Title:	Investigate the accuracy of IOS for full arch and short-span fixed implant restorations compared to the conventional impression methods.
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Abstract

Intraoral scanners (IOS) are widely used to take impressions for dental implants. This narrative review aims to deliver a thorough evaluation of the current evidence on using the direct digital workflow to fabricate implant-based prostheses in patients with partial or complete-arch edentulism in comparison to conventional impression (CI) techniques.

Electronic research was performed on many in-vitro and in-vivo studies to compare the accuracy of digital impressions to conventional methods. This suggests that either technique can be employed to take impressions for dental implants. Regarding full-arch fixed dental prostheses (FPDs), CI techniques have demonstrated greater accuracy compared to digital methods. However, when considering time efficiency and patient satisfaction, IOS may be preferred in certain circumstances such as short-span implant sites.

Since most identified studies were conducted in vitro, to investigate influential clinical factors including scanning accuracy and technical or biological complications, further in-vivo studies are required.

Keywords:

Intraoral Scanners (IOS), Digital Workflow, Dental Implants, Conventional Impressions (CI), Full-Arch Fixed Dental Prostheses (FPDs), Accuracy, Time Efficiency, Patient Satisfaction, In-Vivo Studies, Dental Prosthetics

Contents

Introduction

Dental clinicians have always been concerned about achieving precise and accurate impressions. In the laboratory setting, intraoral impressions are a frequent method of simulating intraoral conditions, as well as treatment planning and fabricating prosthetic restorations. This emphasizes the critical significance of precision in impression-taking and the accuracy of the impressions obtained. (Tidehag, 2014)

To enhance the accuracy of impression-taking and minimise dimensional alteration, multiple methods have been suggested including improving the quality of impression materials, removing laboratory stages, and substituting manual systems with digital methods. Currently, the main materials used for dental impressions involve elastomeric impression materials with prefabricated or custom trays. Although the conventional method of impression-taking is popular, it has certain disadvantages. For instance, the risk of infection transmission via the impression material is significant due to the unreliability of the disinfection systems employed for this purpose. (Seelbach, 2012)

Meanwhile, IOS is gaining popularity in clinical dental practice for direct capturing optical impressions. Therefore, the aim of this narrative review is to evaluate the advantages and disadvantages of utilising IOS compared to conventional methods and investigate whether optical impressions can provide an equivalent level of accuracy compared to CI considering all the studies available in the literature.

Based on the results of this review, optical impressions offer several advantages, including reducing patient discomfort, providing time efficiency and simplifying clinical procedures for the dentist. Furthermore, they enable improved communication between the dental clinician and patients. Nevertheless, the use of IOS can present some challenges, such as the challenge of identifying deep margin lines in prepared teeth. as well as managing the technology and the costs.

Literature Review

This literature review has been written in a 6-month period from November 2022 until April 2023 using electronic research from PubMed and Cochrane Central. Initially, 1380 results were found in PubMed and 34 results on Cochrane Central. Out of which only 173 were related to this audit and finally, only 19 papers were approved by our criteria and selected as main sources for this literature review.

Material and methods

In this literature review, many in-vivo and in-vitro experiments were included to evaluate the accuracy of IOS and CI techniques for the fabrication of fixed dental prostheses (FDPs) of partially and completely edentulous patients. The search was conducted in two electronic databases including PubMed and Cochrane Central for articles published within the last decade. The keywords used are listed below:

PubMed: (Digital impression AND conventional impression [MeSH, Medical Subject Heading]) OR (digital impression OR Intraoral scanning) AND (fixed partial denture [MeSH Terms] OR dental prostheses)
Cochrane Central: (analogue impression OR conventional impression) AND (digital impression OR intraoral scanning) AND (dental prostheses OR implant-supported OR implant-supported dental prostheses).

Background

Digitisation has ushered in Dentistry enormously over the past few decades in many aspects involving technology, science and biomaterials with the aim to improve treatment outcomes. (Kudva, 2016) Digital dentistry is widely used for digital technologies such as the recent advances in Cone Beam Computed Tomography (CBCT), 3D imaging techniques, intra-oral scanners, digital software programmes like computer-aided design/computeraided manufacturing technology (CAD/CAM) and 3D printers. (Dawood, 2015)

These technologies have enhanced many dental procedural workflows by adding efficacy to conventional techniques including 2D imaging, impression techniques and traditional manufacturing methods. In addition, new digital workflows have been employed in conjunction with conventional methods. (Pillai, 2021)

One of the commonly used examples of these digital methods includes IOSs which are digital impression-taking techniques to make dental implants.

Manufacturers are consistently introducing newer versions of IOSs and their relevant software, which offers improved scanning accuracy and patient satisfaction. Furthermore, the dental market is frequently introducing new impression materials that provide better mechanical and physical properties, resulting in improved aesthetics and prognosis. This narrative review aims to provide a comprehensive overview of the current evidence on implementing the direct digital workflow for implant-supported prosthetic rehabilitation in partial and complete-arch edentulous patients. Additionally, the review aims to compare the accuracy of IOSs to conventional implant impression procedures. (Michelinakis, 2021)

Dental Implant Impression Techniques

Dental implants are becoming one of the most favoured treatments used to replace missing teeth, especially in implantology. They have proven to encompass enhanced support, function and aesthetics as compared to complete and/or partial dentures. Both fixed and removable implant prostheses have been found to be one of the best solutions for treating partial and complete-edentulous patients. Nonetheless, the accuracy and success rate of dental implants is dependent on many factors such as the impression technique used to make dental prostheses, the type of impression material including the impression trays and the impression positioning as inadequate impressions could lead to failure of the dental implants upon placement. (Nagargoje, 2020) In this literature review, an evidenced-based quantitative has been performed to evaluate the accuracy of CI compared with IOSs as different impression-taking techniques for partial and complete arch dental implants.

Conventional impression techniques and materials

In order to have a thorough understanding of the differences between digital and conventional impression-taking techniques, we aim to discuss both methods in this review in detail. CI techniques can be classified into Direct impression technique (open tray impression technique) and Indirect impression technique (closed tray /transfer impression technique). In the direct impression technique, the impression post which is usually longer than the body of the screw, is attached to the implant allowing the impression piece to be removed upon removal of the impression material. In the indirect technique, an impression post which is tapered is screwed onto the implant allowing the impression materials to be polymerised. Once polymerisation is taken place, the tray is removed remaining the impression post onto the implant in the mouth. Subsequently, the impression post is detached from the implant and inserted into the implant analogue. (Yasar, 2022)

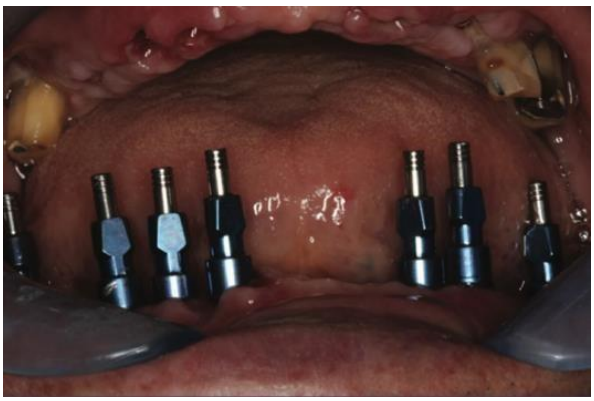

Fig-1 Lower jaw Open tray impression put in place.

Fig-2 Indirect impression technique- post being

The main impression materials used for dental implants are elastomers. There are four types of elastomeric impression materials that are most suitable for dental implants such as polysulfide, Addition Silicone (Polyvinyl Siloxane - PVS), Condensation Silicone and Polyether. (Wee, 2000) However, PVS has been the most used impression material for the past few years. (Siqueira, 2021)

Impression materials have several ideal properties including accuracy, dimensional stability, elastic recovery, hydrophilicity, flexibility, flow, long shelf life, comfort, etc. However, all these properties cannot be found in an impression material. Each of the impression materials possesses different properties. For instance, PVS has the highest dimensional stability and elastic recovery making it useful to record fine details in the implant impressions. In addition, Polyether is known to have the high rigidity and resistance to permanent deformation required for accurate positioning of the impression post. Having these properties makes allows Polyether to be appropriate for implant-supported prostheses. (Cetinsahin, 2022)

CI techniques have many disadvantages despite being used widely. This includes their taste, smell and consistency which may stimulate patients' gag reflexes. In addition, they may have detrimental effects mentally and be uncomfortable for patients. Hence, CI techniques are often avoided and not preferred as desirable impression techniques. Clinical studies have

suggested that the CI technique is one of the most unpleasant experiences during implant procedures. (Siqueira, 2021)

Finally, digital impressions are often preferred over the conventional method by practitioners due to significant volumetric shrinkage (20-30%) in CI materials (e.g., PVS) for up to 24 hours. (Roberts, 2021)

Intraoral scanners

The first intraoral scanner was initiated by Dr Francoise Duret and co-workers in the early 1970s with the aim to introduce an Optical impression to Dentistry. (Michelinakis, 2021) Since then, IOS in conjunction with CAD/CAM software has been used as an advantageous substitute for CI techniques as they provide a 3D image of the area of interest along with a reduced working time, the ability to rescan a neglected area in case an error occurs, as well as an improved patient-reported experience.

Research has shown that the scanned area's size affects the impression's accuracy. For example, quadrant scans provide higher accuracy and require less time hence better patient satisfaction in comparison with full arch scans. Although a variety of IOSs in the market perform differently, their accuracy has been proven to be clinically acceptable. This has allowed the wide use of these digital workflows to be progressively popular. (Siqueira R, 2021)

Advantages and Disadvantages of Intraoral Scanners

Intraoral scanners provide an optical measurement of the superficial shape of the desired teeth and surrounding gums.

IOS has many advantages including increasing patient comfort by reducing pain and operation time. It also minimises the risk of infection and provides thorough visualisation and detection of caries or cracks. In addition, IOS has reduced the waste of material used in conventional impression-taking methods. IOSs are able to reproduce, process and store data easily which further allows the information to be transferred to CAD/CAM and other dental professionals if further communication or examination is required to enhance the treatment outcome. However, the application of IOS is operator-dependent and demands a certain amount of skill and experience. (Suese, 2020)

Digital Vs Conventional impressions for FDPs and dentures

As mentioned above, Impression materials such as alginate are used in the CI techniques which may lead to gagging, mucosal irritation and discomfort for the patient. In comparison, IOS is shown to minimise the effect of the gag reflex yet does not eliminate it completely due to the large-sized head of the scanner. Moreover, although IOS is advantaged by removing unpleasant tastes and odours, many pleasant flavours, such as strawberry and mint, are now available in the market for CI materials. In addition, not only IOS is more comfortable, but it also requires less time for the images to be designed and sent to the CAD software as a digital

file such as a Standard Tessellation Language (STL) involving fewer errors which further improves the patient experience. (Michelinakis, 2021)

Despite the mentioned advantages of intraoral scanners, several factors may compromise the application of IOS including the presence of blood or saliva that could prevent it from acquiring a vivid scan. In addition, studies have shown that some intraoral scanners cannot capture an accurate record of the morphology of mobile or soft tissues such as edentulous arches although accessing those areas might be achievable. Other environmental, operator, patient and equipment-related factors may contribute to increasing errors upon using IOS. For example, the illumination of the room, the operator's dexterity, the patient's oral cavity morphology and the scan body design may have detrimental effects on the precision of IOS. However, the extension of the edentulous area plays a key role in determining the accuracy of CI in comparison with intraoral scanners. (Marques et al., 2021)

Dental Impressions' accuracy is mainly determined by two factors: trueness and precision. Trueness is described as the aberration of the tested impression technique from its original dimensions and precision is referred to the deviation between different impressions within the same test group. (Ahlholm, 2018)

Digital impression versus conventional impression for full-arch fixed dental prostheses (FDPs)

Author	Study Type	Experimental Group	N	Trueness (µm)		Precision (µm)	
Ender and Mehl, 2015	In Vitro	Polyether	5	60.2		66.7	
		Vinylsiloxanether		13.0		12.3	
		Direct scannable		11.5		14.6	
		Vinylsiloxanether		37.7		59.6	
		Irreversible hydrocolloid		29.4		19.5	
		CEREC Bluecam		37.3		35.5	
		CEREC Omnicam		32.4		36.4	
		Cadent iTero		44.9		63.0	
		Lava C.O.S.					
D'haese et al, 2022	In Vitro	**Implant Level**	50	Angular	Coronal	Angular	Coronal
		Primescan v5.1		0.43	66	0.45	65
		Primescan v5.2		0.32	55	0.18	29
		Trios 3		0.48	84	0.64	105
		Trios 4		0.54	91	0.58	101
		Conventional Impression		0.38	86	0.35	51
		Abutment Level					
		Primescan v5.1		0.40	58	0.56	79
		Primescan v5.2		0.23	28	0.19	28
		Trios 3		0.51	71	0.47	89
		Trios 4		0.56	83	0.66	96
		Conventional Impression		0.41	34	0.56	29

Table 1. Trueness and Precision of conventional and digital fabrication of full-arch FDPs

Over the past five years, there have been intensive studies on the accuracy of multiple implant impressions using complete-arch intraoral scanning. The accuracy of various scanners has been tested against the conventional method.

Table 1. illustrates the studies performed in vitro that compare the accuracy of conventional and digital fabrication of full-arch FDPs. Ender and Mehl have conducted an in vitro study using four digital impressions including CEREC Bluecam, CEREC Omnicam, Cadent iTero and Lava C.O.S. and four conventional impressions such as polyether, Vinylsiloxanether, direct scannable Vinylsiloxanether and irreversible hydrocolloid. An extremely precise reference scanner with a known morphology was used to compare the trueness and precision of digital and conventional full arch impressions. The results demonstrated that among the test groups, Vinylsiloxanether, CEREC Bluecam and direct scannable Vinylsiloxanether were measured to achieve the greatest trueness and precision. Overall, IOS had higher local deviations than CI, despite indicating higher accuracy. (Ender, 2015)

Güth et al, also conducted in vitro research to evaluate the accuracy of the conventional compared to the digital impressions. In this study, a mandibular straight metal bar was placed between the second molars of the opposing quadrants to obtain a model that can be both directly and indirectly digitised. The dataset would then be analysed to determine the aberration of the bar length, the angle deviation and the X-, Y- and Z- axis linear shift using inspection software. As a result, the True definition Intraoral scanner showed to have a significantly lower linear deviation than the conventional Impregum impressions specifically in Y- and Z- axis as well as in the coronal angle. This indicates higher accuracy for Digital scanners than the conventional technique. (Keul, 2019)

D'haese et al conducted a more recent in-vitro study to evaluate the accuracy of conventional and digital full-arch impressions, on the implant and abutment level. In this study, two different resin casts, one with six implants and the other with six abutments were poured into conventional gypsum to take an impression and digitise by a lab scanner. In addition, the casts were scanned with four different IOSs including Primescan v5.1, Primescan v5.2, Trios 3 and Trios 4. Finally, a reference scan of both casts was generated using a coordinate machine to assess the trueness and precision of IOSs and CI, considering angular and coronal dimensions. The results illustrated that for the implant level, Primescan v5.2 had significantly higher trueness and precision than all other impressions except for Primescan v5.1 with greater coronal trueness. However, the CI presented superior angular trueness compared to Primescan v5.2. Overall, this study concluded that for full arch FDPs, some digital impressions could be capable of presenting equal accuracy as the CI. (D'haese, 2022)

Digital impression versus conventional impression for short-span FDPs

Short-span dental prostheses are often supported by 2-4 implants in a quadrant. Table 2. illustrates various in vivo and in vitro studies comparing the accuracy of conventional impressions with IOSs for short-span FDPs.

Basaki et al conducted an in-vitro analysis to assess the 3D accuracy of conventional fabrication in comparison with digital impression techniques. A mandibular reference model was used to stimulate a partially edentulous patient with posterior bilateral implants. Ten

implant impressions were made by either IOS with scanning abutment or polyvinylsiloxane in an open-tray technique. The final implant locations were then analysed using a laser scanner to measure the inter-implant distance and angulations. The extent of error was measured in each definitive cast by being compared to the reference model. Hence a statistical analysis was performed to evaluate the accuracy and the influence of implant angulation for both conventional and digital methods. The results show that the digital approach was less accurate in fabricating definitive casts than conventional techniques. In addition, Basaki et al declared that numerous definitive casts fabricated by IOSs did not meet the required accuracy for an FDP to be clinically acceptable. (Basaki,2017)

Similarly, Lin et al, studied in vitro to evaluate the effect of implant divergence on the accuracy of both conventional and digitally fabricated definitive casts with two posterior mandibular implants. In this research, 10 conventional (polyvinylsiloxane, open trays) and 10 digital(iTero) impressions were taken from resin master casts. The impressions were subsequently scanned and digitised using a reference scanner. The results were therefore analysed statistically to measure the deviations of the master casts between the implants, at different angles (15, 30, or 45 degrees). The results proved that the accuracy of conventional stone casts was not affected by the extent of divergence between the implants. However, the digitally made milled casts were influenced significantly. Hence, it was concluded that at higher degrees of deviation, the digital method presented higher accuracy compared to lower degrees of divergence (0 and 15 degrees) where the accuracy of IOS was considerably lower. Ultimately, this study suggested that the conventional technique resulted in more accurate definitive casts with two implants than digital methods. (Lin, 2015)

Finally, Alsharbaty et al conducted an in-vivo study to compare the Trios 3Shape, IOS to the pick-up and transfer conventional method. During this clinical study, 36 patients with two implants, connected internally, participated. Therefore, for each CI technique, 36 working casts were fabricated and similarly, 36 digital impressions were made by Trios 3Shape. Interimplant distances, angular displacements, and linear X-, Y- and Z- coordinates for the working casts were measured using a coordinate measuring machine. Comparably, digital software (CATIA 3D) was used to evaluate the same variables for digital impressions. The data were analysed statistically and revealed substantial differences between the accuracy of the conventional impressions and the digital group. Thus, the pick-up technique was superior in accuracy to the digital groups and similar to the transfer groups.
(Alsharbaty,2019)

Author	Indication	Measurement	Study Type	IOS Type	Conventional Impression Type	Reference scanner	Conclusion
Basaki et al, 2017	Partially edentulous mandible with 4 implants	Distance	In Vitro	iTero	PVS monophase with custom trays	D810	IOS impressions were statistically Less accurate than PVS impressions. IOS accuracy was not affected by Implant angulation. Stone casts were more accurate than milled 3D casts.
Lin et al, 2015	Partially dentate mandible with 2 implants and 4 different angulations (0,15,30 and 45 degrees)	Angulation and Distance	In Vitro	iTero	PVS open tray, non-splinted	Cagenix	IOS was more accurate when the implants diverged more. The milled casts showed no difference with casts created conventionally.
Alsharbaty et al, 2019	Partially edentulous mandibles and maxillae with 2 adjacent posterior implants	Distance	In Vivo	Trios 3	PVS dual mix, plastic tray/splinted (used as reference) PVS dual mix, plastic tray/non splinted in open and closed tray methods (used for comparison)	Coordinate Measuring Machine	Conventional open tray pick-up impression was more accurate than IOS and conventional closed tray pick-up impression.

Table 2. In-vitro and in-vivo studies performed to compare the accuracy of conventional and digital fabrication of short-span FDPs

Results

Upon reviewing the literature, it is evident that the accuracy of digital impressions is analogous to conventional methods when fabricating FPDs, indicating that either technique can be employed in order to take impressions for dental implants.

Conclusions

Precisely, for full-arch FPDs, CI techniques are shown to be more accurate than the digital method and thus preferred by technicians. Whereas for single and short-span implant sites, IOS suggested higher accuracy in complete-arch intraoral scanning, with virtual implant

position deviations falling within acceptable clinical limits. Digital impression systems can also provide an acceptable fit for FDPs. In appropriate situations, IOS appears to be the favoured approach over conventional impressions in terms of time efficiency and patient satisfaction. Moreover, dental professionals have exhibited a preference for this method, indicating that its utilisation will probably expand. It is yet not proven whether the conventional, splinted, custom tray impression procedure is superior to the IOS impression in the case of a complete-edentulous arch with multiple implants. In contrast, digital complete-arch impressions proved to be more precise than non-splinted conventional open or close tray impressions. Nonetheless, since there are only a limited number of studies on the topic, more research is required to validate these outcomes.

Discussion

Amongst IOS devices, those that possess cylindrical-shaped scan bodies with a smooth surface and sufficient length were favoured over other types. The accuracy of IOS was not affected by implant angulation if scan bodies with the aforementioned characteristics were utilised. The precision and accuracy of scans were influenced by both the manufacturing acceptances of scan bodies and the similarity between the IOS and the CAD file. Newer generation scanners have demonstrated complete-arch deviation levels that fall below the currently accepted threshold. In addition, the results have shown that the accuracy of complete-arch scans with these scanners is not influenced by the operator's experience, although the minimum required experience level has yet to be determined. Moreover, Scan accuracy can also be affected by an increase in scanning range and inter-implant distance. Limited evidence is achieved to suggest that the type of implant connection has no significant impact on scan accuracy.

In terms of the complete digital workflow, single implant cases have shown high levels of patient acceptance and total clinical and laboratory time efficiency. On the contrary, the clinical application of this workflow for multiple implants lacks sufficient documentation. Therefore, to obtain conclusive clinical findings, it is imperative to conduct future studies on outcome measures such as time efficiency, patient acceptance as well as technical and biological complications associated with multiple implant-supported prostheses.

Finally, since the majority of identified studies were conducted in-vitro, which limits their clinical prognosis. Therefore, in order to effectively study critical clinical factors such as scanning accuracy and technical or biological complications, further longitudinal in-vivo studies are required.

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Abbreviations

- 3D = Three Dimensional
- CAD/CAM = Computer-Aided Design/Computer-Aided Manufacturing
- CBCT= Cone Beam Computed Tomography
- CI = Conventional Impression
- CT = Computed Tomography
- DI = Digital Impression
- FDPs = Fixed Dental Prostheses
- IOS = Intra Oral Scanner
- NHS = National Health Service
- PPE = Personal Protective Equipment • PVS = Polyvinyl Siloxane
  STL = Standard Tessellation Language