Universidad Europea

GRADUATION PROJECT

Degree in Dentistry

DIGITAL IMPRESSION TECHNIQUES FOR COMPLETE ARCH IMPLANT RESTORATIONS

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RESUMEN

Introducción: En los pacientes que requieren rehabilitaciones implantosoportadas de arcada completa, es necesario realizar una impresión de la cavidad oral que permita registrar la posición exacta de los implantes. Eso se hace para garantizar que la restauración final encaje perfectamente, sin generar tensiones biomecánicas innecesarias sobre los implantes. Tanto los escáneres intraorales (IOS) como la fotogrametría extraoral (EPG) se utilizan como técnicas digitales, cada una con características propias, y, por lo tanto, cada uno ofrece ventajas y desventajas únicas. **Objetivos:** Comparar las técnicas de impresión IOS y EPG en términos de exactitud, veracidad, precisión y eficiencia clínica en pacientes que requieren rehabilitaciones implantosoportadas de arcada completa, y para determinar cuál de los dos técnicas puede lograr mejor el principio de ajuste pasivo. **Métodos:** Se realizó una revisión sistemática, seleccionando 11 estudios que se encontraron en bases de datos electrónicos como Medline o PubMed, de las cuales debían cumplir directamente con los criterios de inclusión: haber sido realizados en los últimos 10 años, comparar IOS y EPG, e incluir pacientes que requieren rehabilitaciones de arcada completa con implantes. **Resultados:** Diez de los once estudios mostraron una mayor exactitud, veracidad y precisión con EPG en comparación con IOS, con menores desviaciones angulares y lineales. Un estudio indicó una mayor exactitud, veracidad y precisión en IOS frente a EPG. Asimismo, un estudio reportó un menor tiempo de escaneo con EPG en comparación con IOS. **Conclusiones:** La EPG mostró mayor exactitud, veracidad y precisión en comparación con IOS, logrando con mayor facilidad el principio de ajuste pasivo, además de presentar un menor tiempo de escaneo.

PALABRAS CLAVE

Odontología, Impresiones digitales, implantes, arcada completa, fotogrametría, escáner intraoral

ABSTRACT

Introduction: Patients requiring complete arch implant restorations must have an impression of the oral cavity taken, with record of the exact positions of the implants. This is done to ensure the final restoration fits perfectly without any unnecessary biomechanical stress on the implants. Both Intraoral optical surface scan (IOS) and extraoral photogrammetry (EPG) are used as digital techniques, each offering their own unique characteristics, and therefore each offer unique advantages and disadvantages; **Objectives**: To compare IOS and EPG impression techniques in terms of accuracy, trueness, precision and clinical efficiency, in patients that require complete arch implant restorations, and to determine which of the two techniques can better achieve the passive-fit principle; **Methods**: A systematic review was completed, selecting 11 studies found on electronic databases such as Medline or PubMed, from which they had to directly match the inclusion criteria set, being; written in English, being conducted in the last 10 years, compare IOS and EPG, and edentulous patients that require complete arch restorations with implants; **Results**: 10 of the 11 studies showed a higher accuracy, trueness and precision with EPG in comparison with IOS, with lower angular and linear deviations. 1 study indicated a higher accuracy, trueness and precision in IOS against EPG. 1 study also mentioned a reduced scanning time in EPG in comparison to IOS. **Conclusions**: EPG showed higher accuracy, trueness and precision compared to IOS, achieving the Passive-Fit principle with more ease, as well as having a reduced scanning time in comparison to IOS.

KEYWORDS

Dentistry, Digital Impressions, Implants, Complete-Arch, Photogrammetry, Intra-Oral Scanner

Table of Contents

1. INTRODUCTION 1

1.1. Dental implants 1

1.1.1 Modern implantology 1

1.1.2 Implant design 1

1.2 Impression techniques 2

1.2.1 Conventional Impressions 2

1.2.2 Digital Impressions 3

1.2.2.1 Scan Bodies 3

1.2.2.2 Scan Body design 3

1.2.2.3 Intraoral Optical Surface Scan (IOS) 4

1.2.2.4 Frameworks 5

1.2.2.4.1 Calibrated Frameworks 5

1.2.2.4.2 Non-Calibrated Frameworks 5

1.2.2.5 Photogrammetry (PG) 6

1.3 Clinical Usage of Digital impressions 7

1.3.1 Clinical Efficiency 7

1.3.2 Patient and Clinician Experience 7

1.3.3 Limitations and Difficulties of Digital impressions 8

2. OBJECTIVES 8

3.1 Research method 8

3.2 Inclusion and Exclusion criteria 9

3.3 PICO question 9

4. RESULTS 11

5. DISCUSSION 15

6. CONCLUSION 19

7. SUSTAINABILITY 20

8. REFERENCES 20

1. INTRODUCTION

1.1. Dental implants

1.1.1 Modern implantology

In the last 30 years we have experienced a vast improvement in the development of dental implants as a technique to rehabilitate edentulous spaces. The majority of these improvements have been recognised as changes to the materials used, implant placement and impression techniques. Most implants nowadays are created with Titanium, initially proposed by Brånemark at the end of the 1970s (1).Titanium offers high corrosion resistance due to the film of inert Titanium Oxide (TiO_2) found on the external surface. TiO_2 offers a very high biocompatibility, so long as the correct screw design and rigorous drilling sequence are followed according to the ideas initially proposed by Brånemark (1). Biocompatibility is the quality associated with a successful implant, where the material used harnesses the ability to be in contact with living tissue, without producing any adverse or toxic effects (1,2). Another key quality that a dental implant must have is osseointegration, a term also introduced by Brånemark (3). A truly osseointegrated implant can be achieved when the implant surface and the host's bone tissues fuse without intervening fibrous connective tissue present (4). This is a complex process that may take several weeks after initial placement (1,4). Almost immediately after implant placement, chemical reactions occur between the surrounding bone and inflammatory cells (1). Subsequently, regulated by several biological factors, bone regeneration occurs, forming a stable structure of bone around the implant body (1). In general, this biological stabilisation of the crestal bone usually occurs at any point between 3 to 6 months (5).

1.1.2 Implant design

Nowadays the preponderance of commercially available dental implants are designed with a threading, macroporosity and a conical shape (6). These characteristics have been implemented to increase the probability of a successful osseointegration, due to the fact that the threading allows for a higher surface area, the macroporosity (pores on the external surface of the implant with a size of 150-300μm) improves the bone ingrowth, and the conical shape mimics the anatomical form of a natural root of a tooth (1). Variations within these qualities are often integrated into different implants depending on the requirements of the clinician and the individual characteristics of each patient's bone quality and quantity (1,2). For example, any specific modification to the threading profile of the implant could impact the contact relationship between the implant and the surrounding bone (2). If this contact area is increased, an improvement in primary

stability could be expected as a result. On the other hand, if the resultant forces are too strong, there may bone resorption as a consequence of increased osteogenic cellular remodelling (2). This would result in a reduced primary stability and therefore a contribution to a potential implant failure in the future (2). Implant success is determined by both osseointegration as well as primary stability (2). The coaction between the macro design of the implant and the osteo preparation is essential for the promotion of primary stability whilst achieving the completion of successful osseointegration (2). In addition, modifications on the nanoscale level of the implant surface have been implemented, based on the concept that the imitation of the micro pattern of bone structure may help to increase the overall surface energy and therefore increase the bond strength between the implant body and surrounding bone (1). This could therefore potentially increase bone cell migration and proliferation and therefore improve osseointegration (1). However, regardless of the role of biomechanics in the process of osseointegration, these design concepts are not expected to directly promote the beneficial functions by direct control of the reactions between the bone and inflammatory cells.

1.2 Impression techniques

Once the implants have been correctly implemented, an impression must be taken of the patient's maxilla and mandibular arches in order to manufacture the complete prosthetic device to restore the function and aesthetics that were previously lost (7). Accurately taken impressions aid in creating a passive fit, as well as granting a long-term success of implant-support prosthesis (7).The passive fit is the ideal scenario when the prosthetic framework created corresponds perfectly with the implants, to the point where the framework can bind onto the implants themselves without any excessive force or angulation (7). On the other hand, an inaccurate impression could result in a poorly fitting prosthesis, which would add unnecessary biomechanical stress on the implants. In these situations, where a clinically acceptable passive-fit is not obtained, potential mechanical issues such as screw loosening can occur, additionally resulting in poor long-term success rates (7). According to Jemt et al (8), a clinically acceptable passive-fit is considered when the margin found between the abutment itself and the framework is any value less than 150μm, and an angulation deviation not exceeding a threshold of 1°(8). Conventional and digital methods are used to capture impressions, each offering a notable variety of techniques.

1.2.1 Conventional Impressions

Conventional techniques for complete arch implant restorations include methods such as splinted open-tray impressions, with the most common material being addition silicone (containing two different consistencies, being light body and putty) (9). In open-

tray impressions (splinted), tray openings are found on the implant bodies, allowing access to loosen the screws once the impression material has set (9). In closed-tray impressions (non-splinted) the copings remain attached to the implants after removal of the impression tray and are then repositioned in the set impression material (9). Open tray copings are recommended for multiple implants with differing angulations, as the closed tray alternatives may distort the impression material upon removal (9).

1.2.2 Digital Impressions

Digital impression methods include two distinct techniques, consisting of intraoral optical surface scan (IOS) and extraoral photogrammetry (EPG) (9). The current trend is towards a more common use of digital techniques over the traditional conventional techniques, as the latter involves multiple complex, technique sensitive manual steps which can produce errors from an early stage of the manufacturing processes. Any error produced during the process may contribute to an ill-fitting prosthesis, lack of a passive-fit, screw loosening, restoration chipping, bacterial accumulation on the implant surface and as a result, a prolonged treatment time (10). Although a narrow degree of tolerance is usually accepted, clinicians should attempt to reduce errors by obtaining a reliable, precise and accurate impression in order to maximise the passive-fit principle and therefore acquire a biocompatible final implant supported prosthesis (10). The quality of the prosthesis and the time required to manufacture it is highly dependent on the clinician's skillset (9).

1.2.2.1 Scan Bodies

When scanning a completely edentulous arch with implants, IOSs are used in conjunction with highly specific components referred to as implant scan bodies (ISBs) (11). These serve to capture the precise spatial, geometric and angulation properties for each implant and therefore provide the necessary data to accurately capture the relationships between multiple implants in the arch (11). Upon scanning and the digital capture of the scan bodies, a Standard Tesselation Language (STL) file is created, which represents the scans as polygonal meshes formed by triangles, which replicate the shape and angulation of the scan body in a digital format (11). Nevertheless, optimal alignment through the implant library is required before the STL file generated can be used as the definitive working cast, through the process known as Best Fit (11).

1.2.2.2 Scan Body design

Typically, vertically-orientated scan bodies are used for the capture of implant angulation and positioning (12). However, these may increase the potential risk of misalignment throughout the arch (13). To mitigate these potential errors, horizontal implant scan bodies (H-ISBs) were suggested as they offer a more reliable capture of

the implant positioning (12). They are able to minimize the edentulous space between implants, which usually lacks anatomical landmarks, therefore reducing the potential necessity for additional devices, such as splinting ISBs (12). H-ISBs can be used to help cover inter-implant spaces without the need for splint customization and therefore reduce the need for additional appointments (14).

1.2.2.3 Intraoral Optical Surface Scan (IOS)

IOS is a technique based on several different technologies, such as confocal microscopy, structured light or laser beam technologies, optical coherence tomography and triangulation (10,15). It offers improved patient comfort, as well as competitive accuracy, most notably for single crown or short span fixed partial dentures (FPDs) (10,15). Upon completion of the scan, STL files are generated on the IOS software, to which they can then be used for the manufacturing of the implant-supported prosthesis (9). There are two methods that can be used for the fabrication, with the first option including the use of the STL file directly to design and create both a definitive and provisional prosthesis, without the use of a printed physical cast (9). The other method includes the conversion of the STL file into a printed cast which can then be used to manufacture both the definitive and provisional framework for later ceramic application, in a conventional manner (9). With the initial option being a fully digital workflow, the latter offers the benefits of a partial digital technique (9).

On the other hand, IOS technology shows inaccuracy in some cases, such as completely edentulous or long span-edentulous arches (10,15). The process by which it obtains 3D images, known as “Stitching by Overlapping”, has shown to be potentially inaccurate when recording large edentulous spaces dominated by soft tissues without notable anatomical landmarks (10,15). Due to this phenomenon, the scan obtained by the IOS will be highly accurate at the beginning of the scan but will slowly lose accuracy towards the final capture of the impression, therefore proving that long-span edentulous areas are difficult to capture with accuracy (10). In addition, technical sensitivity, as well as the complexities of the oral cavity, such as saliva and mobile mucosa, have shown to hinder the accuracy of the impression (10,15,16). Impressions for fully edentulous patients with previously placed implants with the IOS are completed with the use of ISBs. By obtaining information optically, ISBs acquire implant angulation, three dimensional (3D) spatial orientation and position by capturing their topography with IOS or laboratory scanners (LBS) (17). They are then digitally defined in the software library associated to the respective device (IOS or LBS), resulting in the creation of a virtual model which can then be used for digital workflows, or partial digital workflows if the STL file is converted

into a physical cast, which is then used for manual ceramic veneering over a framework (17).

1.2.2.4 Frameworks

Frameworks are also frequently used with the ISBs in the impression process of complete arch implant restorations. Among the five main scanning techniques performed with the IOS to record the 3D positions of the implants, two are most used: Calibrated frameworks (CFs) and non-calibrated frameworks (NCFs) (also named splints, structures, 3D printed…etc) (18).

1.2.2.4.1 Calibrated Frameworks

CFs have been developed to help record implant positions with IOS, by using a the definitive implant working cast by using IOSs. In this technique, a tailor-made metal splint is created. Before manufacturing of the splint, a previously completed scan is required for its fabrication (18). The frame itself incorporates cone-shaped markers into the body of the framework, which then encompass each implant (18). Once the frame is created, it requires specific binding to the individual ISBs with autopolymerising acrylic resin, meaning a final implant scan is required for the creation of the working cast (18). The specific location values that were recorded prior are used again to accurately calculate the exact and final implant positions, thereby creating the definitive implant working cast (18). Following a digital workflow, the definitive working cast is then used with Computer Aided Design and Computer Aided Manufacturing techniques (CAD-CAM) to produce the final restoration (18).

1.2.2.4.2 Non-Calibrated Frameworks

NCFs share the similarity with CFs in the sense that the ISBs are connected in order to maximise the scanning power of the IOS, obtaining an accurate representation of the positioning and angulations of the implants. However, NCFs do not require the fabrication of a custom-made metal splinting frame. Instead, other devices, such as dental floss, orthodontic wire or light polymerised composite resin are used to connect the ISBs (18,19) Although technically more time-efficient than CFs as it does not require the pre-scan for a custom-made fabrication of a framework (19), On the other hand, NCFs have significantly greater variability in accuracy, arising from differences in colour, geometry, and the positioning of the splinting device relative to the implant's structure (18). In a study by Revilla-Leon et al (18), a high variation in the accuracy of NCFs was noticed, showcasing mean trueness values ranging between 49-240μm, and mean precision values ranging between 45-176μm (18). The lack of multiple case reports or clinical studies in both CFs and NCFs demonstrate that further studies are still needed

before significant conclusions can be drawn, specifically on the IOS system used, implant design and position, and splinting material used.

1.2.2.5 Photogrammetry (PG)

PG works by using extraoral stereo cameras to detect the specific geometries of the ISBs, which helps to ensure accurate 3D spatial relationships between the implant bodies (20). EPG technology works by using optical markers or ISBs (which differ in shape and geometry to the ISBs used in IOSs), combined with the extraoral stereo cameras, to digitalise the positioning and angulation of the intraoral implants into a CAD-CAM software, later used for manufacturing (20). Nevertheless, one of the key limitations of EPG is the inadequacy to record soft tissue contouring and occlusal relationships (10), making it occasionally necessary to implement the additional use of IOSs (10). Modern advancements and developments have been the inclusion of IOS with intraoral photogrammetry to condense workflows and reduce treatment complications and time required (10). For example, many companies that offer PG as a product also offer the concurrent use of smartphone technology to be used in conjunction (21). For example, PIC dental offers a mobile application that, using machine learning, can capture 15-25 photographs that are then combined to generate an STL file, containing the specific spatial and angular relationships between multiple implants (22). Although this new implementation of smartphones offers the user a more cost-effective approach, more studies are required in order to determine its trueness and precision before it can be considered as a gold standard method (22).

In recent years, the introduction of a new intraoral device was implemented, which incorporates the use of EPG together with IOS, forming the technique of Intraoral Photogrammetry (IPG) (23). In a single scan, this technique creates a unique STL file that already includes jaw anatomy, implant spatial positioning and occlusion (23). By combining the respective abilities of the two techniques, with the PG's accuracy as well as the IOS's ability to capture surrounding soft tissues, IPG has the potential to offer a more rounded and efficient manner in capturing impressions of fully edentulous patients (23).

With its origins being mostly in military usage (24), PG was introduced into the realm of dentistry in 1994, where it was initially used to detect the marginal adaptation between the prosthetic restorations and implants (25). In 1999, in a clinical pilot study written by Jemt et al (25), it was proposed that EPG could be successful in recording the exact positions of the implant replicas in an edentulous mandibular cast. The evaluation of implant impression accuracy, defined as the value of how precisely a previously fabricated prosthesis pairs with an anatomical structure, is dependent on precision and

trueness (26). Trueness measures the degree in which data varies from its true or accepted value, whereas precision measures the degree in which multiple data points vary among each other (26). In order to evaluate the degree of trueness obtained with EPG, verification casts are often required. Therefore, reliance on these verification casts as a reference standard may produce complications, as the probable errors produced in the manufacturing of the cast may be greater than the errors produced by the EPG itself (10). Nevertheless, the emergence of commercial EPGs in recent years has transformed the manner in which patients are evaluated and treated in the dental clinic (26).

1.3 Clinical Usage of Digital impressions

1.3.1 Clinical Efficiency

Digital techniques can minimise the need for clinical adjustment of full arch restorations in comparison to conventional techniques (27). Notable benefits include, but not limited to; improved patient experience, reduced distortion of impression materials, cost and time effectiveness, and 3D visualization of the of the preparation prior to manufacturing (27). Digital impressions also improve the assessment of prosthetic space, emergency profile configuration prior to laboratory manufacturing, and depth of the restorative interface (27). A completely digital workflow has been proven to reduce the errors and inconsistencies that would normally occur during a conventional or partial workflow (27). Although a conventional workflow can produce a highly accurate and well-fitting prosthesis, due to the multiple steps required and the many intricacies involved, errors can be produced from an early stage of the manufacturing and can therefore have significant effects on the final product (27). In addition, due to the longer working and treatment times associated to conventional methods, such as the setting times of the impression and casting materials, as well as the manufacturing of the custom tray required for the impression, it can be said that conventional workflows offer a reduced time-efficiency when it comes to the manufacturing of a prosthesis (27).

1.3.2 Patient and Clinician Experience

Digital techniques offer an improved overall experience for the patient as well as the clinician (27). For example, the working time needed for a conventional impression is much longer, and therefore if any error is produced, the impression will need to be repeated (27). In addition, due to the large size of the trays required, as well as the quantity of impression material employed, the patient may experience discomfort and the gag reflex may be triggered (27). With a digital approach, the patient is able to spend less time with an open mouth (27), as well as the fact that immediate feedback on the impression can be seen on the display of the selected IOS, therefore any error produced can be fixed during the impression scan (27,28). Furthermore, digital impressions create

electronic files that can be stored easily and sent digitally, saving costs in laboratory transport and storage, improving the overall experience for the clinician (28).

1.3.3 Limitations and Difficulties of Digital impressions

Digital impressions are completed with highly expensive IOS or PG devices and are therefore not entirely available for the widespread community of dental clinics around the world. Additionally, it is a sensitive technique with a steep learning curve, therefore it requires experience prior to usage (27). Notable limitations of digital impression techniques include difficulties capturing deep subgingival margins or sharp edges. Moreover, highly reflective surfaces are not captured accurately with the IOS, and therefore the use of a contrast powder, such as TiO_2, is sometimes required. IOSs are accurate for single or short edentulous space restorations, however they show inaccuracies when it comes to full arch restorations (27).

2. OBJECTIVES

Primary objective

- To compare Intraoral Optical Surface Scan (IOS) and Extraoral Photogrammetry (EPG) impression techniques in terms of accuracy and clinical efficiency, in patients that require complete arch implant restorations.

Secondary objective

- To analyse how the use of the intraoral scanner and photogrammetry-based digital impressions affects the passive fit principle

3. MATERIALS AND METHODS

3.1 Research method

This systematic review was implemented to analyse which of the two digital impression techniques used for complete-arch implant restorations offer the most notable accuracy. In order to establish this review, online databases such as PubMed and Medline (accessed via the Biblioteca CRAI) were used to acquire articles, specifically within the last 10 years (2015 – today).

To improve the specificity of the search function, articles would only be included if they were fully accessible, as well as being written in English. (as later described in the inclusion and exclusion criteria). In addition, the use of key words was employed, such as; Dentistry, Digital impressions, Implants, Complete-arch, Photogrammetry and Intra-Oral Scanner.

Furthermore, Boolean operators were used to further refine the selection of articles. The search function employed was as follows: (((Intraoral scanner) OR (Photogrammetry)) AND (Complete Arch Implant Restorations) AND ((Accuracy) OR (Trueness) OR (Precision) OR (Patient Comfort)) NOT ((Conventional) OR (Single Span edentulous spaces))

3.2 Inclusion and Exclusion criteria

The selection of articles was finally completed through the use of the inclusion and exclusion criteria mentioned below:

Inclusion criteria

- Fully accessible articles (through an institutional account)
- Articles written in English (or with a translated copy)
- Articles dated post-2015
- Patients requiring complete arch implant restorations
- Articles directly comparing intraoral scanning and extraoral photogrammetry
- In Vivo and in Vitro Studies

Exclusion criteria

- Articles with restricted access (even with an institutional account)
- Articles written in any other language other than English (which don't include a translated copy)
- Articles dated pre-2015
- Patients requiring implant restorations in short edentulous spaces
- Articles without a primary focus on digital impression techniques, not including any relevance to their respective trueness and precision.
- Case reports, systematic reviews and meta-analyses, not including primary data.

3.3 PICO question

P (POPULATION): Patients that require complete-arch implant restorations

I (INTERVENTION): Intra-Oral Optical Surface Scan (IOS)

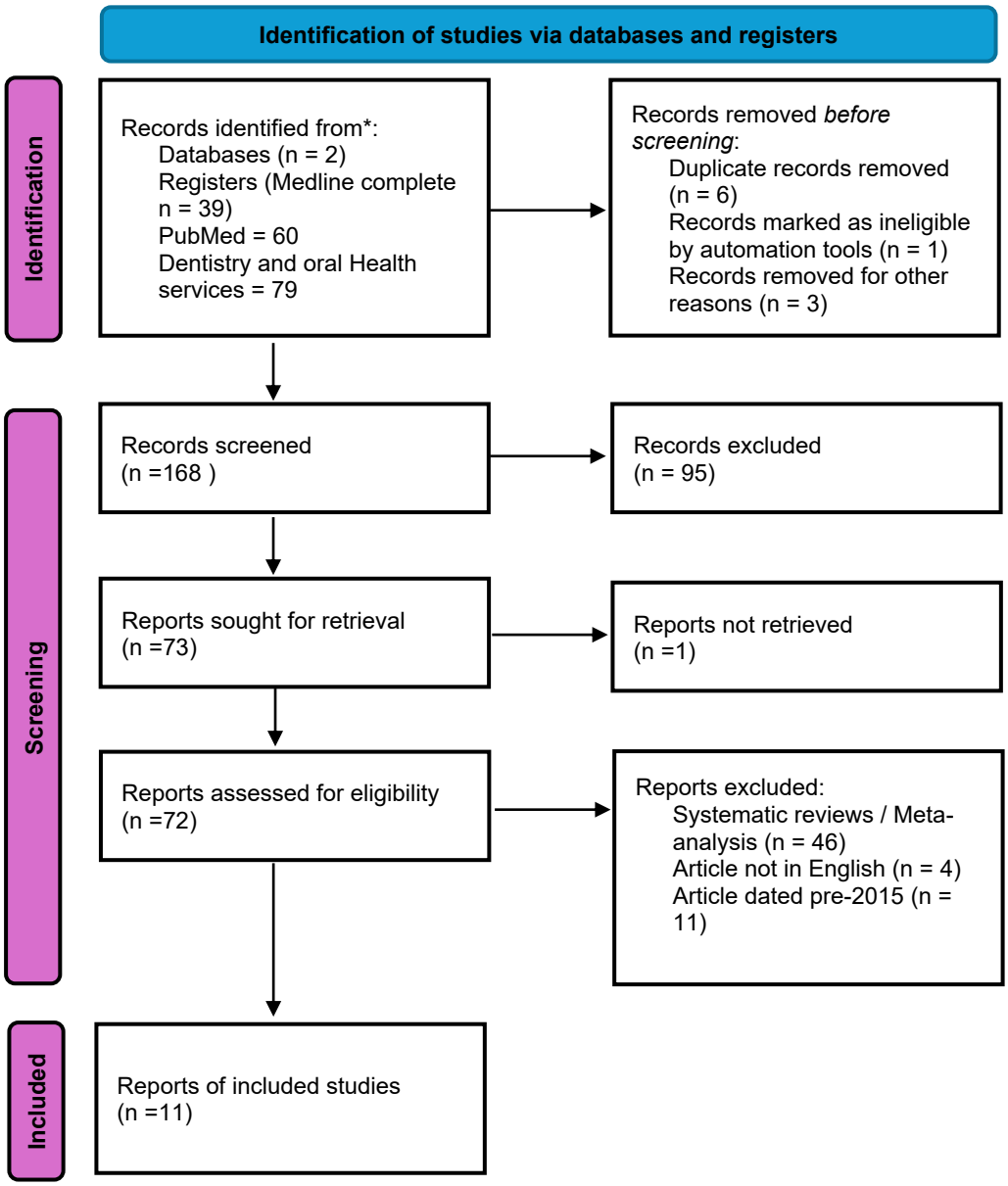
C (COMPARISON) Extraoral Photogrammetry (EPG) impression techniques

O (OUTCOME): Accuracy and clinical efficiency

Therefore, the resulting formulated PICO question is as follows:

"In patients undergoing complete arch implants restorations, How do Intra-oral Optical Surface Scan (IOS) impressions compare with Photogrammetry (EPG) impressions in terms of accuracy and clinical efficiency?

Figure 1. PRISMA flow diagram



4. RESULTS

Figure 2. Results Overview comparing IOS and EPG

Author / Year	Study Type	Number of Implants / Maxilla / Mandible	IOS / SPG devices used	Reference Scan	Outcomes	Results (Trueness)	Results (Precision)	Conclusions
Pozzi et al. 2023 (29)	In Vitro	Mandibular: 4	IOS iTero Element 5D EPG PiC Dental	D2000, 3Shape 5 µm accuracy	Linear Deviation (X, Y, Z, 3D) (µm) Angular Deviation (°)	IOS Mean 5.21µm -2.03µm -1.85µm 52.81µm 0.28° EPG Mean 12.81µm 0.95µm 20.78µm 33.42µm 0.24°	IOS SD ±50.51µm ±14.54µm ±37.31µm ±37.11µm ±0.14° EPG SD ±19.23µm ±7.15µm ±20.42µm ±17.71µm ±0.04°	EPG overall showed a higher accuracy than IOS
Pozzi et al. 2023 (30)	In Vivo	Maxilla: 4 or 6 Mandible: 4 or 6	IOS TRIOS 4; (3Shape A/S) EPG PiC Dental	D2000, 3Shape 5 µm accuracy	Linear Deviation (X, Y, Z, 3D) (µm) Angular Deviation (°)	IOS Mean -19.8µm, -4.1µm, -41.9µm 137.2µm 0.79° EPG Mean -24.8µm, -3.4µm, 20.9µm 87.6µm 0.38°	IOS SD ±110.2µm ±44.3µm ±127.5µm ±115.5µm ±0.59° EPG SD ±71.8µm ±29µm ±79.1µm ±74.2µm ±0.29°	EPG overall showed a higher accuracy than IOS
Fu et al. 2025 (31)	In Vitro	Maxilla: 6	IOS TRIOS 5, 3Shape A/S, Copenhagen, Denmark EPG ICam4D, Imetric4D	T8, Medit Corp, Seoul, Korea	RMS error Distance Deviation Angular Deviation	IOS Mean 39.93 ± 7.98 µm 0.40° ± 0.28° EPG Mean 31.72 ± 0.59 µm 0.36° ± 0.24°	IOS Mean 33.38 ± 13.95µm EPG Mean 2.30 ± 1.31 µm	EPG showed significantly better accuracy than IOS

Prott et al. 2025 (32)	In Vitro	Mandible: 4	IOS Primescan, v.SW5.2.10; Dentsply Sirona EPG Micron Mapper, v.1.3.1; SIN 360	inEos X5; Dentsply Sirona 2.1 ±2.8 µm accuracy	Linear Deviation (µm)	IOS Mean 56 ±0.7 µm EPG Mean 20.5 ±0.6 µm	IOS Mean 9.5 ±3.3 µm EPG Mean 6 ±1.2 µm	EPG was more accurate than IOS for complete arch implant impressions
Cheng et al. 2024 (26)	In Vitro	Maxilla: 6 Mandible: 6	IOS TRIOS 3, (3Shape) EPG ICam4D 1st Gen, (Imetric 4D)	3shape D2000, 3shape	RMS 3D Deviation (µm) Angular Deviation (XZ, YZ)	RMS 3D Median IOS 79.6µm (72.3, 102.4) SPG 69.2µm (56.0, 75.0) Linear deviation D1 IOS 32.30µm (25.80, 48.63) EPG 55.40µm (51.60, 71.78)	RMS 3D Median IOS 59.2µm (46.9, 94.6) SPG 41.1µm (11.0, 45.9) Linear deviation D1 IOS 21.00µm (8.25, 35.20) EPG 11.80µm (4.50, 18.50)	EPG showed better truenes s and precisio n, as well as fewer errors in 3D, angular and linear measur ements
Yan et al. 2023 (16)	In Vivo	Maxilla: 4 to 8 Mandible: 4 to 8	IOS CS3600, CareStream EPG ICam4D, (Imetric 4D)	E4; 3Shape A/S 4 µm accuracy	Surface Deviation (RMS)	IOS Median 48.95µm EPG Median 17.00µm	N/A	EPG showed a higher accurac y than IOS
Ma et al. 2021 (15)	In Vitro	Maxilla: 6	IOS TRIOS 3, (3Shap	EOS 4; 3Shape	Surface Deviati	IOS Mean 43.78 ± 4.03µm	IOS Mean 37.07 ± 3.98µm	EPG showed the lowest

			e v19.2.2) EPG ICam4D 1st Gen, (Imetric 4D)	A/S v2.1. 4.2 4 µm accuracy	on (RMS)	EPG Mean 24.43 ± 0.35µm	EPG Mean 2.32 ± 0.85µm	overall 3D discrepancy, whereas IOS showed the highest in terms of trueness and precision
Revilla-Leon et al. 2021 (33)	In Vitro	Maxilla: 6	IOS TRIOS 3, (3Shape A/S) (IOS2) EPG ICam4D (Imetric 4D)	CMM Contura G2 10/16/06 RDS; Carl Zeiss Industrielle Messtechnik GmbH 1 µm accuracy	Linear Deviation (X, Y, Z, 3D) Angular Deviation (XZ, YZ)	IOS2 Median 9.7, 18.0, -4.9, 21.1µm; -0.2°, 0.2° EPG Median 23.8, 73.7, -4.7, 77.6µm; 0.1°, 0.3°.	IOS2 IQR 54.6, 54.9, 20.7µm, 0.4°, 0.4°. EPG IQR 308.7, 273.6, 27.2µm; 0.6°, 0.6°.	EPG showed higher deviations in comparison to the IOS systems used
Liu et al. 2024 (34)	In Vitro	Maxilla: 4 parallel 4 inclined 6 parallel	IOS TRIOS 3, (3Shape A/S) EPG PiC Dental	Medit T8; Medit Corp 4 µm accuracy	Distance Deviation (RMS) Angular Deviation (RMS)	IOS Mean 168 ± 133µm 0.43 ± 0.34° EPG Mean 35 ± 19µm 0.25 ± 0.16°	IOS Mean 100 ± 122µm 0.29 ± 0.26° EPG Mean 10 ± 10µm 0.07 ± 0.08°	EPG showed the best recording accuracy
Abuduwaili et al. 2025 (35)	In Vitro	Mandible: 6	IOS TRIOS 3, 3 Shape EPG	D2000, 3Shape 5 µm accuracy	Linear Deviation (X, Y, Z, 3D)	IOS Median 41.6, 49.93, 16.65, 77.58µm; 0.51, 0.36°	IOS Median 27.91, 29.76, 15.83, 45.33µm; 0.30, 0.16°	EPG showed the highest accuracy in compari

			Icam4D (SPG-1) PIC Dental (SPG-2)		Angular Deviation (XZ, YZ)	EPG-1 Median 12.59, 13.56, 7.91, 25.23μm; 0.08, 0.06° EPG-2 Median 15.53, 17.35 ,9.18, 28.15μm; 0.09, 0.08°	EPG-1 Median 10.03, 7.15, 6.41, 15.80μm; 0.04, 0.03° EPG-2 Median 12.21, 9.03, 7.18, 17.78μm; 0.07, 0.09°	son to IOS
Lyu et al. 2025(36)	In Vitro	Maxilla: 6	IOS TRIOS 3, (3Shape A/S) EPG ICam4D 1st Gen, (Imetric 4D)	3Shape D2000 Scanner; 3Shape A/S	Best Fit Algorithm Absolute Linear Deviation Angular Deviation	IOS Mean + SD 68.49 ± 22.27μm 120.47 ± 62.88μm 0.31 ± 0.06° EPG Mean 38.07 ± 1.71μm 72.35 ± 16.17μm 0.25 ± 0.02°	IOS Median + IQR 23.06 (28.64)μm 63.50 (73.01)μm 0.06 (0.08)° EPG Median + IQR 1.78 (1.98)μm 10.66 (17.39)μm 0.01 (0.04)°	SPG showed similar truenes s and precisio n to convent ional techniq ues, wherea s IOS showed lower truenes s and precisio n

From the 11 studies included in the results, 9 of them were in vitro studies and the remaining 2 were in vivo. One of the key differences between the studies included were the number of implants used for the scans, varying anywhere between 4 to 8 implants per arch. Furthermore, the arch used for the scan also varied between maxilla, mandible or both. In general, for capturing the digital impressions, the most common IOS system used was the TRIOS3 3Shape, and the most common SPG system used was the ICam4D 1st Generation, although there were some occasional differences in the systems used. The system used to capture the reference scan varied significantly among the studies, with the most common one being the 3Shape D2000 laboratory scanner. In

general, the laboratory scanners used showed an accuracy of up to 5 μm, although some studies did not state the accuracy of the laboratory scanners used.

In addition, the methods used to measure the outcomes of each study showed some variation, although the most common outcome obtention method included linear deviation (measured consistently with X, Y, Z and 3D values) and angular deviation (measured in degrees). 10 of the 11 studies included both trueness and precision in their results, with 1 study only showing the trueness values. However, some studies, including Yan et al, only measured the outcomes with Surface Deviation or Distance Deviation (both measured in RMS, Root Mean Square). Studies varied with the quantity of results significantly, with some showing multiple values (e.g. Pozzi et al.), and others showing limited values (Liu et al.)

All studies included in these results showed very similar conclusions, stating that SPG systems had a higher accuracy than the IOS systems. One study (Lyu et al.) stated that SPG had similar accuracy to conventional techniques, whereas the IOS systems showed a lower accuracy than the previous two.

5. DISCUSSION

This systematic review was undertaken to determine which of the two digital impression techniques mentioned (IOS and EPG) demonstrates superior trueness and precision when used for complete-arch implant restorations. In total, 11 studies met the inclusion criteria, each displaying variation in several aspects, including type of edentulous arch studied, number of implants involved, study design and data collection techniques.

Among the selected studies, 2 were conducted in vivo (16,30), whilst 9 were performed in vitro (15,26,29,31–36. In vivo research tends to obtain findings reflecting clinical scenarios, as they account for the challenges that arise in the oral cavity, such as saliva or mobile mucosa (10,15,16). Conversely, in vitro studies are expected to produce more accurate results, since the impressions are taken on stable casts under controlled conditions. However, it is crucial to recognise that IOS is more susceptible to the challenges produced by the oral environment than EPG. As the EPG impression occurs extraorally, it is less influenced by the previously mentioned variables.

Notably, the two in vivo studies included reported greater accuracy for EPG than in the in vitro studies, with trueness values of 17.00μm (16) and 24.43μm (15) respectively. On the other hand, IOS demonstrated the opposite, with trueness values of 48.95μm for in vitro (15) and 43.78μm for in vivo (16). Due to these discrepancies, as

well as the fact that most available studies are in vitro, further clinical research is required before definitive conclusions can be drawn and confidently applied to clinical practice.

A further source of variation amongst the studies included is the differing brands of IOS and EPG systems used for data collection. The most frequently used devices were the TRIOS 3shape for IOS and the Icam 4D IMetric 4D for EPG. Differences within the system's technology, as well as their ease of use, can influence outcomes, making direct comparison between studies challenging. To mitigate this, some studies, such as those undertaken by Abuduwaili et al (2025) and Revilla Leon et al. (2021)(33,35) incorporated multiple brands within the same study.

Within IOS systems, discrepancies may arise due to factors such as type of scan body employed, sensitivity to intraoral conditions and the stitching algorithms used (37). In contrast, EPG system variations are related to aspects such as camera calibration or triangulation accuracy (33). Although these technological differences exist, several studies suggest that their overall impact on clinical accuracy is small (37). Nonetheless, future research, comparing the same brands would be beneficial to obtain more comparable, consistent and clinically relevant results.

Additionally, inter-study variability was observed in the number of implants studied per arch, ranging from four to eight. In the context of IOS, a greater number of implants could be associated with improved accuracy, as the decreased edentulous space limits the amount of soft tissue required for scanning (15). This is clinically relevant because IOS systems are known to be inaccurate in scanning soft tissues (10). As a result, cases with fewer implants had the potential to produce less accurate scans and therefore affect the inter-study analysis. Accuracy may also differ depending on whether the impressions were taken on the mandibular or maxillary arch, as these regions present differing alveolar morphology and surrounding anatomical structures. Despite these differences, most of the literature indicates that these differences do not have a statistically significant effect on the accuracy of both IOS and EPG (30,38).

Another aspect to consider is the LBS used for the reference scan in all studies. Whilst the most common was the D2000 3Shape, different LBSs with differing accuracy (2.1µm - 5µm) were used amongst studies. Subsequently, inter-study comparison is made more complicated as each study obtained accuracy data only relevant to the respective LBS used. Therefore, for future studies, it would be beneficial to select studies that collectively use the same LBS for further homogenisation of results.

The overall geometry of ISBs plays a significant role in determining scanning accuracy (11). Variation in ISB design can influence how effectively IOS and EPG systems can detect and capture surface details and angulation. As different ISBs were used across the studies, it is likely that this contributed to the observed variability in IOS

accuracy. Furthermore, differences in methodology were identified regarding the use of supplementary materials to enhance scan quality. Some studies implemented the use of a contrasting powder (TiO_2), whilst others introduced artificial landmarks such as CFs or NCFs. These inconsistencies may have affected the reported outcomes, therefore making it once again more difficult to achieve inter-study analysis.

One of the most important differences discovered amongst the studies included in this review is the varying methods of resulting measurement, including linear deviation, surface deviation, Best Fit Algorithm, or absolute linear deviation. Along with these variations, differing units were used, therefore making it challenging to complete inter-study comparison. Lyu et al. was the only study to use the Best Fit Algorithm and absolute linear deviation as a methods of measurement, meaning that values obtained, although useful, are made difficult to compare with other studies (36). In addition, some studies included a large quantity of data for trueness and precision from taking multiple scans, whereas others only contained a few, or even only one value for trueness and one for precision. For the studies containing limited data, results may not be entirely conclusive.

Another important difference in all these studies, and consequently a concurrent issue in all systematic reviews on this topic, is the variation in operator skill and knowledge of the respected system used. IOS systems have a steep learning curve and require a notable amount of practice and experience in order to maximise the accuracy of the impression taken (27). Within the technique required to use an IOS, the path used for the scan has a great impact on the results. Only a few of the studies included mentioned the path used, such as Pozzi et al 2023, stating that the starting point was always on the occlusal-lingual surface of the ISB in the position of 4.5, and finishing at the position of 3.5 (29). Variations are seen between studies, as each IOS system requires a specific protocol to follow.

Time required to complete the scan varies according IOS systems used as well as the ability of the operator. Only a few studies, such as Fu et al 2025 included the scanning time as part of the data in the results. IOS showed a significantly higher scanning time than SPG, with 91.01 ± 20.31s and 57.40 ± 5.19s respectively (31). This can be attributed to the frequent need of re-scanning missed surfaces or incorrectly scanned areas with IOS.

Differences amongst professionals has a notable impact, which would result in variations between the different studies included. Although these variations may be minimal, they remain present in current literature and can therefore make it difficult to draw any definitive conclusions from the results. Future studies should prioritise standardisation of methodologies. For example, employing a single operator to perform

all impressions and by systematically comparing IOS and EPG systems under the same controlled conditions. This would help to reduce overall variability and therefore improve the consistency and comparability of data.

EPG works by using two extraoral infrared cameras to record the spatial positions of the implant bodies in the oral cavity (20). During the process indicated, the operator performs multiple micromovements to obtain the images necessary to replicate the implant positions accurately. Due to the fact that the scan is performed extraorally, EPG is not associated to the limitations commonly associated to IOS, such as saliva or mobile soft tissue (10,15,16). This clear difference is one of the reasons as to why EPG demonstrated higher trueness and precision in the studies included in this review. Interestingly, Out of the eleven studies included in this review, just one obtained results showing EPG with a lower accuracy in comparison to IOS (33).

While the impression technique employed has a significant role in achieving the Passive-Fit principle (8), other factors play into the final prosthetic fit. The multistage manufacturing workflow, being either fully digital or partial-digital in this case, can also influence accuracy and therefore introduce variability. With different brands offering their unique 3D printers, software algorithms and production protocols, considerable differences arise both in the manufacturing process and in the final outcome. This variability must be taken into consideration before considering the results of this review, as the lack of standardization amongst systems used makes direct comparison of data challenging.

As mentioned previously, a key limitation of this review was the inclusion of both in vitro and in vivo studies. This can produce a difficult direct comparison of data, due to the differences arising from scanning a cast and scanning an oral cavity (10,15,16). The cast remains completely stationary during the scan, with no anatomical structures interfering with the impression. When scanning an oral cavity however, the combination of patient movements and the surrounding anatomical structures may provide difficulties in producing an accurate digital scan. As the majority of studies included in this review were in vitro, it would be advisable to complete a review on purely in vivo studies in order to improve real life application (39,40).

This review is also potentially limited by the lack of direct comparisons between digital and conventional impression techniques. Given that conventional techniques remain widely used in clinical practice, it would be beneficial to also include and compare data taken from studies measuring their accuracy (41).

In addition, the invariability of scanners represented among the included studies may increase the risk of publication bias (42). Studies demonstrating favourable results are, in general, more likely to be published and readily accessible, whilst on the contrary,

studies reporting inconclusive or even negative results are often overlooked (42). On the other hand, if there was a comparison of different brands amongst studies to reduce this bias, due to the differences in individual technologies and systems used, the resulting data would not be homogenised and therefore difficult to compare. Therefore, further research of each type must be completed, either comparing multiple brands of IOS or EPG, or focusing on a single brand. As a result, stronger data that is clinically applicable will be obtained (42).

The integrity and specificity of the search function and criteria for study selection offered some limitations (41). For example, It would be useful to limit the search to different studies using the same implant configuration, laboratory scanner and methods of outcome measurement, as this would help homogenise the data obtained and therefore allow for direct comparison without interference (41). In addition, the lack of homogeneity amongst studies with regards to the inclusion of a splint, or the method used for the splint creation for the IOS scan, further emphasises the importance of strengthening the search function and maximising the extension of the inclusion criteria.

Another limitation of this review is the lack of data regarding the long-term outcomes, such as the implant survival rates over a given period, or overall patient satisfaction. For future research, it would be advantageous to incorporate said data, so more comprehensive conclusions that would also account for the long-term performance and durability of prostheses can be drawn.

6. CONCLUSION

From the data obtained amongst the different studies, the conclusions that can be drawn from this systematic review are as follows:

1. EPG showed higher accuracy, trueness and precision than IOS in 10 of the 11 studies for taking digital impressions in patients requiring complete-arch implant restorations. For 1 study, EPG showed significantly lower trueness and precision with greater angular and linear deviations along the X, Y and Z axes. EPG also showed a higher clinical efficiency than IOS, with one study showing a reduced scanning time of 57.40 ± 5.19s against 91.01 ± 20.31s respectively.
2. EPG showed less difficulty in achieving the Passive-Fit principle, with an average angular deviation of 0.192°, nearly half the IOS average angular deviation of 0.342°. However, both did not exceed the 1° threshold required to obtain the Passive-Fit.

7. SUSTAINABILITY

Achieving sustainable practice in a constantly evolving dental healthcare landscape has become a key priority. The more frequent use of digital techniques in modern day dentistry may produce an improvement in general sustainability. By reducing the need for materials such as gypsum and conventional impression products, as well as reducing the need for physical transport of items between clinic and laboratory, digital impressions contribute to more sustainable practices; therefore, this review indirectly supports the progression to a more sustainable practice of implant dentistry.

Enhancing the proficiency and techniques associated to digital impressions could help to reduce the need for repeat visits and impression retakes, thereby lowering energy usage and material waste. Consequently, a thorough, case-specific understanding of the digital techniques available in today's market would support a sustainable clinical practice. Although digital workflows also result in environmental costs, including product manufacturing, maintenance and energy required for processing data, the overall reduction in materials required and transport obtained suggests a progression to a more sustainable dentistry. Among the 17 Sustainable Development Goals, this review aligns to Goal 3: Health and wellbeing, as well as Goal 12: Responsible consumption and production (43).

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