken. Due to increased angulation of implants, a conventional impression is distorted when the tray is taken out of the mouth,[33] and this angulation is limited to 25° for accurate conventional impressions.[34,35] Digital impressions made by confocal microscopy technology

Table 5: Levels of evidence and risk of bias (according to Oxford centre for evidence-based medicine 2011 levels of evidence)

Author and year	Study design	Level of evidence	Risk of bias
Beatriz Gimenez *et al*., 2013	Prospective comparative study	III B	High
Beatriz Gimenez *et al*., 2015	Prospective comparative study	III B	High
Beatriz Gimenez *et al*., 2014	Prospective comparative study	III B	High
Beatriz Gimenez *et al*., 2015	Prospective comparative study	III B	High
Beatriz Gimenez *et al*., 2015	Prospective comparative study	III B	High
Wicher *et al*., 2012	Prospective comparative study	III B	High
Stefan *et al*., 2016	Prospective comparative study	III B	High
Paolo Pesce *et al*., 2018	Prospective comparative study	III B	High
Hussam *et al*., 2018	Prospective comparative study	III B	High
Leonardo *et al*., 2017	Prospective comparative study	III B	High
Mario Imburgia *et al*., 2017	Prospective comparative study	III B	High

Table 6: List of excluded articles

Author and years	Title	Reason for exclusion
Wicher *et al*., 2012	Application of intra-oral dental scanners in the digital workflow of implantolgy	The outcome measure used was absolute error
Tabea V. Flugge *et al*., 2016	Precision of dental implant digitization using intraoral scanners	The cast used was partially edentulous
Paolo *et al*., 2018	Precision and accuracy of a digital impression scanner full-arch implant reahabilitation	The outcome measure used was sheffield test

are not significantly affected by the implant angulation or depth of the[32] implants.[36] The same was reported in another study where the information of the scan bodies in submerged implants was captured sufficiently without affecting the accuracy.[22] Angulated implants and the deeply placed implants did not seem to decrease the accuracy in digital impressions.[22] The present review observed the implant site and number did not influence the accuracy of impression making using the various intraoral scanning devices. Furthermore, the time and speed of impression making, which is a potential variable that could affect the accuracy of impressions, were not clearly mentioned in the studies included for the systematic review.

The accuracy of full-arch multiple implant scan is related with the correct scanning method. The scanning method and camera movement play an important role in the accuracy of the virtual model.[37] Müller *et al*. reported that the zigzag strategy for intraoral scanning has a lower trueness value but a better precision value than buccal–occlusal-palatal strategy.[38]

In this systematic review, we could identify only *in vitro* studies. The overall level of evidence is Level 3B; hence, we require well-designed clinical trials with standardized outcomes to recommend the most useful technology and scanner for making an accurate multiple implant digital impression.

CONCLUSION

Despite the limitations of this study, we can conclude that AWS technique possesses a greater degree of accuracy for making multiple implant digital impression. The degree of expertise of the user is also observed to influence the accuracy of the digital impressions. Implant angulation and depth do not affect the accuracy of digital implants. However, longer clinical trials are required to provide a stronger level of evidence to validate the results of this systematic review.

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Conflicts of interest
There are no conflicts of interest.

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