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

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
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]

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]
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.
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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 5: PubMed search showing AND boolean for population, intervention and outcome

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

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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 \( \mu m \))
- 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 \( \mu m \))
- 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 \( \mu m \))
- 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 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
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- 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. These impressions made from the impression materials have been gold standard for multiple implant impressions for decades. These impressions are time-consuming,
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]\n
The digital revolution has engulfed the dental profession through the introduction of digital impressions through IOSs.\[19,20]\n
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]\n
They are rapidly overtaking the conventional methods, with the latter likely to disappear in the next few years.\[19]\n
The last decade has seen an increasing number of optical IOSs, and these are based on different technologies.\[11]\n
An IOS is a medical device which takes an optical impression of teeth and implants, using a beam of light.\[21,24]\n
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.\[19]\n
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]\n
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]\n
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 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...
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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 | 0, 0 | 4, 2 | 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 | 0, 0 | 4, 2 | 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 | 0, 0 | 4, 2 | 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 | 12, 22 | 0, 0 | 4, 2 | 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 | 0, 0 | 4, 2 | - | 50 per group | - | 4 Group 1-2 experienced, Group 2-2 inexperienced |
| Stefan et al., 2016 | In vitro | Acrylic edentulous mandible model | AWS | Lava COS | 36, 46 | - | - | - | 10 per group | Light powder dusting | 1 experienced |
| Hussam et al., 2018 | In vitro | Edentulous stone model with core structure of tungsten bodies | Confocal microscopy | Trios | 12, 22 | 0, 0 | 4, 2 | Nonparallel positions | BOP | 30 per group | Nil |
| Mario Imburgia et al., 2017 | In vitro | 2 models: Stone model of partially edentulous maxilla Stone model of edentulous maxilla | Active speed 3D video microscopy | CS 3600 | 23, 24 | - | - | - | 5 per group | Nil | 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 Intracan - 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.

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. 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. 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. 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.
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. 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. 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. Contrary to this study another study concluded that the performance of the operator is not necessarily dependent on experience. However, the author was keen to note that expertise even at the lack of experience, is definitely crucial to the accuracy of digital impression.

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 and this angulation is limited to 25° for accurate conventional impressions. Digital impressions made by confocal microscopy technology

### Table 2: Outcome variables of 5 included studies

| Distance deviation (µm) | 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 |
|-------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| Group 1                 | −29.39±5.49                  | −28.49±26.91                 | −14.3±25.6                   | −32.7±11.1                   | 28.8±94                      |
| Group 2                 | −33.35±15.64                 | −22.46±30.92                 | −16.2±34.6                   | −157±292                     | 9.3±29.5                     |
| Group 3                 | −45.02±37.31                 | −107.25±68.65               | −27.9±61.6                   | −142.8±487.7                 | 164.5±268.3                 |
| Group 4                 | −11.02±28.12                 | 116.84±94.23                | −23.1±148.0                 | −216.7±836.6                 | 484.6±1057.3               |
| Group 5                 | −35.28±22.19                 | −123.09±138.31              | −32.0±16.1                  | −150.6±1080.3               | 497.4±1346.6               |

### Table 3: Outcome variables of 3 included studies

| Author and years | 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±1.7 | 65.5±16.7          |
| Confocal microscopy and ultrafast optical scanning | Trios 3 | 67.2±6         | 31.5±9.1 |
| Optical triangulation and confocal microscopy | CEREC omnicam | 66.4±3.9 | 57.2±9.1 |
| Active wavefront sampling 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 assessing outcome

| Type of parameter | Total number of studies |
|-------------------|-------------------------|
| Accuracy          | 5                       |
| Precision         | 3                       |
| Trueness          | 3                       |
| Operator experience | 6                       |
| Implant depth and angulation | 7                       |
are not significantly affected by the implant angulation or depth of the implants. The same was reported in another study where the information of the scan bodies in submerged implants was captured sufficiently without affecting the accuracy. Angulated implants and the deeply placed implants did not seem to decrease the accuracy in digital impressions. 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. 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. 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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