Universidad Europea

GRADUATION PROJECT

Degree in Dentistry

TRUENESS AND PRECISION OF INTRAORAL SCANNERS FOR FULL-ARCH IMPLANT REHABILITATIONS

Madrid, academic year 2022/2023

Identification number: 202

ABSTRACT

Introduction: This systematic review aimed to evaluate the trueness and precision of intraoral scanners for full-arch implant rehabilitations; pointing out the CAD/CAM components, the advantages, the disadvantages of the intraoral scanner, the indications and the limitations of the system; **Objectives:** three objectives were chosen in this systematic review: the first objective is to evaluate the trueness of digital impressions, the second to evaluate the precision of digital impressions and the third to assess the usefulness of the intraoral scanners in full-arch implant rehabilitations; **Material and methods:** the electronic databases Medline, PubMed, Web of Science, and Scopus were systematically explored using MeSH terms and a search strategy based on the focused PICO question. The selection of the articles focused on the inclusion and exclusion criteria and took into account also articles about conventional impression technique to make a comparison between the two methods; **Results:** 12 scientific articles we are analyzed following the inclusion criteria and PRISMA guidelines. Articles highlighting the conventional and digital impression techniques that showed the trueness and precision results of both methods and measured the accuracy for full-arch implant restorations; **Conclusion:** digital impressions can be considered a good method in case of short-span implant prosthesis but not very useful and accurate in case of full-arch implant rehabilitations; improvements and in vivo studies are needed to give stronger evidence and still the most accurate way to take an impression for full-arch over implants is the conventional technique with elastomeric materials such as polyether or light and heavy body silicones with open-tray technique.

Keywords: dentistry, trueness, precision, intraoral scanner, full-arch implant prosthesis.

RESUMEN

Introducción: Esta revisión sistemática tuvo como objetivo evaluar la veracidad y precisión de los escáneres intraorales para rehabilitaciones con implantes de arcada completa; señalar los componentes CAD/CAM, las ventajas, las desventajas del escáner intraoral, las indicaciones y las limitaciones del sistema; **Objetivos:** se eligieron tres objetivos en esta revisión sistemática: el primer objetivo es evaluar la veracidad de las impresiones digitales, el segundo evaluar la precisión de las impresiones digitales y el tercero evaluar la utilidad de los escáneres intraorales en las rehabilitaciones con implantes de arcada completa; **Material y métodos:** se exploraron sistemáticamente las bases de datos electrónicas Medline, PubMed, Web of Science y Scopus utilizando términos MeSH y una estrategia de búsqueda basada en la pregunta PICO focalizada. La selección de los artículos se centró en los criterios de inclusión y exclusión y tuvo en cuenta también artículos sobre técnicas de impresión convencional para hacer una comparación entre los dos métodos; **Resultados:** se analizan 12 artículos científicos siguiendo los criterios de inclusión y las guías PRISMA. Artículos que destacan las técnicas de impresión convencionales y digitales que mostraron los resultados de veracidad y precisión de ambos métodos y destacando la utilidad de las impresiones digitales para restauraciones sobre implantes en arcada completa; **Conclusión:** las impresiones digitales pueden considerarse un buen método en el caso de prótesis sobre implantes de tramo corto, pero no muy útiles y precisos en el caso de rehabilitaciones con implantes de arcada completa; se necesitan mejoras y estudios in vivo para brindar evidencia más sólida y aún la forma más precisa de tomar una impresión sobre implantes de arcada completa es la técnica convencional con materiales elastoméricos como poliéter o siliconas fluida y pesada con técnica de cubeta abierta.

Palabras clave: odontología, veracidad, precisión, escáner intraoral, prótesis implantosoportada de arcada completa.

INDEX

1. INTRODUCTION

The discipline of digital dentistry is being propelled by computer-aided design and computer-aided manufacturing (CAD/CAM) technology, it is rapidly developing. (1)

1.1 History of CAD/CAM system

CAD/CAM technology, which was created in the 1950s, helps to model, design, and create objects. Since the 1980s, dentists and technicians have been creating inlay, onlay, overlay, crowns, veneers, fixed dental prostheses (FDPs), and implants using this technology. The first CAD/CAM system to be utilized in dentistry offices was called "CEREC" and was released to the market in 1987. At the beginning was used for the preparation of ceramic restorations with a beautiful appearance. The system has evolved into the fourth iteration of the hardware, allowing for the production of implants, crowns, laminates, FDPs, and inlay and onlay fillings. (2)

The process of creating a digital prosthetic is broken down into four steps: gathering information using a scanner to produce a mesh (ME) or a surface reproduction of the scanned model; calculating the ME with CAD software to design the prosthesis; creating the prosthesis with CAM software via milling or 3D printing; and final step is the clinical use. The effectiveness of each of these steps are crucial in the therapeutic outcome. (3)

In the initial stages CAD/CAM in dentistry wasn`t accurate because it created restorations from direct photo shoot, for that the first choice was the conventional process that made prosthesis more precise.

Subsequently, a new well-constructed technology was devised using an optical impression to scan the operating model. With the establishment of CAD/CAM technology, the manufacturing process for restoration products saw a significant improvement in both product quality and precision.

The development of intraoral scanner (IOS) technology has advanced greatly as a result of a recent European-centered drive to revert to basic scanning-technology research.

In recent years, enormous advancements have occurred with the aim of improving digitization, such as reducing the scanner tip, decreasing weight, optimizing scan time, and enhancing image resolution. (1)

1.2 Data processing in CAD/CAM system

In order to create an optical impression, an IOS must optically measure and offers 3D model data, such as information on the surface formation of the abutment tooth, gum, the antagonist tooth, or the dental occlusion.
All information that was taken is converted into digital data with standard tessellation language (STL) data, which are subsequently used to flow into the production equipment and are applied for designing in CAD software and manufacturing in CAM software. (1) (Figure 1.)

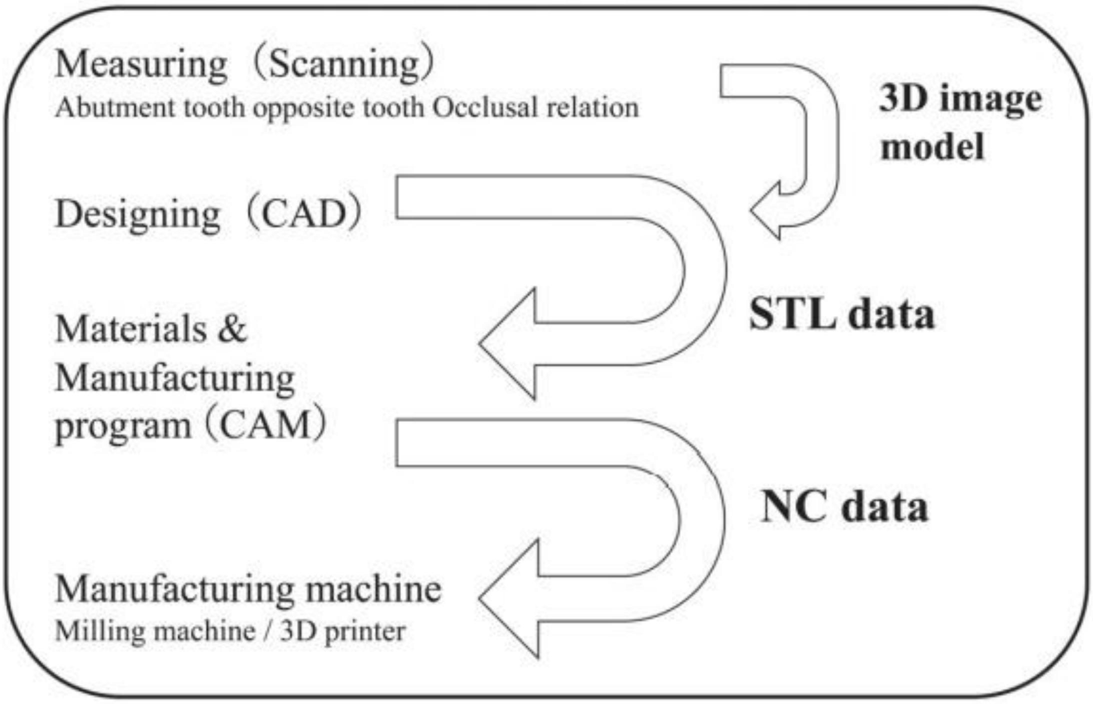


Figure 1. Data processing in CAD/CAM system. (1)

1.3 Advantages of IOS

In addition to understand how an IOS works and what are the CAD/CAM components, it is also necessary to underline what are the advantages and disadvantages of IOS.

One of the advantages of digital impressions (DI) is the reproduction of the 3D models of the arches of the patients, instead of traditional physical impressions. In fact, conventional impressions (CI) with trays most of the time create distress for the patient, particularly those with severe gag reflexes. For these patients, using light instead of traditional impression materials has advantages; optical impression is therefore valued. (4)

Intraoral digital scanning is efficient in terms of time and steps because of the omission of the selection of trays, material consumption, material setup, material sterilization and wrapping.

In addition a lot of laboratory processes are no longer necessary such as plaster pouring, die cutting, trimming, articulation, and extraoral scanning. (5)

Despite recent technological developments in IOS, which allow for the scanning of a full-arch scan in less than 3 min on the market's newest devices, there are no obvious differences in taking the impressions with digital and conventional techniques because the times used are more or less the same but especially in the following steps there is a big saving of time.

In fact, optical impressions allow the dental laboratory receiving patient-specific 3D virtual models (proprietary or STL files) by email instead of having to send anything by courier. As a result, significant time and financial savings are possible throughout the working year. (4)

Another positive point is clinically**,** in fact, once the acquisition of the knowledge has been achieved, using IOS may be easier for scanning complex cases such as multiple implants than the traditional technique. Additionally, if the dentist is not happy with some parts of the virtual model, it is possible to remove them and retake the impression without having to go through the entire process again, just that area and this is as well a time-saving feature.

There are less consumable expenses, the dentist directly saves money by doing away with traditional impression materials.

More effective is also the exchange of information with the dental technician: the dental technician and the dentist are able to check the quality of the impressions at the same time, this is because they are sent quickly and easily and therefore the dental technician can analyze them in real time. Without wasting time calling the patient back for a subsequent appointment and then requesting to take the impressions at the same moment. (4)

The DI is a potent instrument for marketing and patient communication. In fact, optical impressions make patients feel more invested in their care and make it possible to communicate with them more effectively. This emotional investment may benefit the treatment as a whole, for instance by increasing patient compliance with dental hygiene. Patients are also fascinated about the technology and share it with their colleagues and families, which increases interest in dental offices that have these cutting-edge tools. IOS has indirectly developed into a very effective instrument for marketing and advertising.

But adopting IOS in the dental clinic has a learning curve, therefore pay close attention to this issue. Young dentists, for example, who have a stronger affinity for computers and technology, will find it quite simple to implement IOS in their offices. The use of the tools and associated software may be more difficult for older practitioners who lack experience and enthusiasm for technical advancements.

Last but not least, it should be remembered that because manufacturers give so little information about their scanning protocols, it is still uncertain which scanning strategy is superior than the others. (4)

The risk of infection in the digital process is also reduced as the trays have to be sterilized by the operators following the removal of the materials and disinfect them in the traditional impression method.

The dental office and dental laboratory may become infected by using impression materials that have been tainted by different oral bacteria carried by the patient. An IOS's scanning tip can be sterilized by autoclaving. Additionally, since no traditional models or impression materials need to be handled, which could be a source of infection, the 3D models by IOS are exchangeable data.

Another significant benefit is of course the file archiving and management. The impressions made using IOS devices may be managed with the right media, unlike traditional plaster models, which need room and degrade over time. Digital files make it simple to keep the data for a long time, and users can access the files at any moment to simply recover the data. (1)

1.4 Disadvantages of IOS

But despite all the advantages that an IOS can bring, its limitations must also be highlighted.

Training is required for IOS operation because oral-cavity optical impression measurements must be made quickly and precisely.

In DI the point to be scanned must be clear in the visualization. Controlling liquid in the oral cavity, especially gingival fluid and saliva, is crucial because, due to optical refraction, it can lead to measurement errors.

Scan bodies (SBs) are needed for a DI with an IOS over implants, the implant system's software, and the CAD/CAM technology needs to work together. (1)

An IOS can be purchased up to 40.000 euros**,** depending on the type. Engineers have introduced a large number of new models over the past several years, and the increase in supply should be matched by a decrease in the price of purchases. Nevertheless, by incorporating the IOS through the many dental fields (prosthodontics, orthodontics, implant surgery), it should be possible to amortize the cost over the course of a year. The additional management of costs associated with software updates for reconstruction is a crucial factor to take into account.

Before acquiring an IOS, the dentist should be thoroughly notified of the administration charges, that can be applicable.

Lastly, in the case of "closed" software, "unlocking" the files so they can be utilized by any CAD application or any laboratory may require paying an annual or monthly fee. Again, the dentist needs to be appropriately informed of these extra management expenses. (4)

1.5 Steps in digital CAD/CAM process

The steps of the digital process include data collection, CAD phase, and CAM phase. The IOS cannot scan in a direct manner the implant during the data collecting step; instead, it had to be done through a SB. (6) (Figure 2.)

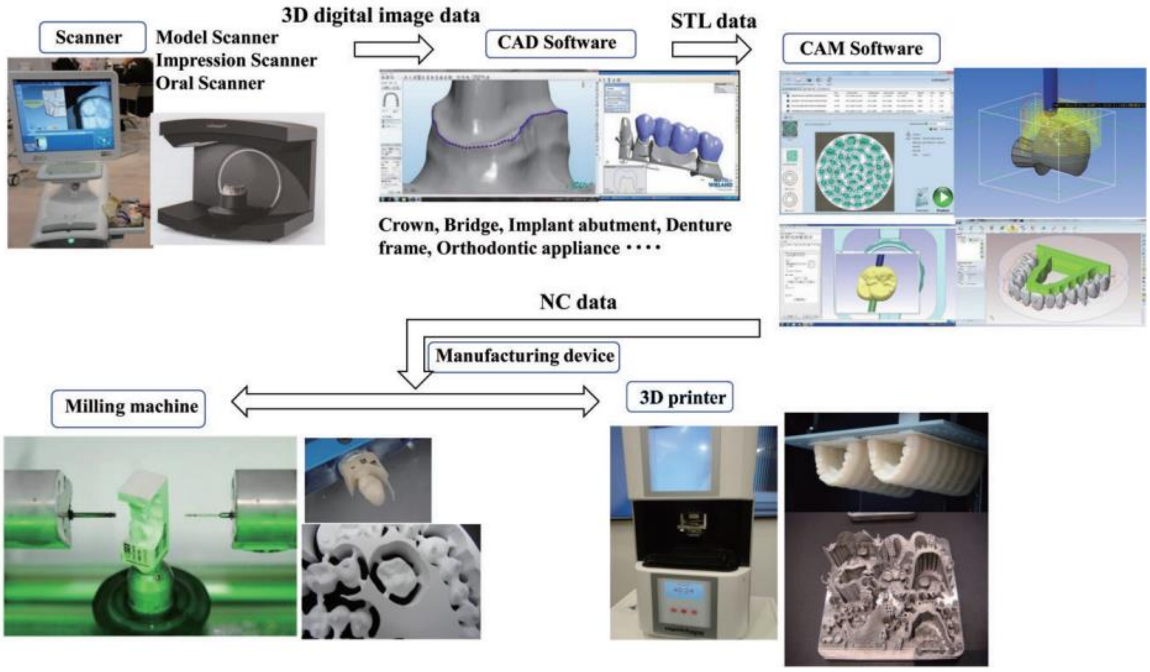


Figure 2. Digital CAD/CAM process. (1)

1.6 Definition of scan-body

Particularly in fixed implant prosthodontics, the SB, a transfer device placed onto the fixture and scanned with an IOS, make possible to record the 3D location of the implant. (3)

There are numerous different SBs available on the market right now, with variable geometry, heights, materials, and surface treatments. (6)

After this scan is submitted to the laboratory, which utilizes CAD software to construct the prosthetic devices, in addition to those of the master model without SB, the antagonist, and the occlusion registration in standard tessellation language (STL) file.(3)

During CAD phase of the digital workflow, the implant SB is crucial. The size, shape, material, and surface characteristic of the SB may have an impact on accuracy, compromising the scanning process and causing an adverse effect on the virtual alignment phase. (6)

Initially, the dental-specific CAD program imported the original scan of the SB. Based on two-step alignment protocol, the CAD model from the implant library was superimposed each SB one by one. First, a rough alignment (original VS library) is carried out identifying the dimensional characteristics on the SB. To obtain "best fit" between the surfaces, automatic overlapping is then used. After being aligned, the model is exported as a single STL file. (6)(Figure 3.) From STL file is obtained the associated digital working cast. (7)

The most important task in the CAD program is to replace the ME of the SB on the master model with the equivalent library file (LF). The ME is a 3D surface composition that results from a scanning and is generally a rough estimation of the digitized item, in contrast to the LF, which is geometrically perfect. (3)

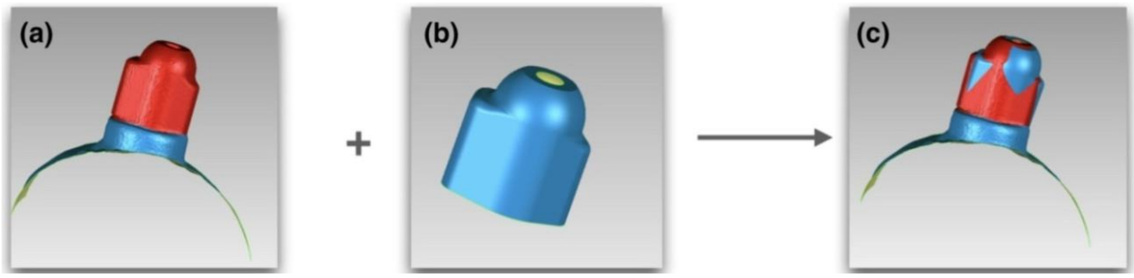


Figure 3. Original scan of the SB (a), equivalent library file (b) and an aligned model was created by the software (c). (6)

1.7 Passive fit concept

The impression material, impression technique, implant angulations, and implant count all have an impact on the accuracy of the impression, which is thought to be the primary factor influencing the fit of the structures according to a study of the literature. For the implant-fixed prosthesis to be successful over time, it must fit perfectly and a passive fit is crucial. Any improper framework could affect the bone-implant interaction and the uniformity of the mastication forces in addition to causing biological issues such as screw fracture or loosening. (8)

Although digital processes (scanning, transfer, and milling) can also result in slight errors, they have a decreased affection by hand-operated mistakes and require smaller number of procedures. The distortion increases with the length of the span, which may lead to misfit. If the implant and framework surfaces are manufactured with perfect plainness, a perfect passive fit is obtained in the absence of tensions between the implant and the framework after closing all screws. (9)(Figure 4.)

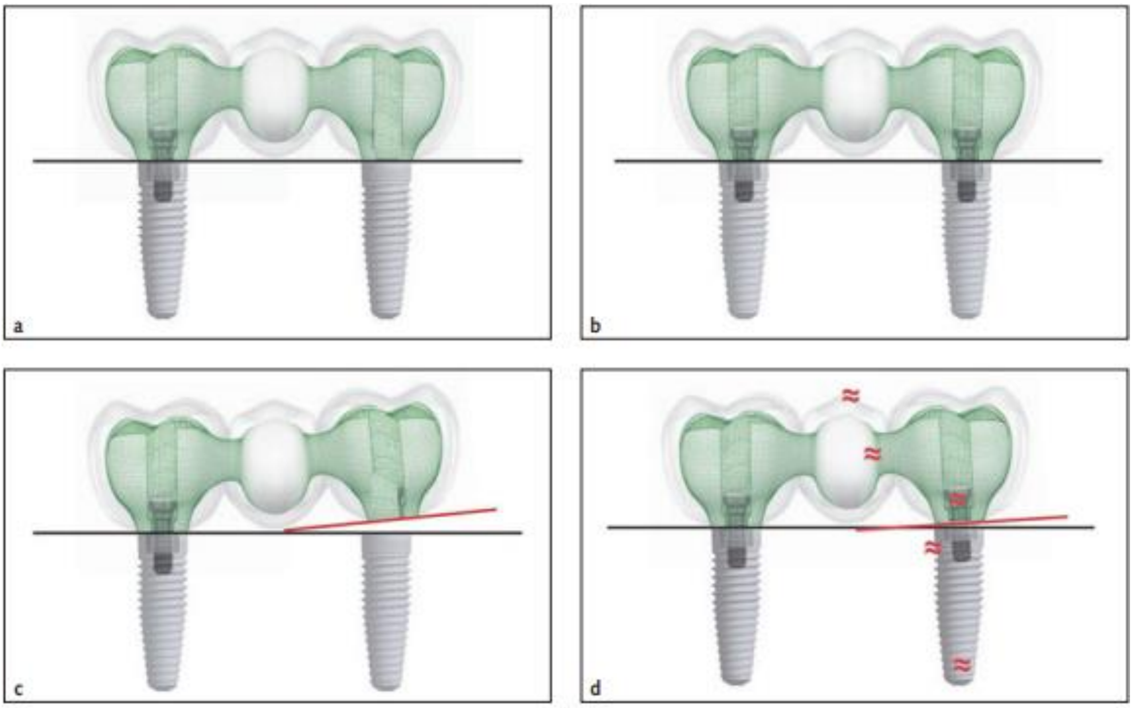


Figure 4. Visual representation of a screw retained implant-supported prosthesis and the two corresponding implants. The completely fitting shows passive fit in the one-screw test (a) and with all screws closed (b). The bad fitting shows a gap in the one-screw test (c) and a non-passive fit with tension in the components and a remaining micro space between them (d). (9)

Prior to intraoral try-in over implants, the prosthesis may be placed on the implant analogues in the master cast. Several workflow phases, whether traditional or digital, could result in a deformed prototype and an inadequate reproduction of the mouth.

The most important clinical assessment methods for passive fit are: visual (eye, binoculars) in order to see macroscopic gaps but this method is not easy to assess in case of subgingival implant-prosthesis interphase and it may result complicated also in case of conical implants connections. Very often the micro-gaps are not visible to the human eye and a probe is used for the evaluation. Deeply subgingival interphases that are inaccessible to direct vision and tactile probing can be visualized by radiographic analysis. Despite the fact that a paralleling device aids the dentist in more precise evaluation of implant-framework interphase. (9)

One screw is tightened after another during final prosthesis installation using a technique based on maximum torque. Hand tightening can be used to subjectively gauge screw resistance, but specialized torque-angle monitoring systems provide a more accurate measurement.

Combining various chair side procedures can increase the specificity and sensitivity needed to identify fit or misfit of the prosthesis. (9)

1.8 Digital impressions in implant rehabilitations

DI may be a trustworthy substitute for prosthetic restorations over implants, however there isn`t a gold standard technique. It has been demonstrated that the development of a digital strategy is even more accurate and effective than traditional materials. (8)

Both techniques, the conventional and the digital, cannot be regarded as accurate in cases of prosthesis including higher number of implants than four. Although it is advised to splint the implants before fabricating the final prosthesis for both the procedures (CI and DI). (10)

In order to have a good scanning in the full-arches implant rehabilitations, above all, it is essential to know the scanning strategy. (11)

The application of IOSs for obtaining DI for the creation and production of small rehabilitations**,** like single crowns (SCs) and partial prostheses (PPs), has been scientifically supported in fixed implant prosthodontics.

On the other hand IOSs do not currently appear to be sufficiently precise in the case of large rehabilitations, especially for complete arches, according to a variety of studies in the literature. (12)

1.9 Definition of trueness and precision

Trueness and precision are the key characteristics that an IOS should dominate; it should be allow to take a true and precise impression; so accuracy is an essential component for ensuring a passive fit between implants and the prosthetic construction. (13)

ISO 5725 utilizes the terms "trueness" and "precision" to characterize the accuracy of a method of measurement. "Trueness" pertains to how close the arithmetic mean of a significant number of test outcomes agrees to the reference value. On the other hand, "precision" concerns how close the test outcomes are to each other.

In case of trueness and precision of IOS for full-arch implant rehabilitations:

- Trueness means that “the impression’s proximity to measured reality, it is the main concept associated with accuracy**.**“(13)
- Precision means that there is “similarity between a group of impressions of the same case.”(13)

Around the implants there isn`t the periodontal ligament that cushions the forces for this reason the precision required for prostheses over implants is greater (59–72 µm) than that supported by the teeth (100 µm). (6)

An IOS should ideally be highly true and precise, which means recognizing every aspect and enable the production of a model that is as close to reality. (4)

A reference is needed to assess a measurement's trueness; this acquisition must have been conducted with a device with attested accuracy (potentially <= 5µm), like a coordinate measuring machine (CMM), an industrial optical system, or a desktop scanner. In order for the acquisitions made using IOSs to be mathematically certified, they must be evaluated to those made with reference machines.

While in order to determine precision it is necessary to compare the results taken using the same scanner and assess the variations among them without the need for a reference.

It is difficult to measure the trueness of optical impressions using IOS in vivo since it is impossible to utilize instruments with very high precision, like CMMs, articulated arms, or industrial scanners, inside the oral cavity.

However, most of researches on the trueness and precision of IOSs have been conducted in vitro on plaster casts. Recently in vivo, some researchers tried to establish indices o structures with acknowledged sizes (custom measuring aids) to assess how them affect the DI. (12)

Other elements that influence this technology include the patient's mouth opening, the dimension of the head of the scanner, the lumination of the environment, luminosity diffraction, oral fluid, vapor, the quantity and positioning of the SBs, the fabrication element of the SBs, the space among them, the extension of the toothless region, and the arch dimension. (7)

Significant deformity in a full-arch implant is due to two causes of IOS scanning. First, in order to recreate the prototype of the mouth, multiple overlapping of obtained images is necessary because the IOS scanner view-frame is short. This leads to accumulated stitching mistakes.
Second, there are no qualifying anatomic landmarks for correct stitching between the SBs, because there are shiny and moveable mucous tissues. (14)

1.10 The use of splinted scan-bobies and auxillary elements

Splinted SBs may be quite useful for digital impressions in full-arch implant rehabilitations, particularly in situations where there is a significant inter-implant space. (15)
The splinting between the SBs is done by a robust bar that protrudes from the cylindrical element of the SB was included in the design so it could serve as a stable reference point for stitching at the implant locations. (16)(Figure 5.)

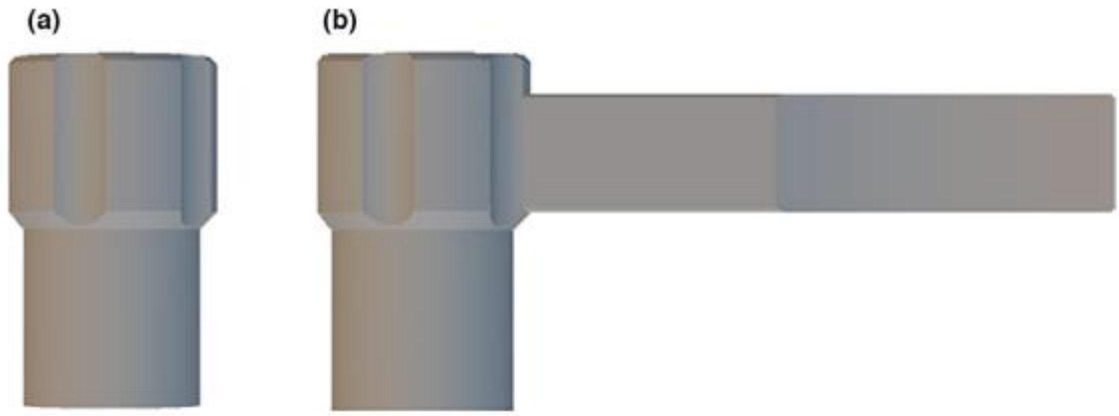


Figure 5. The CAD/CAM scan bodies. (a) Scan body without splinting bar. (b) Scan body with splinting bar.(15)

To improve accuracy, others auxiliary devices it has been suggested employing manufactured elements as marks. (14) (Figure 6.) (Figure 7.)

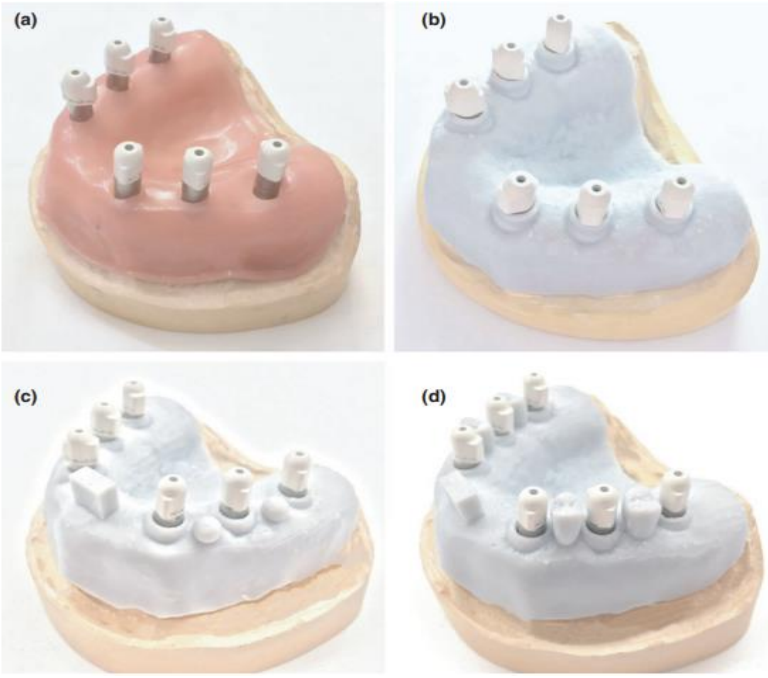
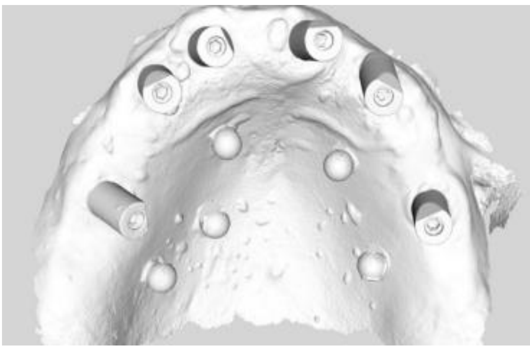


Figure 6. Novel auxiliary devices to improve scanning accuracy. (a) Master model covered with silicone material with thickness of 2mm simulating the mucosa. (b) A base of 1.5 mm thick covering the cast with holes at the implant areas. (c) A parallelepiped block (8.0 × 4.0 × 7.0 mm) and four circles (Ø 5.0 mm) were attached to the base. (d) The four circles were substituted by premolars. (14)


a.

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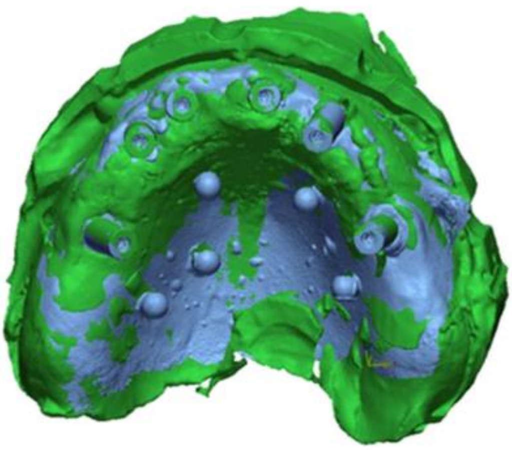
c.

Figure 7. Artificial dots on the palate to improve scanning accuracy. (a) SBs and artificial dots in upper jaw. (b) STL file elaborated by True Definition®. (c) STL files from the DI with True Definition® scanner (STL files 1) were overlapped with the STL files from the plaster casts (STL files 2). Superimposition of the two STL files with reverse engineering software (Geomagic®). (17)

1.11 Stereophotogrammetric technology with PIC Dental ® system

As well as other devices based on stereophotogrammetric technology have been created in addition to IOSs.

A more advanced method than photogrammetry, stereophotogrammetry, assesses the 3D coordinates on an item, speeding up the process.

Three components make up the PIC Dental® system: a device with CAD software (PIC Pro®) for managing patient private information, fusing information from its library with the STL collected from patients, the black flag-shaped abutments (PIC Abutment®) each bearing four distinct white dots to serve as a unique identification mark and an extraoral stereo camera (PIC Camera®, PIC Dental®) with an infrared flash. (18) (Figure 8.)

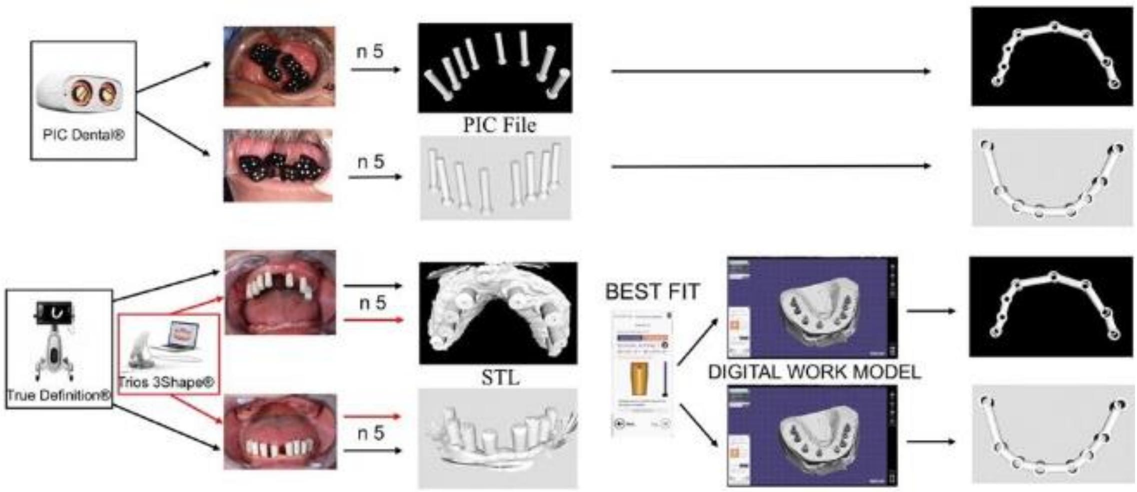

Figure 8. Digital workflow with PIC Dental ® and True Definition ®. (7)

With the help of its system (PIC pro®) and the precise recognition of the scan flags known as PIC abutments®, the PIC camera® recognizes the implants inserted into the mouth. This generates a file (PIC File) instantaneously with the angulations and spaces between the implants. (7)

With a discrepancy error smaller than 10 µm, this stereophotogrammetry equipment can capture 64 images per second. Without coming into contact, it locates each implant's spatial position.

PIC Transfers® can be utilized in any buccal or lingual position, and the PIC Camera® is usually placed around 20 cm from the patient's mouth. Furthermore, it is not required to align the stereo camera with the PIC Transfers®. The entire process takes around four to five minutes. (18)

This review aims to gather available data and evaluate the trueness and precision results of various IOSs and the impact of different variables on the accuracy result, to assess the usefulness of digital scanners in full-arch implant rehabilitations.

2. OBJECTIVES

2.1 To evaluate the trueness of intraoral scanner in full-arch implant rehabilitations.

2.2 To evaluate the precision of intraoral scanner in full-arch implant rehabilitations.

2.3 To assess the usefulness of intraoral scanner for full-arch implant rehabilitations.

3. MATERIALS AND METHODS

3.1 PICO Question

This systematic review was done under the guidelines of PRISMA.

The PICO question was:

- Digital impressions with intraoral scanners are useful and accurate in terms of trueness and precision for full arch implant rehabilitations?

-Population: edentulous patients in need of full-arch implant rehabilitations.

-Intervention: digital impression taking with intraoral scanner.

-Comparison: conventional impression.

-Outcome: trueness and precision of digital impression.

3.2 Search strategy

The electronic databases Medline, PubMed, Web of Science, and Scopus were systematically explored using MeSH terms and a search strategy based on the focused PICO question. Table 1 presents the details of the search strategy. Initially, articles were selected focused on their titles and abstracts, and then a choice was done after reading the full text.

Focused question (PICO)		
Digital impressions with intraoral scanner are useful and accurate in terms of trueness and precision for full-arch implant rehabilitations?		
Search strategy	**Population**	Edentulous patients in need of full-arch implant rehabilitations. #1-((dental implants [MeSH]) OR (edentulous patients [MeSH]) NOT (partially edentulous patients [MeSH]) OR (multiple implants[MeSH]) NOT (single implant [MeSH]) OR (complete arch [MeSH]) OR (full arch [MeSH]))
	Intervention	Digital impression (DI) with intraoral scanner (IOS). #2-((digital impression [MeSH]) OR (intraoral scanner [MeSH]) NOT (extraoral scanner [MeSH]) OR (dental scanner [MeSH]) OR (implant impressions [MeSH]) OR (impression making [MeSH]) OR (implant rehabilitation [MeSH]) OR (implant restoration [MeSH]) OR (digital techniques [MeSH]))
	Comparison	Conventional impression (CI). #3-((conventional impression [MeSH]) OR (traditional impression [MeSH]) OR (open-tray impression [MeSH]) OR (conventional techniques [MeSH]))
	Outcome	Trueness and precision of digital impression (DI). #4-((impression accuracy [MeSH]) OR (trueness [MeSH]) OR (precision [MeSH]))

Table 1. Search strategy according to the focused question (PICO).

3.3 Inclusion criteria

Inclusion criteria were as follow:

- Studies in vitro and in vivo, but most of them in vitro because this is the only way to evaluate the trueness of DI with IOS.
- Articles with full text available.
- Articles within the last 10 years.
- Articles in English language.
- Studies that evaluate impressions methods of full edentulous patient with multiple implants.
- Studies that assess one or different conventional techniques versus digital technique using one or different IOSs. So basically, studies that examine the two modalities of impressions.
- Studies that estimate the trueness and/or precision of IOS for full-arch implant rehabilitations and explain the modalities.

3.4 Exclusion criteria

Studies, clinical case reports, articles about single implant or partially edentulous patients and all of the researches that hadn`t correlation with the purposes of this review were rejected.

Some articles were excluded secondly, after a careful analysis due to employ of extraoral scanner, not IOS. Another exclusion was made because in some articles were assess scanning learning curve or patient`s predilection or because of the use of healing abutments instead of SBs.

3.5 Information extraction

An interpretation that described the chosen studies was carried out, and the results that was obtained is as follows:

- Study design.
- Maxilla or mandible.

- Impression method.
- IOS used.
- Number of implants.
- Number of impressions done by each analyzed methods.
- Method used to evaluate the accuracy.
- Trueness and precision outcomes.

4. RESULTS

The articles have been included in this study following the PRISMA guidelines.

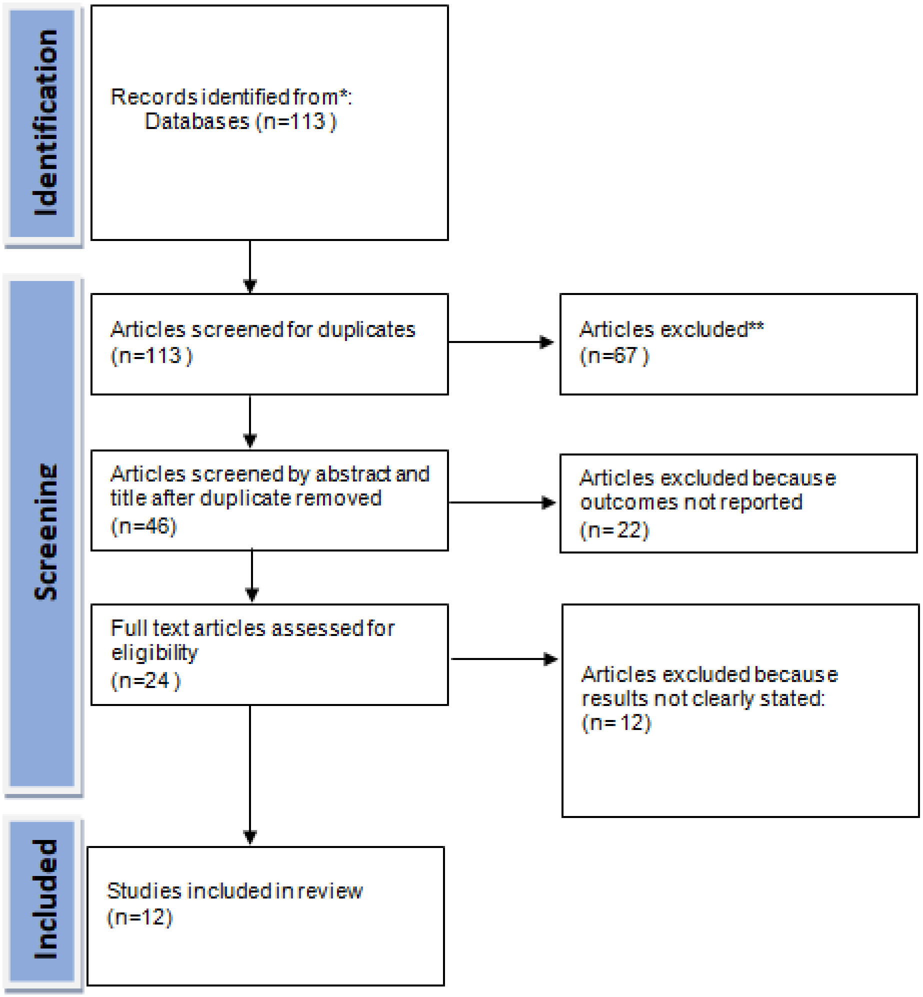

Figure 9. PRISMA flow chart diagram.

Below a summary table was created with the analyzed results in this review.

Author	Type of study	Maxilla/ mandible	Impression method	IOS used	Num of implants	Num of impressions	Trueness / Precision	Results
Pan et al (2021) (14)	In-vitro study	Maxilla	Digital	Trios 3 ® 3ShapeA/S	6	10 times for each group	Geomagic ®	Group 0: Trueness 75.8 µm Precision 71.0 µm Group 1: Trueness 44.1 µm Precision 47.3 µm Group 2: Trueness 44.2 µm Precision 57.5 µm Group 3: Trueness 38.8 µm Precision 44.6 µm
Miyoshi et al (2020) (19)	In-vitro study	Maxilla	Digital	3M True Definition ® Cerec Omnicam® TRIOS Scanner 2® CS 3600 ®	6	5 times for each IOs	PolyWorks Inspector®; PolyWorks Japan	3M True Definition®: Precision: 16.0 ± 5.3 µm CerecOmnicam ®: Precision: 19.0 ± 1.4 µm TRIOS Scanner 2 ®: Precision:29.0 ± 10.0 µm CS 3600 ®: Precision: 21.0 ± 6.1 µm
Imburgia et al (2017) (20)	In-vitro study	Maxilla	Digital	CS 3600® Trios 3® Cerec Omnicam® True Definition®	6	5 times for each IOs	Geomagic Studio 2012®	CS 3600®: Trueness 60.6 ± 11.7µm Precision 65.5 ± 16.7µm Trios 3®: Trueness 67.2 ± 6.9 µm Precision 31.5 ± 9.8 µm Cerec Omnicam®: Trueness 66.4 ± 3.9 µm Precision 57.2 ± 9.1 µm True Definition® :Trueness 106.4 ± 23.1µm Precision 75.3 ± 43.8µm
Mangano et al (2016) (21)	In-vitro study	Maxilla	Digital	Trios ® CS 3500 ® Zfx Intrascan® Planscan®	6	5 times for each IOs	Geomagic Studio 2012®	Trios ®: Trueness 71.6 µm Precision 67.0 µm CS 3500 ®: Trueness 63.2 µm Precision 55.2 µm ZfxIntrascan®: Trueness 103.0 µm Precision 112.4 µm Planscan®: Trueness 253.4 µm Precision 204.2 µm
De Angelis et al (2017) (22)	In-vitro study	Maxilla	Digital	CS3500®	6	50 scans	EGS® (Enhanced Geometry Solutions, Bologna, Italy)	Trueness: 79,6 ± 12,87 µm Precision: from 24 to 52 µm

Huang et al (2020) (15)	In-vitro study	Mandible	Digital and conventional techniques	TRIOS3 ®; 3Shape	6	10 repeated scans for each group	Geomagic Control X ®; 3D systems	Group I: Trueness 35.85 µm Precision 48.40 µm Group II: Trueness 38.50 µm Precision 48.90 µm Group III: Trueness 28.45 µm Precision 27.30 µm Group IV: Trueness 25.55µm Precision 19.00 µm
Di Fiore et al (2019) (23)	In-vitro study	Mandible	Digital	True Definition® Trios 3® Cerec Omnicam AC® 3D progress® CS3500® CS3600® Planmeca Emelard® Dental Wings®	6	15 digital impressions were made	Geomagic Studio Software®	True Definition®: Trueness 31 µm Precision 8 µm Trios 3®: Trueness 32µm Precision 5 µm Cerec Omnicam AC®: Trueness 71µm Precision 55 µm 3D progress®: Trueness 344µm Precision 121 µm CS3500®: Trueness 107 µm Precision 28 µm CS3600®: Trueness 61 µm Precision 14 µm Planmeca Emelard®: Trueness 101 µm Precision 38 µm Dental Wings®:Trueness 148 µm Precision 64 µm
Vandeweghe et al (2017) (24)	In-vitro study	Mandible	Digital	Lava C.O.S.® 3M True Definition® Cerec Omnicam ® 3Shape Trios®	6	10 scans for each IOS	Geomagic Qualify 12®	Lava C.O.S.®: Trueness 112 µm Precision 66 µm 3M True Definition®: Trueness 28 µm Precision 30 µm Cerec Omnicam ®: Trueness 61 µm Precision 59 µm 3Shape Trios®: Trueness 28 µm Precision 33 µm
Chochlidakis et al (2020) (17)	A prospective study	Maxilla	Digital and conventional techniques	Conventional : open-tray technique Digital: True Definition®	Group 1: 4 implants Group 2: 5 implants Group 3: 6 implants	—	Geomagic®	Conventional: 162 ± 77 µm 4 implants: 139 ± 56 µm 5 implants: 146 ± 90 µm 6 implants: 185 ± 81 µm
Kernen et al (2022) (25)	In-vitro study	Maxilla	Digital	CS3600®	6	10 digital impressions with different colours and shape with custom aids	GOM Inspect®	Trueness with scan aids: 26-181 µm Trueness without scan aids: 20–358 µm

Pesce et al (2018) (26)	In-vitro study	Maxilla	Digital	True Definition Scanner, 3M ESPE®	4 tilted implants	5 digital impressions for each master cast	Superposition test	Precision Cast 1: 24 ± 19 µm Cast 2: 22 ± 14 µm Cast 3: 27 ± 15 µm Cast 4: 21 ± 12 µm Cast 5: 21 ± 16 µm
Pesce et al (2021) (27)	In-vitro study	Maxilla	Digital	Itero® Opera system®	4	10 scans by expert operator (5 for each IOS) 10 scans by unexperienced operator (5 for each IOS)	Geomagic Studio 2012®	Trueness Expert operator Itero®:96.02 ± 12.05 µm Opera system®: 66.23 ± 17.53 µm Unexperienced operator Itero®: 140.84 ± 13.97 µm Opera system®: 39.82 ± 7.18 µm

Table 2. Results selected in this review.

5. DISCUSSION

The accurate replication of morphological aspects and the placement of the implants in the maxilla or mandible are prerequisites for the design and production of implant-supported prosthetic devices.

A crucial step to achieving a passive fit is the accurate reproduction of the position of the implants to the master model.

An improper passive fit due to the shrinkage and dilatation from the casting procedure may result in the fixing screw becoming loose or breaking, or it may prevent implant osseointegration.

It is not easy to establish a tolerable degree of fit in implant supported prosthesis.

Regarding Jemt et al (28) a discrepancy of fit below 150 μm does not produce any problems. But for other researchers the range of acceptable fit is lower, between 50 and 75 μm. (29)

Currently the tolerance range that has been defined in the literature is 30-150 μm. The researchers propose that dentists should aim to achieve positioning errors between 30-50 μm to minimize mechanical and biological issues. (23)

However, various reviews confirmed that there is still no agreement on the worth of misfit.

Dental technology has undergone a transformation recently thanks to the introduction of digital workflow. The advancement of digital cameras and IOSs has coincided with this trend.

The new digital methods have encountered some issues for taking impressions over implants. (10)

Most of the studies present in this review are suitable for one-piece prostheses but not for full-arch rehabilitations.

The aim of this review is to evaluate the trueness and precision of IOSs in particular in complex rehabilitation cases such as full-arch rehabilitations comparing with the CI technique, so access the usefulness of these IOSs.

The concepts "trueness" and "precision" as various measurements of accuracy were first introduced by Ender and Mehl in 2015. Comparing two STL datasets—a control and a test—is how trueness is determined.

Comparing various datasets obtained using the same digital scanner constitutes precision. (26)

Miyoshi et al. (19) in a vitro study used an edentulous maxilla with six dental implants to study the precision of four IOSs 3M True Definition®, Cerec Omnicam®, TRIOS Scanner 2®, CS 3600® and 5 scans per each IOSs have been made.

The precision of the IOSs was for 3M True Definition® 16.0 ± 5.3 µm, Cerec Omnicam® 19.0 ± 1.4 µm, TRIOS Scanner 2® 29.0 ± 10.0 µm, CS 3600® 21.0 ± 6.1 µm.

Within the limits of this in vitro study, the extension of the scanned ranges is accompanied by a deterioration in the DI precision. Hence, for now, only tiny prostheses, like the three elements retained by two implants, should use DI for implant rehabilitation. (19)

Other authors, Imburgia et al. (20) studied the trueness and precision of DI in a maxilla with six implants highlighted how four IOSs work in oral implantology: CS 3600®, Trios 3®, Cerec Omnicam®, True Definition®.

The scans were performed with a zig-zag method: the head of the IOS makes an arc from the first quadrant (superior right) to the palatal region and back, slowly moving forward to scan the SBs, and soft tissue from the vestibular region to the palate (and returning), going through the occlusal area.

The calculation of the trueness has been carried out importing all STL files from the various IOSs in a potent reverse-engineering software (Geomagic Studio 2012®); then the five scans from each scanner were overlapped on the appropriate reference model, produced with the industrial desktop scanner. The three marks were quickly located on the surface of the SBs when the "three point registration" function was first employed. The two 3D surface models might be roughly aligned using this function and then the superimposition has been finished by the "best fit" algorithm surface fitting.

For the examination of the four distinct IOS's level of precision, a similar process was used. Yet in this instance, the reference for superimposition was a virtual model from digital scanning with the best trueness outcome for each scanners. In essence, all the scans made with the same IOS were placed on top of this model in this way, making it simple to determine each IOS's precision.

The study found that the CS 3600® scanner had the best trueness result, followed by Cerec Omnicam® and Trios 3®. True Definition® had the lowest trueness result. Additionally, when considering the fully edentulous upper jaw, CS 3600®, Trios 3®, and Cerec Omnicam® showed higher trueness compared to True Definition®, but there were no significant variations among the three scanners (CS 3600®, Trios®, and Cerec Omnicam®).

Regarding the precision, Trios 3® was the most precise scanner, followed by Cerec Omnicam®, CS 3600®, and True Definition®. However, there were no significant deviations within the distinct IOSs in terms of precision when considering the totally edentulous case. The authors stated that the realization of complete prosthesis over implants offer issues because, despite the significant advancements achieved by the most recent generation of scanner, a fully edentulous patient is still challenging instead of scanning a smaller surface. (20)

Also Van der Meer et al. (30) carried out the initial investigation in which the reliability of three IOSs in implant rehabilitations has been compared. This in vitro work evaluated the performance of Cerec Bluecam®, Itero®, and Lava COS® scanning a cast with three polyether-ether-ketone (PEEK) cylinders.

According to the authors, again, the accumulation of registration mistakes observed as the scan progressed in the space.(30)

Mangano et al. (21) studied the veracity of Trios 2®, Carestream CS 3500®, Zfx Intrascan® and Planmeca Planscan® by performing five scans by each scanner in maxilla model with six cylinders made of PEEK attached over implants.

In this case regarding trueness the best was CS 3500® (63.2 µm) and precision (55.2 µm), then Trios® (trueness of 71.6 µm and precision 67µm), Zfx Intrascan® (trueness 103 µm and precision 112.4 µm) and Planscan® (trueness 253.4 µm and precision 204.2 µm). About trueness, Trios® was more efficient than Planscan®, CS 3500® more competent than Zfx Intrascan®, and Zfx Intrascan® superior than Planscan®.

About the precision, the best was CS 3500® following by Trios®, Zfx Intrascan® and Planscan®.

This study seems to support the idea that even in difficult circumstances, it is possible to capture precise enough impressions utilizing IOSs of the most recent generation to fabricate fixed implant-supported prosthesis, in particular with CS 3500® and Trios®.
However, it was determined that Zfx Intrascan® and Planmeca Planscan®, were not acceptable for capturing implant impressions in patients who were completely toothless. In light of this, and in line with earlier research, the findings of this study indicate that caution should be exercised when employing IOSs to capture DI over implants especially in complex situations such as full-arch rehabilitations. Before direct digitalization of edentulous jaws can be advised in vivo, the trueness and precision of IOSs must be enhanced. (21)
In patients receiving implants, Papaspyridakos et al. (31) compared the accuracy of DI and CI procedures. Briefly stated, the master cast was a completely edentulous mandible and had five implants. After attaching the SBs, the cast was digitalized using a potent, contemporary IOS (Trios®, 3-Shape, Copenhagen, Denmark). The master cast was then conventionally replicate using polyether, utilizing splinting and non-splinting approach, correspondingly. The master cast, the splinting and non-splinting CI, as well as a reference STL dataset were all scanned using a potent extraoral scanner. The STL files from the master model was then overlaid with datasets from DI and CI in order to check mistakes and variances.
In conclusion from this study, we can understand that the accuracy of DI was comparable to the CI, with better results in case of splinting technique instead of non-splinting one.
This is because the IOS with splinting technique had more references but also a more continuous surface to detect. (31)
A clinical study (32) examined the trustworthiness of the DI and CI with the same IOS as the previous one (Trios®, 3-Shape, Copenhagen, Denmark).
From this article has been demonstrated greater efficacy when using DI as opposed to CI, not only because impression techniques were completed in less time but also because patients perceived the results to be more favourable due to increased acceptance, less distortion in the impression materials, and 3D previsualization.

From a clinical standpoint, SBs perfectly match the dental implant in the mouth because to their geometrical shape, allowing for the accurate capture of the implant position, much like with CI-taking methods. (32)

However, additional clinical research is required to more fully evaluate the effectiveness of DI.

De Angelis et al. (22) in an in vitro study studied an acrylic resin model of a toothless upper arch with six implants in position of 16-14-12-22-24-26 and they scanned 50 times with the IOS CS3500®.

The mean of the misfit was 79,6 (± 12,87) μm. The highest distortion value was 102 μm in scan number 31 and the lowest distortion value was 60 μm in scan number 36.

The precision of the obtaining values have measurements ranging from 24 to 52 μm.

Under the constraints of this investigation, the CS3500® has proven to be accurate enough to rehabilitate an entire arch on implants.

As the in vivo study progresses, challenges connected to the mouth may arise and in addition the accuracy of the IOSs could change because of the arches in particular near the median and lateral frenulum. This may be a difficulty during scans because the system overlaps various images thanks to stable reference points.

Similar to the flat ridge, a larger inter-implant distance may result in more mistakes during the acquisition phase because there are fewer reference points available for matching. (22)

In contrast to an in vitro model, the space among implants could be higher in a real situation, which would make scanning more challenging and lower the veracity of the 3D model.

Another important factor is the knowledge of the dentist that affects the trueness and precision of the DI.

This aspect emerges in the article published by Pesce et al. (27) where the authors examined the trueness of 3 different clinical scenarios such as unique implant in position of 16; a bridge over implants with an implant in position of 16 and another in position of 13 and a complete edentulous maxilla with 4 implant (16-13-23-26) scanned with newly released scanner Opera System ® against one of the most popular scanner currently available Itero® and relatively performed by the expert operator and the unexperienced one.

The results obtained were for the expert operator: Itero®: 96.02 ± 12.05 µm and Opera system®: 66.23 ± 17.53 µm; instead for the unexperienced operator: Itero®: 140.84 ± 13.97 µm and Opera system®: 39.82 ± 7.18 µm.

In the complete edentulous situation, the unexperienced one got better outcomes using the Opera System ® scanner, whereas the experienced person got better results using the Itero® scanner for trueness. It's also interesting to observe that the full-arch scenario, which likewise had the lowest levels of trueness, saw a rise in discrepancies between expert and novice operators. The findings demonstrate that implant-supported full-arch rehabilitations may provide greater intraoral scanning challenges than short-span restorations. (28)

Canullo et al. (33) discovered that a not expert operator could produce higher trueness values when performing a complete arch impression utilizing the CS3600® (Carestream) scanner.

Trueness mean results were better in the study published by Pesce et al. (27) compared to Canullo et al. (33), excluding the scans done by the unexperienced person in the complete edentulous case with Itero®.

Another thing is that accuracy is influence by the type of IOS used, regarding this aspect from the study of Fiore et al. (23) has been emerged that not all IOSs can take DI for rehabilitating an edentulous mouth.

The results of the 3D position analysis indicate that the True Definition® and Trios® had the best performance among the group with an average value of 31 µm and 32 µm respectively. The Cerec Omnicam® and CS3600® were a little bit less efficient with values of 71 µm and 61 µm respectively. The CS3500® and Planmeca Emelard® had a middle-low efficiency with values of 107 µm and 101 µm respectively, while the 3D progress® and Dental Wings® had a low efficiency with values of 344 µm and 148 µm respectively. In addition, the analysis of 3D distance revealed that there was a positive correlation between mistakes and SB distance, but this association was only observed in the case of the True Definition® and CS3600® scanners. (23)

An additional in vitro study by Pesce et al. (26) analyzes the precision of True Definition® scanner utilized to scan 5 models of maxillae with 4 tilted implants that were placed in accordance with an immediate loading implant protocol.

The precision was assess by the superimposition test and the outcomes that have been obtained were for the first cast: 24 µm, the second cast: 22 µm, the third cast: 27 µm, the fourth cast: 21 µm and the fifth cast: 21 µm.

Within the parameters of this research, the True Definition® scanner's DI constitute a dependable way for creating frameworks for an edentulous mouth when there are angled implants. (26)

Vandeweghe et al. (24) analyze the accuracy of Lava C.O.S.®, 3M True Definition®, Cerec Omnicam ® and 3Shape Trios® for scanning six implants inserted into a model of an edentulous jaw made of acrylic. The implants were placed in the positions where the first molar, first premolar, and lateral incisor teeth would be located.

The findings in this study suggest that Lava COS®(112 µm for trueness and 66 µm for precision) is not accurate to scan a totally edentulous case. The top performing products were 3M True Definition® (35 µm for trueness and 30 µm for precision) and 3Shape Trios® (28 µm for trueness and 33 µm for precision), which exhibited the most impressive outcomes. The increased accuracy was likely a result of adjustments made to both the wand and software. Specifically, the expansion of the focus depth made the scanning process easier while simultaneously decreasing the incidence of scanning errors. The employment of contrast powder by the various scanners constituted a significant distinction.

Contrast powder was utilized by Lava COS® and 3M True Definition® scanners but not by Cerec Omnicam® or 3Shape Trios®. One cannot conclude from the results that powdering produced a better or worse outcome. Yet, it was demonstrated that the contrast powder increased the accuracy by making it easier for the projected light pattern to reflect when scanning shiny or translucent materials. The accuracy displayed by the other scanners seemed to be at a level that is clinically acceptable except for Lava COS®. (24)

Nonetheless, if an edentulous jaw has multiple implants that require scanning, there may be some challenges. Since same SBs are utilized, it can be problematic for the IOS to differentiate one from the other and determine the precise position in the arch.

Scanners placed inside the mouth, which operate using a photo system, may overlay pictures of various SBs on each other. While the first quadrant could be captured with a relatively high degree of accuracy, the precision of the scans reduced considerably when the second one was also recorded.

A prospective clinical study in vivo to assess the precision between DI and CI techniques for 16 toothless maxillae was performed by Chochlidakis et al. (17).

CI were taken with heavy and light body silicone with open-tray technique instead the DI were made by True Definition®.

The study revealed that there were 3D deviations of 162 ± 77 µm between virtual models from scans by True Definition® and digitized plaster casts made by CI. When broken down by implant group, the 3D discrepancies were 139 ± 56 µm for the 4-implant group, 146 ± 90 µm for the 5-implant group and 185 ± 81 µm for the 6-implant group.

The discrepancies between DI and CI range from 65 to 200 µm. The 162 µm mean distortion among the models produced by DI and CI revealed in the current study seems to be consistent with earlier reports in the literature.

There is a positive correlation between the increasing 3D discrepancies and the number of the implants in the arch, although the changes were not statistically relevant. One theory is that the accumulation of more mistakes is caused by augmenting the quantity of the implants or the curve of the maxilla or mandible. (17)

It is possible to use digital scans and a fully digital process to create complete dentures over implants but the current approach to full-arch implant rehabilitations combines both traditional and digital methods.

To overcome these problems regarding the digital scanning of the complete arches over implants, some authors have carried out studies introducing auxiliary elements that can help the IOS to capture more precisely as they help to provide more references.

Regarding this Kernen et al. (25) assess the effectiveness of a recently developed scanning aid, which comes in different designs and colours, in order to enhance the precision of scanning for multiple implants.

The three designs were circular, square and irregular; instead the three different colours were beige, gray and white.

These scan aids were applied around the six SBs in an edentulous maxilla.

The size of the scan aid was calculated assuming that the implants would be placed bilaterally at the position of the lateral incisor, first premolar, and first molar. Nevertheless, it is flexible if the implants are positioned with a comparable allocation.

This scan aid is made by brace, connector and bridge. The place where the brace and the bridge are connected is the connector, which is where the brace can be fastened to the SB. The "optical bridge" runs parallel to the oral portion of the implants.

In comparison to unsplinted scans, the employment of a scan aid increased the accuracy of IOS over implants, but regarding the precision was either the same or less with the usage of a scan aid and the unsplinted scans.

In this investigation, the beige scan aid with the irregular pattern proven to be more effective than unsplinted scans due to its much higher trueness. Trueness using the scan aid described in this study varied from 26 to 181 µm, and for unsplinted scans, varied from 20 to 358 µm depending on which intraoral SB was measured. Generally, the usage of the scan aid benefits longer scan distances since they are less prone to errors. (25)

The implementation of an auxiliary element or the changing of existing SBs has been studied by various researchers like Pan et al.. (14)

In the study of Pan et al. four different models were created with different characteristics and all of them have been scanned 10 times with Trios 3, 3ShapeA/S®.

The first model was covered with silicone material with thickness of 2mm simulating the mucosa; the second model with a base of 1.5 mm thick with holes at the implant areas; in the third cast a parallelepiped block (8.0 × 4.0 × 7.0 mm) and four circles (Ø 5.0 mm) were attached to the base and in the fourth model the four circles were substituted by premolars.

The extra element in the second model was just a resin base over the soft tissue with no references, however the trueness was better compared to that obtained by the other groups. (14)

From the results of this study we can conclude that to improve DI may be possible with just a basic resin base covering the mucosa.

The enhancement may have resulted from the resin base's various optical qualities, such as reflection coefficient, refractive index, and translucence, which make more sensible the IOSs sensor and improved the STL files produced.

The third group's bad performance revealed that a circular reference it is not useful for improving scanning. It could be because the circles employed in this investigation were very little (Ø 5 mm), making it impossible to scan the entire surface. Moreover, the circles have no geometric markers for giving an orientation to the images in the space and are identical in all directions.

The landmark in the fourth group, in contrast, resembled a premolar and had a larger surface area. The tooth-shape also produces an asymmetric contour and helps with identification and orientation during stitching. Consequently, for precise full-arch scanning, the premolars appeared to be superior auxiliary devices to the circles.(14)

As well as Huang et al. (15) compare the trueness and precision of CI, a new CAD/CAM SBs and original SBs utilized in DI.

Have been used for the first group original SBs (Straumann, Basel, Switzerland®) the SB was 4.1 mm in diameter and 9 mm in height; for the second group CAD/CAM SBs without extensive bar, the SB was 5.5 mm in diameter and 9 mm in height; for the third group using CAD/CAM SBs with extensive bar, the SB was a one-piece unit and the cylindrical segment was 5.5 mm in diameter and 9 mm in height, and the extensive bar was 20 mm in length and the fourth and last group conventional splinted open-tray impressions.

The average of trueness was 35.85, 38.50, 28.45, and 25.55 µm for the first, second, third and fourth group. Instead the precision was 48.40, 48.90, 27.30, and 19.00 µm for the first, second, third and fourth group, in the order given. (15)

From these results we can understand that the most accurate impressions is still the conventional splinted open-tray impressions, succeeded by DI made using CAD/CAM SBs with extensive bar. Using the original SBs and CAD/CAM SBs without extensive bar DI revealed poor trueness and precision.

The limitation of this systematic review was that many results are based on in vitro studies related on the trueness and precision of IOS for full-arch implant rehabilitations.

These findings need to be confirmed by more in vivo research with clinical outcomes taking into account patient`s related aspects like the saliva, the patient`s tongue, the patient movements, etc.

Currently, caution should be used when IOSs are used to capture DI to fabricate implant-supported prostheses, such as in case of full-arch rehabilitations and nowadays the privileged technique is still the conventional open-tray technique with light and heavy body silicone or polyether impression materials.

6. CONCLUSION

Based on the articles analyzed in this systematic review we can assume that:

1. It is difficult to measure the trueness of optical impressions using intraoral scanner in vivo since it is impossible to utilize instruments with very high precision, like coordinate measuring machines, articulated arms, or industrial scanners, inside the oral cavity. The average of trueness emerged in this systematic review is 80,87 µm. Improvements are needed to give a stronger evidence and reliability.

2. The average of precision of the articles included in this review was 47,08 µm. More in vivo evaluations are necessary and it is required to make enhancements in order to provide more robust support for using digital impression for full-arch implant restorations.

3. Actually the use of intraoral scanner to take impressions in complex cases such as full-arch implant rehabilitations is not the best option because it is lost in the absence of anatomical references; scarce in vivo evidence is present, so more studies on the patients are needed to confirm the usefulness of digital impression taking into account the patient`s related factors.

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8. ANNEXES

8.1 Abbreviations

- CAD/CAM= computer-aided design/computer-aided manufacturing
- FDP= fixed dental prostheses
- ME= mesh
- IOS= intraoral scanner
- STL= standard tessellation language
- DI= digital impression
- CI= conventionalimpression
- SB= scan-body
- LF= library file
- SC= single crown
- PP= partial prostheses
- CMM= coordinate measuring machine
- PEEK= polyether-ether-ketone
- µm= micrometer

8.2 Figures and tables

<u>**Figures**</u>

- **Figure 1.** Data processing in CAD/CAM system.

- **Figure 2.** Digital CAD/CAM process.

- **Figure 3.** Original scan of the SB (a), equivalent library file (b) and an aligned model was created by the software (c).

- **Figure 4.** Visual representation of a screw retained implant-supported prosthesis and the two corresponding implants. The completely fitting shows passive fit in the one-screw test (a) and with all screws closed (b). The bad fitting shows a gap in the one-screw test (c) and a non-passive fit with tension in the components and a remaining micro space between them (d).

- **Figure 5.** The CAD/CAM scan bodies. (a) Scan body without splinting bar. (b) Scan body with splinting bar.

- **Figure 6.** Novel auxiliary devices to improve scanning accuracy. (a) Master model covered with silicone material with thickness of 2mm simulating the mucosa. (b) A base of 1.5 mm thick covering the cast with holes at the implant areas. (c) A parallelepiped block (8.0 × 4.0 × 7.0 mm) and four circles (Ø 5.0 mm) were attached to the base. (d) The four circles were substituted by premolars.

- **Figure 7.** Artificial dots on the palate to improve scanning accuracy. (a) SBs and artificial dots in upper jaw. (b) STL file elaborated by True Definition®. (c) STL files from the DI with True Definition® scanner (STL files 1) were overlapped with the STL files from the plaster casts(STL files 2). Superimposition of the two STL files with reverse engineering software (Geomagic®).

- **Figure 8.** Digital workflow with PIC Dental ® and True Definition ®.

- **Figure 9.** PRISMA flow chart diagram.

<u>**Tables**</u>

- **Table 1.** Search strategy according to the focused question (PICO).
- **Table 2.** Results selected in this review.