ACTA SCIENTIFIC DENTAL SCIENCES (ISSN: 2581-4893)

Volume 3 Issue 7 July 2019

Review Article

Intraoral Scanning Devices Applied in Fixed Prosthodontics

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Received: May 10, 2019; **Published:** June 19, 2019

DOI: 10.31080/ASDS.2019.03.0568

Abstract

Workflow in fixed prosthesis requires a strict compliance of the exploration, diagnosis and treatment plan processes. Execution of this plan begins with the dental preparations and the impressions to obtain the working models. New technologies to design and machine fixed prosthesis are giving way to a higher frequency of digital impressions through intraoral scanners (IOS). It is expected that the use of these scanners generates an absolute digitalization in the fixed prosthodontics protocol. This review of the literature aims to provide knowledge by collecting the findings of several studies on dental prostheses manufactured from intraoral digital impressions. Likewise, it aims to describe the different IOS systems used; in addition to its advantages and disadvantages over conventional impressions for the manufacture of prosthetic restorations. The results of this review provide data on each of the systems currently available. The possibilities of use in the realization of partial restorations, crowns and bridges are viable using impressions by intraoral scanners.

Keywords: Intraoral Scanners; Fixed Prosthodontics; Clinical Procedures; Clinical Efficiency; Digital Impressions; CAD/CAM

Introduction

Interest in CAD/CAM (Computer Aided Design/Computer Aided Machine) systems continues to grow and new devices are continuously introduced in the clinic and the dental laboratory. IOS, performs the first phase of the digital workflow acquiring the images. These devices are reaching popularity by replacing conventional impressions, made with trays and elastomeric materials. Scanners can be extraoral and intraoral devices. The optical impressions seem to reduce the patient's discomfort, are efficient over time and simplify clinical procedures, in addition to allowing better communication with the dental technician and with patients. However, some factors must be observed for mastering this protocol such as: the learning curve, a high initial inversion and the difficulty of accessing more complex anatomical structures such as the subgingival margin or access to the distal areas in prepared teeth.

Therefore, it is appropriate to analyze the most used IOS systems based on the available scientific literature. In the last decade there has been the greatest development of dental scanners for the realization of the digital workflow, presently on the market several brands and models of these systems, with increasingly better features to obtain digital prints, accurate, accurate, with appropriate colors, and that are achieved in a comfortable working time for the patient and the operator. Francois Duret, in France, pioneered optical impressions in 1971. In the early 1980s, Professor Werner H. Mormann, together with italian engineer Marco Brandestini, were the first to patent and design an intraoral scanner, giving rise to the first generation of Chairside (CEREC) [1,2], marketed by Siemens and tested this technology directly in the dental office. They used an intraoral camera to digitize the teeth and oral tissues, to then perform the design and subsequent machining using a milling machine [3]. This system was very innovative at that time, making restorations in a single visit. [4-6]. Nowadays, CAD/CAM technology is widely spread among dentists and laboratory technicians and even in patients. However, there are still large gaps of knowledge about it. Both CAD and CAM are included in what is known as CAE (Computer Aided Engineering), which means computer-aided engineering [7]. CAD / CAM systems consist of three components [8,9]:

- A digitizing tool or scanner that transforms the geometry into digital data that can be processed in a computer.
- A software that processes the information and according to the application, produces a set of data for the product that will be manufactured

A production technology that transforms the data set into the desired product by addition or subtraction. Depending on the location of the components of CAD/CAM systems, in dentistry there are three different production concepts available [8]:

- Impressions, Digitalization and Production in the dental clinic (Chairside).
- Digitalization and Production in the laboratory based on a conventional work model (Labside).
- Manufacture of centralized restorations in a production center based on digital impressions and designs made in other sites.

CAD/CAM systems can be classified into open and closed systems according to the data exchange. In closed systems all the steps are integrated in a single system and there is no interchangeability between different systems of other companies. Open systems allow the adoption of the original digital data by CAD software and CAM devices of different companies [10], in addition they handle three-dimensional data in stereolithographic format (STL), the most commonly used format in dental CAD/CAM systems [11]. The acquisition of digital data improves treatment planning, provides greater efficiency, facilitates data storage, reproducibility, documentation of treatment and effectiveness in terms of costs and time and also improves communication between the dental office and the laboratory [12-14]. A scanner is a technological device that, through the use of light, is responsible for obtaining and digitizing images of any type of objects [15].

A device for digitizing dental surfaces can be based on contact or non-contact methods where three-dimensional images are captured [4,16]. The three-dimensional contact scanners scan the surface of the object by means of a probe with a hard steel tip or sapphire. The non-contact or three-dimensional laser scanners emit a laser beam or, failing that, another type of light source and detect its return, capturing the geometry of the object by triangulation [17,18]. The optical scanner uses the collection of three-dimensional structures, in this system the light source and the receiving unit are at a defined angle in a reciprocal relationship. Through this angle, the computer can calculate a set of 3D data from the image on the receiving unit. Projections of white light or a laser beam can serve as a source of illumination [19]. It is important to calibrate the scanner on a surface with properties similar to the object to be scanned [20]. Most of these systems use active triangulation, which means that the optical axes of the projector and the camera form a triangle with the line connecting the projection centers of both units [21]. The mechanical scanner for this type of systems uses a gypsum model previously obtained from a conventional printing. The master model is read mechanically line by line using a ruby ball and the 3D structure is measured. This type of scanner is distinguished by a high scanning accuracy, the drawbacks of this technique of data measurement are highly complicated mechanics, which makes the device expensive with long processing times compared to optical systems [19]. The scanners have four main components: the measurement probe, the control or computing system, the machine that handles the movement of the probe and the measurement software [22]. The introduction of the IOS as devices within the dental practice allow to obtain a digital impression of the dentition of the patient and are an alternative to the use of conventional impression materials. The intraoral optical scanner eliminates the selection of trays, dispensing and polymerization of impression materials, disinfection and shipping to the laboratory, as well as an additional advantage that is the comfort of the patient [14,23-25]. In addition, digital dental models allow the creation of virtual configurations for an improved treatment planning and the manufacture of removable and fixed devices made to measure [26]. These scanners can be separated into two types; a) Photographic technology scanners: record individual images of the denture. These systems have a field of view in the form of a cone, so they cannot collect information from those hidden surfaces, being necessary to make several shots of the same area to collect all the information. b) Video technology scanners: Those that record the scanned areas working in a similar way as a video camera through sequential shots at high speed [10,27,28]. In this type of systems, the most used digital format is the open STL (standard tessellation language). This format is already used in many industrial fields and describes a succession of triangulated surfaces where each triangle is defined by three points and a normal surface. However, other file formats have been developed to record the color, transparency or texture of dental tissues [29]. Main intraoral scanning systems currently available are differentiated by characteristics such as the operating principle, the light source, the need to eliminate the shiny surfaces, the operating system and the export file format among others [9,28,30]. The main IOS systems are mentioned in table 1.

Scanner Name	Manufacturer	Image Caption	Powder use
CEREC Bluecam	Sirona	Foto	Cerec Optispray
CEREC Omnicam	Dentsply-Sirona	Video	No
PrimeScan	Dentsply-Sirona	Video	No
Trios	3 Shape	Video	No
Sistema Lava C.O.S.	3M ESPE	Video	No
Sistema iTero	Cadent/Straumann	Video	No
Sistema E4D	Tecnologías D4D	Video	No
Zfx Intrascan	MHT technologies® Zimmer	Photo	No
CondorScan	Biotech dental	Video	No
PIC dental	PIC DENTAL	Photogram-metry	No
Dental Wings	Straumann	Video	
Wow	Biotech Dental	Video	No
Medit 500	Dent Core	Videopho-togram-metry	No

Table 1: Main scanners and characteristics.

Cerec bluecam

The CEREC system (Sirona - Germany) was introduced to the market in 1985 and was the first to use the CAD / CAM concept. Bluecam was the first Sirona system based on photography for intraoral protocol after the ideally originated and CEREC 2. The CEREC Bluecam intraoral camera allows the acquisition of high-resolution images through a powerful light-emitting diode (LED). This system requires a thin layer of titanium dioxide powder as a contrast medium (CEREC Optispray) on the surface or tissue to be scanned [2,9]. Bluecam can be applied to a single quadrant [31] and is obtaining a series of photographs that are incorporated into digital processing. Nowadays this scanner is disappearing from the market due to the introduction of more modern, precise, accurate and comfortable systems for the patient.

Cerec omnicam

This scanner (Dentsply-Sirona-Germany) is an evolution of CEREC Bluecam, already incorporating the videophotometry technology. It presents a video camera that generates a three-dimensional model with real color and in real time without the need to apply dust before scanning. The scanning process with Omnicam should be performed in dry conditions and the camera should be kept as close as possible to the tooth to acquire an accurate digital intraoral scan. Software updates for the system have minimized scanning errors [32]. This system focuses mainly on the production of inlays, partial and total crowns as a chairside system [33]. Variations may occur in the designs but with results not scientifically supported in treatments such as long-span fixed bridges. Omnicam can be used for a single tooth, implant, quadrant or complete arch [31]. In addition, through a specific license you can export the STL files to external systems open to the manufacturer.

Cerec primescan

It is the latest evolution of the IOS of this manufacturer (Dentsply-Sirona - Germany). It has a screen and touch panel, together with the new CEREC 5 software. It allows to perform full-arc and individual zone scans with great efficiency and precision [34]. It is within the scanners with greater advances, using video, artificial intelligence, eliminating unnecessary artifacts, with a depth of scanning according to its manufacturer of up to 20 mm, so that the impressions of the sulcus in subgingival preparations or postextraction sockets could be feasible. This scanner has a processor that allows processing up to 1000000 of 3D points per second, with a higher scanning speed.

Shape trios

In December 2010, the TRIOS™ Intraoral Scanner was introduced to the market (3Shape, Copenhagen, Denmark). It is an intraoral scanner, without the use of powder, based on permanent confocal images. This system uses a structured light that is projected onto the tooth through interference fringes. The mechanical oscillation of light is combined with the variation of the confocal plan. The signal is recorded by video-photometry with a charge device sensor coupled with a fast scan time [29,33,35]. The most recent version of this device, 3Shape Trios 4 Wireless, was presented at the IDS (International Dental Show) in Cologne in March 2019 [36].

Lava COS

The Lava Chairside oral scanner (Lava COS; 3M ESPE, Seefeld, Germany) was introduced in 2009 and operates according to the principle of active wave front sampling [37]. It is a system that consists only of one scanner (it does not contain a portable milling machine) and captures continuous 3D video images for digital prints. The scanner/software combination is capable of capturing approximately 20 sets of 3D data per second [38].

iTero system

The iTero System optical system (Cadent, Carlstadt, NJ-USA) was introduced in 2007. This system uses parallel confocal images to capture the image. The parallel confocal imaging uses laser and optical scanning to achieve the impression of the surface and the contours of the structure of the tooth and the gum. The system uses a touch screen monitor to view 3D images. This touchless screen scanner allows the dentist to virtually rotate the digital impression without touching the screen [38]. Currently, the iTero Element Flex scanner has been developed, a system that presents probes with a personalized portable case that allows precise intraoral captures even when the patient moves and presents an improved color for extraordinary images of great precision. In addition, it makes clear 3D scans in high definition and full color in just 60 seconds according to its manufacturer (Brochure iTero 2018).

Sistema E4D

The E4D system was developed by D4D Technologies, LLC (Richardson, TX-USA). It works under the principle of optical coherence tomography and confocal microscopy [29]. The system bar contains a digital micromirror device and uses a red diode laser to acquire a 3D image in grayscale. The E4D system contains a portable milling machine in the dental chair [9,39]. The E4D has a high-speed laser that formulates a digital impression of the proximal and prepared teeth, as to create an interactive 3D image. The images are obtained in all angles with laser technology. The software will compile all the images. The image library can obtain an accurate virtual model in seconds [5].

ZFX intrascan (MHT technologies® zimmer)

It is based on a system that presents a light scanner and a hardware that can be adapted to any computer (Zimmer-Indiana-USA), the concept is to be as portable as possible. It is an optical scanner of confocal parallelism laser technology in three dimensions, with a working distance of 18mm. It is capable of taking 18 images per second, using photogrammetry, without using any auxiliary powder. Its main advantages are portability and simplicity when managing software. In addition, the digital files obtained are free, that is, they do not require specific systems of restricted use to decode them [28].

PiC dental

The PiC camera is not a scanner, and neither is intraoral. The PiC camera is a high precision optical measurement device based on photogrammetry. Photogrammetry is the technology used to obtain reliable measurements of physical objects and their surroundings, through recording, measuring and interpreting images [40]. The PiC camera is the complement of an intraoral scanner, to complete a workflow digital of multiple implant restorations.

Dental wings

Its acronym is DWIO (Dental Wings Intraoral) Straumann-Canada. It is a system with open architecture (STL files) to capture digital impressions. The small tip that the scanner has helps make 3D capture easier, using a technology called "Multiscan Imaging Technology". The system incorporates 5 3D scanners that work simultaneously to capture all the anatomical details from multiple orientations, helping to capture areas of difficult access. The hand piece is made of metal and is very light (105gr.). This camera has its own DWOS CAD software for the design of the restoration (Dental Wings Brochure 2019).

Wow

The WOW intraoral scanner marketed by the house Biotech Dental (France), according to its manufacturer allows to develop a complete digital workflow, because it is an open system that supports data exchange, it is also used in different specialties of dentistry, such as orthodontics, dental prosthesis and implantology, allows to capture images with hyper realistic texture and color, for its video photo grametry technology, the scanning process does not require the use of powder on surfaces and intraoral tissues (Brochure Biotech Dental 2019).

Medit 500

This intraoral scanner developed by the commercial company Dent Core (Spain), is a system that bases its operation on costs, efficiency and productivity. According to its manufacturer, it presents two high-speed cameras, which allow the scanning to resume from the pause site. It does not use dust during the acquisition of the image facilitating the process, providing the user with high resolution images to help determine the accuracy of the scan. His technology is based on video photo grammetry. The image quality facilitates the differentiation between the dental structure and the soft tissue, easily locating the termination of the dental preparations and the undercuts (Brochure Dent Core 2019).

Methodology

To carry out this review of the literature, the MEDLINE digital databases (PubMed) and the Cochrane Library were analyzed with a search strategy based on the combination of MeSH (Medical Subject Headings) keywords controlled by the National Library of Medicine. The search was conducted from July 2018 to March 2019.

This systematic review used the PRISMA guide (Preferred Reporting Items of Systematic reviews and Meta-analysis) to ensure the quality of the information included [53]. The PICO question (Population, Intervention, Comparation, Outcomes) was also used as an eligibility criterion in the selection of the articles [54,55].

Population: Scientific articles *In vitro, In vivo,* Literature reviews that investigate on image acquisition systems (intraoral scanners) in fixed prostheses.

Intervention: Scanning of partial dental arches, complete, unitary pillars and prefabricated models.

Comparison: Conventional impressions or between the same IOS.

Outcome or Results: Clinical Applications, Comfort, Time, Clinical Conditions.

Inclusion Criteria

For the inclusion of the articles in this systematic review they had to meet eligibility criteria such as: Experimental studies *in vitro* or *in vivo*. Reviews of literature. The studies should include the IOS and its clinical applications, patient comfort, scan time and/or clinical conditions. Finally, articles in English published between the period January 2010 to March 2019 were included.

Exclusion criteria

Items that are not within the established period. Scientific articles that are not related to the fixed prosthesis area. Articles whose objectives are not according to the search characteristics.

Search terms

The search terms were derived from the previous reading of scientific articles used as a guide for the writing of this systematic review. Intraoral scanners, fixed prosthesis, clinical procedures, Clinical efficiency, Clinical Conditions, CAD / CAM.

Results

6 search strategies were made using the following equations with keywords and Boolean operators: {(“intraoral scanners” [MeSH]) AND (fixed prosthesis)}, {(“intraoral scanners” [MeSH])} AND ((clinical procedures)}, {(intraoral scanners [MeSH]) AND (Clinical efficiency)}, {(intraoral scanners [MeSH]) AND (Clinical Conditions)}, {(intraoral scanners [MeSH]) AND (CAD/CAM)}.

After the search, 234 articles were obtained in total, of which 168 studies were eliminated because they did not meet eligibility criteria and 5 of them were duplicate citations. The remaining articles were analyzed according to title, year of publication and design and 66 were chosen. If during the reading of the summary it was verified that the article did not have relation with the selection criteria it was discarded, for which 22 studies were excluded, being a total of 44 articles of which 14 were selected for fulfilling the inclusion criteria for this review.

Discussion

Through this literature review it can be evidenced that the IOS are a valid alternative to conventional techniques of impressions with elastomeric materials for obtaining accurate models of the preparations in fixed prosthodontics. The modernization of intraoral equipment allows obtaining digital impressions that have a wide range of applications, ranging from providing models for treatment planning or communication with the patient to providing final models for the production of definitive or provisional restorations, with metallic, polymeric, ceramic and hybrid materials. Patzelt., et al. observed that digital impressions are efficient over time since they allow the reduction of work times, when compared with a conventional impression. In addition, the implementation of IOS within the dental practice improves the workflow of impression making, leads to greater patient satisfaction and provides better restorations compared to the conventional approach [41]. Revilla in coincidence with Patzel concluded that digital impression was more efficient in time and comfortable for the patient. The use of IOS to obtain digital models clinically serves for diagnosis, planning, provisionalization and treatments with definitive restorations [42].

Mangano in his study, also agreed that the IOS are effective over time, in terms of the scanning of short arcades. However, despite the recent technological advances in IOS, in terms of the scanning of complete dental arches there is no significant difference compared to conventional impressions since a scan can take 3 to 5 minutes, a time similar to that required for conventional impressions [43]. Atieh., *et al.* in their study, also established that the IOS for full-arch impressions still have no decrease in work times and improvements in accuracy for complete arches [14]. The new scanners present guided scanning protocols that allow greater trueness in the sensitive areas of the arch as the angles between the canines and premolars. It is necessary to carry out further studies to obtain better data in this regard.

When carrying out a scanning protocol it is necessary to take into account the modifying factors. In this regard, Ryan Jin-Young., *et al*. in 2018, concluded that within a clinical setting, the performance of the IOS would be affected by the presence of saliva, crevicular fluid, blood and moisture characteristic of the intraoral environment. The examination procedure would be further complicated by the movement of the patient, as well as by contiguous anatomical structures such as the tongue, lips and cheeks. In the case of complete arches, more time was used [44]. The positioning of the camera for the acquisition of images and its proximity to the area to be scanned is also an important factor. Some scanners need some distance from the surface without touching it. New scanners encourage the possibility of obtaining easy acquisition without too much proximity and without so many angles. Using artificial intelligence technology, certain areas that are artifacts for digitization can be eliminated and accurate models could be obtained [53].

Regarding the comparison of conventional impression materials with new technologies and scanning times, Bjorn Gjelvold., *et al*. conducted a randomized clinical trial in 2015 in which they specifically investigated scan times, with results focused on the patient. In this study it was concluded that conventional impression materials such as polyether are well developed and presented a high precision, however the use of IOS in the digital impression technique had superiority in work efficiency and material savings. The authors also mentioned that, the number of prepared teeth that must be scanned with a digital impression seems to increase the impression time (an average increase of 62.8 seconds for each additional tooth), which should be considered [45].

Comfort of the patient during the taking of impressions is an important factor to consider. Emir Yuzbasioglu., *et al.* determined that the use of IOS decreased discomfort at the temporomandibular joint and did not cause difficulty in breathing or dizziness. Therefore, patients preferred the use of these digital systems to obtain impressions [46,47]. Digital scanners that require dust are technically more difficult for clinicians and less comfortable for participants than other types of digital scanners and conventional impressions [48]. The time with which the patient remains open-mouthed is important. With a refined technique, the development of impressions through an intraoral scanner is much less than the use in an impression with elastomeric materials [11].

One of the most common problems encountered with IOS and with optical impressions is the difficulty in detecting deep finishing lines in prepared teeth or in the case of gingival bleeding. All scanners are optical systems that can only record visible areas. In some cases, especially in aesthetic areas where the cervical finishing lines are usually paragingival or subgingival it may be more difficult for the light of the scanner to correctly detect the entire finishing line, as evidenced by several studies discussed below. A general drawback of digital impressions is that there is no device on the market, capable of capturing subgingival areas of a tooth abutment with adequate precision. Therefore, the use of retraction cords is still indispensable in order to achieve an adequate scanning of the preparations and their finishing lines [41]. The introduction of a new intraoral scanning system (PrimeScan Dentsply-Sirona) with a greater depth of capture, (up to 20 mm according to its manufacturer) could open the doors for this possibility but full and well-designed studies are required to prove it. Keeling., et al. identified as factors that affect the marginal quality of an intraoral exploration, the size of the oral cavity, presence of adjacent teeth, proximity to the gingiva and positioning of the scanner inside the cavity [5,49,50]. Studies have compared the marginal gaps of dental restorations made after intraoral scanning. Keul and Ueda in previous studies reported that, for fixed dental prostheses, the marginal adjustment with direct digital impressions obtained through the use of intraoral scanners was equal to or better than that obtained with indirect digital systems [54,55]. Seelbach., e*t a*l. reported a good marginal adjustment in the dental restorations produced with the CEREC Bluecam, Lava Chairside oral scanner, the iTero system and the 3Shape TRIOS intraoral scanners. [32].

According to Malaguti., *et al.* Marginal and internal adjustments are key factors for the clinical success of oral rehabilitations. The internal gap was evaluated using the silicone replica technique validated by Laurent in 2008. All the values obtained in this study were much lower than 70 μm described in the literature, which suggests that both the digital workflow and the traditional ones are accurate enough. The authors finally concluded that the marginal adjustment was greater than the ideal values for all the techniques performed, but comparable with other studies in the literature and within the limit of clinical success. The intraoral scan obtained the best results for the internal gap, but more in vivo clinical investigations are needed to confirm these results [56].

The internal and marginal adjustment of a fixed dental restoration is key to determining its long-term clinical performance [57]. Marginal adaptation and internal adjustment have been examined in several *in vitro* clinical studies that show a wide range of results [58,59]. Unfortunately, all these results are not very comparable due to the numerous differences in the measurement protocols. In a recent systematic review, the authors concluded that there is a lack of uniform consensus in the literature since the current state of research does not allow for an adequate comparison of the various systems by the authors suggest further investigations [60].

When analyzing the different impressions systems available, the advantages of IOS are obtaining highly accurate models, simplifying the traditional workflow, the possibility of creating and updating periodically a database of dentitions for future interventions, the possibility of simulating interventions, making surgical procedures in the digital model, cleaning of the impression procedures, reduction of operative time, better communication with the laboratory and greater comfort for the patient [14,29,30,38,51-54].

Finally, and with respect to the precision and accuracy of the models obtained, a recent work by Ender., *et al.* concluded that the accuracy of the IOS is widely studied and accepted within the clinical parameters in those cases scanned for single unit prosthetics and quadrants. However, there is some controversy as to the accuracy of these systems in the registration of full-arch impressions. The precision of the IOS is limited in most of *in vitro* studies to the accumulated error from the conventional impression taking, elaboration of the model, scanning of the master model with the IOS and superposition using the software. This leads us to believe that if more *in vivo* studies were carried out, this accumulation of errors would decrease since so many steps would not be necessary and the accuracy of these scanners could be more reliably assessed [58].

Conclusion

IOS are modern devices incorporated to the digital workflow in dentistry. IOS allows obtaining accurate digital models. The use of intraoral scanners reduces stress, patient discomfort, simplifies the traditional workflow and achieves better communication with the laboratory. IOS have some disadvantages such as difficulty in detecting deep or subgingival margin lines in prepared teeth and/or in the case of bleeding. After this review it is necessary to mention there is no scanning, scanner or technology that can now be considered unanimously more accurate due to the lack of standardized procedures or comparable *in vivo* studies. Although dentistry has a tendency towards the digitalization of processes, scientific research still shows little agreement with this trend. Therefore, clinical comparative studies are necessary to generate data that provide greater knowledge on this subject.

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Volume 3 Issue 7 July 2019