TRABAJO DE FIN DE GRADO

Grado en Odontología

HISTORICAL EVOLUTION OF INTRAORAL SCANNER IN DENTISTRY

Madrid, curso 2020/2021

Número identificativo 124

Historical evolution of Intraoral scanners in Dentistry

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Abstract

In dentistry, during the prosthetic rehabilitation phase, the impression is an important step because it allows a diagnosis and a communication between the practitioner and the prosthetist for the realization of prosthesis (fixed or removable). Nowadays, immense technological progress has been made and this allows the arrival of optical cameras and digital impressions that will free the physical impressions and their constraints due to the physico-chemical properties of conventional printing materials.

The objectives of this final study are to see how the iOS have been introduced in dentistry, to understand their operation and to see what are the advantages and disadvantages that they present compared to the traditional techniques of impressions.

To achieve this work, searches were carried out in specialized databases such as Google scholar, Pubmed or from the CRAI library catalog using specific keywords.

In conclusion, the iOS were introduced for the very first time in 1970 with Dr Francois Duret then they knew a slow evolution (limited indication, very expensive device) until the 2010s. Then after the 2010's, a second phase of expansion took place with the arrival of several competitors on the market. Currently, optical cameras can reconstitute a 3D digital impression from several images or videos thanks to different technologies: active triangulation, confocal microscopy, AWS (Active Wavefront Sampling), ... For a last conclusion: according to the current data, iOS devices present more advantages such as a good precision for short span prosthetic rehabilitations, a better communication with the patient and the lab, less discomfort for the patient, less operator risk errors, but they still present limits to make complete impressions, subgingival preparations, and they still are expensive.

Resumen

En odontología, durante la fase de rehabilitación protésica, la impresión es un paso importante porque permite un diagnóstico y una comunicación entre el profesional y el protésico para la realización de la prótesis (fija o removible). Actualmente, se han realizado inmensos progresos tecnológicos que permiten la llegada de cámaras ópticas y impresiones digitales que liberarán de las impresiones físicas y de sus limitaciones debidas a las propiedades fisicoquímicas de los materiales de impresión convencionales. Los objetivos de este estudio final son ver cómo se han introducido los iOS en la odontología, entender su funcionamiento y ver cuáles son las ventajas e inconvenientes que presentan frente a las técnicas tradicionales de impresiones.

Para la realización de este trabajo se han realizado búsquedas en bases de datos especializadas como Google Scholar, Pubmed o del catálogo de la biblioteca del CRAI utilizando palabras clave específicas.

Conclusiones: El iOS se introdujo por primera vez en 1970 con el Dr. Francois Duret y luego conocieron una lenta evolución (indicación limitada, dispositivo muy caro) hasta la década de 2010. Luego, después de la década de 2010, una segunda fase de expansión tuvo lugar con la llegada de varios competidores en el mercado. Actualmente, las cámaras ópticas son capaces

de reconstituir una impresión digital 3D a partir de varias imágenes o vídeos gracias a diferentes tecnologías: triangulación activa, microscopía confocal, AWS (Active Wavefront Sampling), ... Para una última conclusión: según los datos actuales, los dispositivos iOS presentan más ventajas como una buena precisión para rehabilitaciones protésicas que no superen los 4 dientes, una mejor comunicación con el paciente y el laboratorio, pero siguen presentando límites para realizar impresiones completas, preparaciones subgingivales, ...

1- Introduction

In the prosthetic dentistry, the impression of the 2 dental arcades is a fundamental step for any type of indirect restoration (crown, bridges) and even for full or partial removable prosthesis. It very important because it permits the exchange of the oral dental information between the dentist and the dental technician for the realization of the prosthetic treatment.

The errors made during the fundamental step during the dental rehabilitation process may lead to several problems such as bad aesthetics issues, misfit of the prothesis and bad prognosis in the long-term following premature wear due to occlusal load too much important.

Before the coming of the digital impression, the dental impression was only physical: according to the case, the dentist does the impression with alginate or other materials like addition putty/lite silicones (PVS: Polivinyl Siloxanes). Then, this impression will be poured with solid material like plaster to get the study or the master cast for the dental technician and the dental professional.(1)

The problems of this traditional approach were the possible accumulations of loss of “accuracy” due to the bad practice of the practitioner during the impression process (tearing, air bubble trapped inside, loss of information, impression not centred, etc …). Those problems linked to the operator are, in addition associated with the chemical-physical properties of the material that can modify the dimensional stability (contraction effect) over time after the impression. (1)(2)(3)

Plus, the impressions with this kind of materials may prove to be uncomfortable for the patient during the process and especially for patient with gag-reflex.(4)

Note: In this work, the “accuracy” is defined as a combination of “trueness” (ability for a measure to match with the real value) and “precision” (ability for a measure to be constant in the repeatability). (4)(5)(1)

Face from theses inconveniences, a new technology has been developed: the intraoral scanner (IOS). This new device also called “optical camera”, allows the dentist to record a 3D digital impression (or “optical impression”) without any contacts with the dental structure or preparation, directly from the mouth of the patient in the dental clinics (“chairside device”). (6)

It must be differenced from an extra oral scanner and a mechanical scanner where a cast is required for the impression like the system Procera or CELEY. In this type of scanner (mechanical scanner), a mechanical piece with a form of rugby ball for example, will read mechanically line by line the cast previously done with classical impression per palpation. (7)(6)

Figure 1: Mechanical digitalization from: "Evolution of the Software and Hardware in CAD/CAM Systems used in Dentistry 1"

The IOS can be defined as a medical device with 3 components:

- <u>The handheld camera</u>: It allows the direct digital impression without any contact with the oral structure like the alginate for example. Whatever the imaging technology used (triangulation, confocal optics, …), all the cameras require a projection of light toward the target to be scanned and then, the reflection will be recoded as individual static image or video from a receptor (usually a charged-coupled device video ship or CDD). (8)

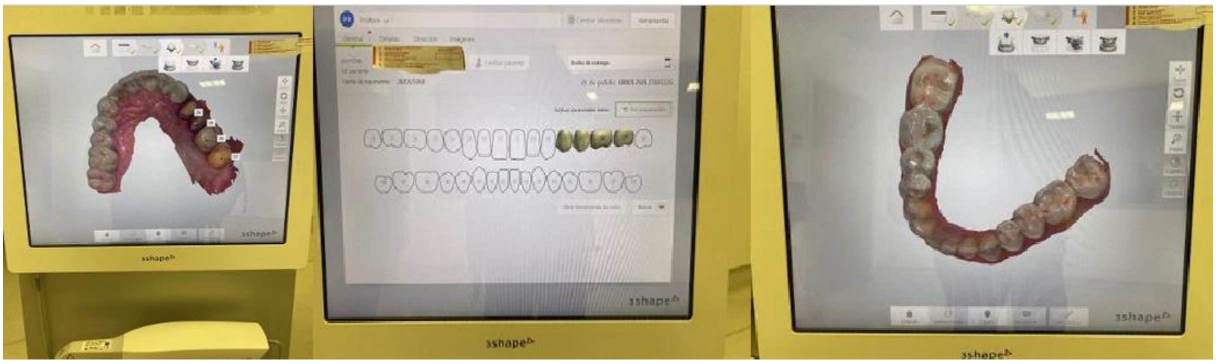
Figure 2: Handheld camera from 3Shape (own ressource)

  The source of light can be the ambient light (passive camera) or a light with a selected wavelength spectrum (white, red, blue …) directly projected from the optical camera itself (active camera). Some studies have demonstrated that the passive camera is more reliant regarding the texture and the colour of the object than the active one. (8)

  About the objects to be scanned, some of the iOS need a previous coating of the soft tissue and the surface of the teeth with titanium oxide to prevent the light reflexion (coting scanner (CS) or Powder Scanner) to get more details. The other is called non-counting scanner (NCS) or powder-free scanner. The CS has shown very good accuracy results for partial restoration but it is now used less because of the difficulty to apply powder in the month of the patient (not comfortable for the patient and also the risk of contamination with the saliva that force the reapplication of the powder), the necessity of additional time for a scan and the difficulty of the full-jaw scans. (2) (8) (1)

- The computer: Other essential part of the hardware for the 3D calculations. Some models are directly linked with a touch screen which permit to the practitioner to see the advancement of the 3D impression during the process and other relevant information about the patient. (9)

Figure 3:Example of the hardware with touch screen from 3Shape (own resources)



- The software: Specific of the system used. It is responsible to compile the static images or the images from a video (in continuous data flow or per wave analysis) to obtain a 3D cloud points of the object scanned. This 3D cloud point is obtained from recognition of the point of interest (or POI) per the software and each POI have 3 coordinates (x, y for the position in one plan and z depending of the distance to object). (8)

  The software (could be an open source program or not) developed, can have several tools for the 3D design and for manipulation of 3D digitals model. The range of the indications and the capabilities of the software depend of the add-on modules included. For example, some software permit the smile design, virtual wax-up, virtual articulator, full denture design, implant design, …. (10)

The data can be registered in format STL (Standard Tessellation Language or Stereolithography) as a succession of triangulated surface and this format is the most used in the Dentistry field. However, some iOS, add the colours, the transparency, and the texture with other format such as PLY (Polygon File Format or Stanford Triangle Format) developed at the Stanford University or the OBJ files (Object). Another problem of the STL files is the lack of possibilities to store patient data with the 3D model as the DICOM file do (Digital Imaging and Communications of Medicine) (*Figure 3*).(10)(8)(11)(12)

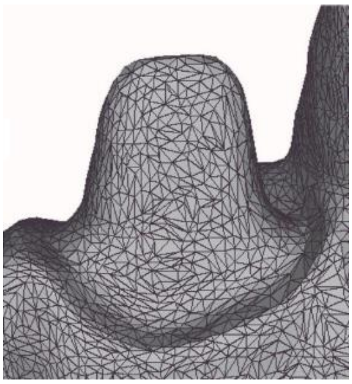


Figure 4: STL image from "Intraoral Scanner Technologies: A Review to Make a Successful Impression"

Whatever the format chosen, the digital file which store the 3D data captured by the iOS can be open or not. It depends of the manufacturers of the iOS to force the dentist to use all the machines from the same company (iOS, software, and the production unit). (10)

Nowadays, we can find several software design in the field of the dentistry such as the SW CEREC developed by Sirona, the Dental System by 3Shape, the Dental Wings Open System by the Dental Wings company, the DentalCAD created by the Exocad company, … (10)

To make a brief history, the IOS appear for the first time in the 1973 with Francois Duret who presents his system in 1983 at French Dental Association's international. He will elaborate later the Duret system. Then in the mid-1980, Dr Mormann in association with an electric engineer Dr Marco Branndesti, will create the first commercial side-chair (using a handle camera to scan teeth) CAD/CAM system: the CEREC system. (13)

During all the 1990's decade, the CEREC system was the only one "chair-side" system commercialized, and it was improved during this period with the evolution of the hardware (memory and speed of the computer). It was not until the year 2010, to see more optical cameras commercialized with the improvement of the treatment digital imaging and also the rise of using of the universal language STL (StereoLithiography or Standard Transformation language) in 2005, participating to the elaboration of the communication between the different systems, because at the beginning, the first IOS systems commercialized were very locked. In addition, this opening allowed a larger possibility of reconstruction (possibility of reconstruction with traditional material like porcelain fused metal with the dental lab). (13)(14)(15)

If at the beginning, the IOS were poorly used in dental office. But with the fall in price and the coming of the concurrency with models more and more efficient, this new technology will be more used in the future. In 2010, it was possible to find more than 10 iOS models in the market. (16)

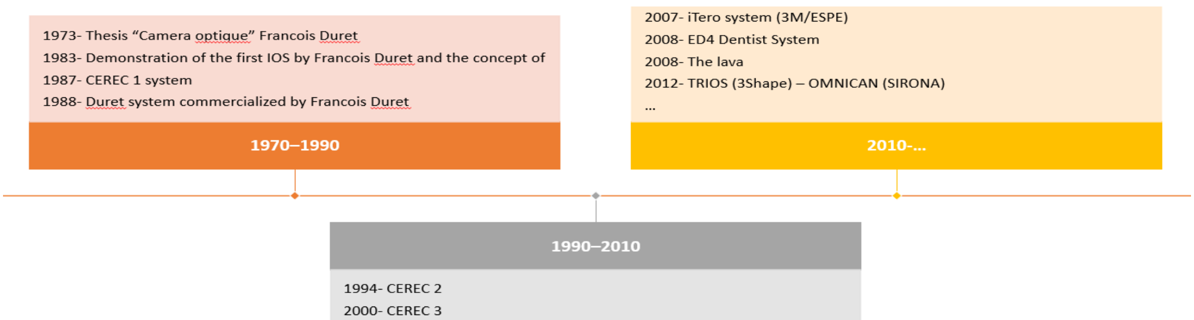


Figure 5: Dates of apparition des iOS

The IOS can be included in prosthetic restoration process called "Computer-Aid Design (CAD) and Computer-Aid Manufacturing system (CAM)". It is based around 3 elements:

About the data acquisition, there are 2 types. In the first one, it is done by the prosthetist with an extra-oral scanner from a classical impression (alginate/silicon) sent by the dentist. In this case, all the CAD/CAM restoration is done in the lab. But with the increasing of the capacities of the computer processing, the dentist can directly do the digital impression with an intraoral scanner and then, send the 3D digital impression through internet to the dental lab: chair-side digital impression (CSDI). (17)

It is also important to notice that the data acquisition can be done by the contact-digitization technique: the data are acquired by a contact probe (already explained above in Figure 1).

The data processing is related to the software of the CAD/CAM. The dentist or the dental technician can design a virtual prothesis/restauration on the digital impression. This part can be done with a closed system like the CEREC system. And in the other hand, there is open system where the optical impression can be processed with other CAM system through open STL files.

The manufacturing process is the last step of fabrication of the prothesis through the STL files or other digital files (PLY, DICOOM, …). It based on 3D printer with two type of processes: the subtractive and the additive manufacturing. (17)(13)(11)

Subtractive printer	The most classic-one. A single bloc is milled by several drill. This type of printer at the beginning, were not able to make complex structures. This technique is slow because it can do only one structure each time. (17)
Additive printer	It works by addition of slide of materials. The addition of each slide will form a 3D object at the end of the process. This technique permits the fabrication of multiples structures per cycle. (17)

With the increasing of the computing processing power and a more important integration of the computer science in the dentistry (especially with the coming of the IOS as substitute of the conventional technique of impression), the use of the CAD/CAM will be predominant in the fabrication of the prothesis. In fact, the IOS can bring multiple advantages in the dental clinics, like less loss of information during the impression, less discomfort for the patient, possibility for the patient to get the prothesis in the same day of impression with the CAD/CAM restoration, better communication between the prosthetic lab and the dentist, … (3)(17)

2- Objective

In 2020, there are few information about this new technology (IOS), as well about its evolution and its functioning itself. And it also accompanied of few studies about the current advantages and disadvantages compared to the traditional approach for the dental impression.

It is necessary to understand that this new technology is very recent and there is not enough reliable information like clinical randomized comparative studies in vivo and a large part of these optical scanner are closed private system with poor objective communication.

That why the purposes of this literature review are:

- Explain the evolution of the of the intraoral scanner (iOS) since its apparition in 1980's through a chronological narrative approach.
- Explain the different technologies used by the iOS (light projection and the technics to record the correct distance to object).
- Find the advantages and the disadvantage of this system compared to the classical impression with the alginate and the silicon.

The history of the iOS will be described on the first part in the discussion (5.1), the physical principles used for its operation in the second part (5.2) and then the advantages and the advantages compared to the traditional approach will be analysed in the third part (5.3).

3- Methods

3.1- Design of the study

The following work will be focused on the answer to these questions:

1. When and how the intraoral scanner is arrived in dentistry?
2. How the CAD works and what are the different type of the optical scanner used?
3. What are the advantage and the disadvantage of the digital impression compared to the traditional approach?

3.2 Strategies

This review had been done by research in scientific review through specialized database like MEDLINE (PubMed), Embase: ("intraoral scanner" OR "optical camera" OR "Computer-Aided Design" OR "Chair-Side") AND ("Dentistry") AND ("Evolution" OR "History" OR "Use" OR "Development").

Some extract from specialized dentistry book found in the library catalogue of CRAI "Dulce Chacón" have also been taken in account for this work: "Computer-Aided Design" AND "Intraoral scanner" AND "Dentistry".

The results of this research have given more than 121 results.

Full-text scientific are extracted after analysing of the abstract with these following inclusive/exclusive criteria for the 2 last research questions:

Inclusive criteria	Exclusive criteria
- Current scientific paper (>2010). - Scientific article with strong evidence: Review, Standardized studies (in vivo and vitro), comparative studies with control group, consortium peer-review. - Articles related the intraoral scanner in dentistry.	- Exclusion of the comparative studies about one private system with another (too much heterogenic data with poor evidence). - Exclusion of the articles dealing with CAD-CAM not related to dentistry. - Exclusion of the articles with interest conflict (from a private lab) - Exclusion of the articles dealing with the optical impression with a specific problem (implant, orthodontics appliance …). - Article not in English

Note: To answer to the first research question, an exception has been made compared to the inclusive/exclusive criteria. In fact, to do a historic research, the old papers (4 articles sectioned) such as the French paper from the founder of the iOS (Francois Duret) and the founder of the CEREC system cannot be excluded. 11 articles have been selected for the historic part of this paper.

Note 2: Another exception have been made with (18) to find more information about the Active Wavefront Sampling principles. (Article not directly related to the iOS).

At the end, 28 articles have been selected for a complete full text analyse.

Mesh keyword used:

"optical scanners"/"Computer-Aided Design"/"Intraoral scanner"/"3D model"/"Intraoral digital impression"/"Evolution" or "History”/ “CEREC” or “Duret”/ “Optical triangulation” or “Confocal tomography” or “Optical coherence tomography” or “Active Wavefront Sampling “ or “Parallel confocal imaging”/”Coating Scanner” or “Powder Scanners” or “Monochromatic Scanners”/”Non-coating scanners” or “Powder-Free Scanners” or “Chromatic scanners”/”Comparison”/”Chair-side”

4- Results

4.1 Chronology of iOS and technology used

Table 1: Chronology of iOS and technology used

Name of the iOS	Date of origin	Commercialized by	Type of technology used	Powder need
Duret System	1983	Duret	Active camera + Moire interferometry	Yes/No
CEREC 1	1985	Sirona	Active camera camera + Active triangulation	Yes/No
CEREC 2	1994	Sirona	Active camera camera + Active triangulation	Yes/No
CEREC 3	2000-2005	Sirona	Active camera camera + Active triangulation	Yes/No
E4D Dentist	2008	D4D Technologies LLC	Active camera (laser) + Optical Coherent Tomography	No
iTero	2007	Cardent	Active camera + Parallel confocal imaging	No
MIA3d	2007	Densys3D	Passive camera + Active triangulation	No
LAVA Chairside Oral Scanner (C.O.S)	2008	3M ESPE	Active camera + Active Wavefront Sampling	Yes
Trios	2010	3Shape	Active camera + Parallel confocal imaging	No
IOS Fast scan	2010	iOS technologies Inc	Active camera (laser) + Active triangulation	No
DirectScan	2011	Hint -ELs	Passive camera + Passive triangulation	No
Bluescan -I	2014	GMBH	Active camera (laser) +Active triangulation	No

After a compilation of the data from the 11 articles selected for the historic part, a non-exhaustive chart has been made of the different systems of iOS commercialized classified according to the date of apparition and the technology used for the acquisition of the data (type of source of light and the type of distance object technology).

In this table, it is possible to observe a sudden rising of new manufacturer in the market after 2008. Before 2008, only the model commercialized by SIRONA was disponible with the Duret system with the Moire interferometry (which wasn't more developed).

We can also observe more model after 2008 powder free with new technology of optical printing such as the parallel confocal imaging, the active wavefront sampling (AWS) and the optical coherent tomography.

But the most used technology by the constructor for the iOS is still the active triangulation introduced the first time with the CEREC 1 in 1985.

4.2 Comparison between the iOS and the traditional approach

Table 2:Comparison between iOS and traditional approach

Name of articles	Type / Date	Advantages	Disadvantages
"Intraoral scanner in dentistry: a review of the current literature"(4)	Review / 2017	- Less patient discomfort. - Better communication with the dental technician.	- Problem detection of marginals line. - Learning curve. - High cost of the system.

		- Time efficiency. - Simplified clinical procedure. - No plaster used.	- Learning curve high for some patient with low affinity with technology.
“Accuracy of Intraoral Scanner: A Systematic Review of Influencing Factors”(19)	Review / 2018	- Good accuracy compared to the alginate for the study cast.	- Less accuracy compared to the silicon for the working cast. - Not recommended for long span edentulous. - Less accuracy for in the case of excessive reflection (Metallic restoration, excessive saliva).
“Assessment of Chair-side Computer-Aided Design and Computer-Aided Manufacturing	Review / 2015	- Time efficiency. - Better compliance from the patient. - Similar accuracy of restoration.	- Same difficulty to learn the technics. - More local deviation for full arch model.

Restorations: A Review of the Literature"(20)			
"Digital Impression system" (2)	Article from book "Extra-coronal restoration"	- High accuracy for local restoration.	- Decreasing of the accuracy for the full arch scan. - Gingival retraction required.
"Influence of abutment tooth geometry on the accuracy of conventional and digital methods of obtaining dental impressions Jeison"(3)	Comparative study "in-vitro"/2017	- Better accuracy for the iOS group compared to the conventional impression group for single impression teeth. (case of Total occlusal convergence (TOC) < 8°)	-
"Accuracy of an intraoral digital impression: A review"(5)	Review/2020	- Precision clinically acceptable compared to the traditional approach if the scanning	- Deviation observed for long-span restoration. - Less accuracy observed in vivo

		concern less than the half of an arch.	(saliva movement, …). - Significant difference of accuracy between the different iOS (technology used, software, …). - Greater deviation in the case of chance of curvature: avoid grooves, sharp preparation edges, boxes, …
“Validity and reliability of intraoral scanners compared to conventional gypsum models measurements: a systematic review”(21)	Review/2016	- Equivalent result of accuracy between the IOS and the conventional approach (limited evidence).	- High cost of the IOS - High time of impression process in dental chair with IOS. - Less comfort for the patient.

5- Discussion

5.1 When and how the intraoral scanner is arrived in dentistry?

During this research, 11 articles among the articles elected for this work have a historic part about the IOS. And all the 11, inform the lector about a consensus to recognize the professor Francois Duret as the father of the dental CAD/CAM concept even if the article (13) prefers to include also Dr Mormann (who developed the CEREC system) and Dr Anderson who developed the Proceca system but this system doesn't include a intraoral scanner: mechanical scanner (already explained above in the introduction in mechanical digitalization definition).

According to the results of the investigation, the first concept of the IOS was introduced with Francois Duret, when he defended his thesis entitled "Empreinte Optique" in 1973 in the University Claude Bernard in the city of Lyon.(22)

Later, in one of his proper articles, Francois Duret describes his first prototype of his IOS (as he called "optical camera") presented to the public in 1983 at French Dental Association's international. To record a 3D model, Francois Duret has decided to use the Moiré interferometry as he explained in one of the articles in French published in 1984 in the "dentist news 40". (23)

Specifically, a moiré interference is a 3D virtual image obtained from the interference pattern produced by 2 sources of light passing through 2 grating (one on the specimen to scan and another which serve of the reference) with periodic fringes (Figure6). (23)

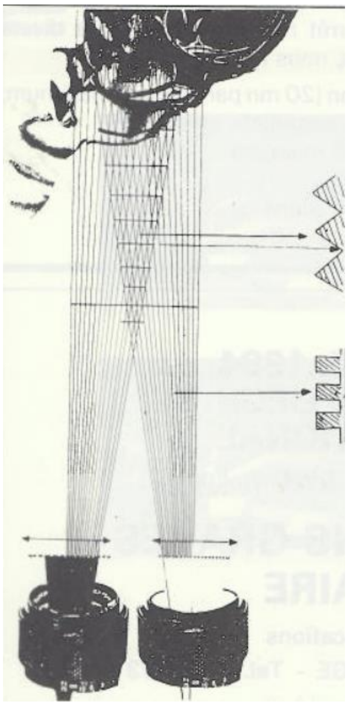


Figure 8: Moiré interferometry

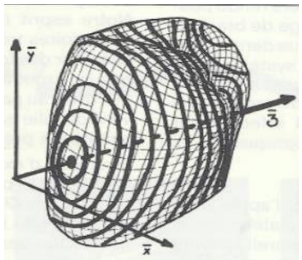


Figure 6: Reconstruction obtained from Moiré interferometry

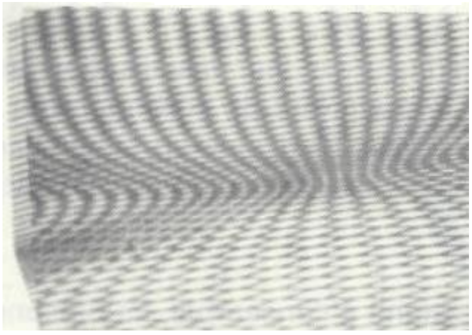


Figure 7: Exemple of Moiré interference pattern

The 3 images directly extracted from the article (23), permits to illustrate the optical system to create a moire interference.

In another article "CAD-CAM in dentistry" published in JADA in November 1988,

Dr Duret presents its system "Duret system" the first CAD/CAM system equipped with an intraoral scanner composed of 3 parts. The first part of the process is a device called "The optical camera" which was composed of 2 endoscopes adjacent to each other. The first one project a light to the target and the second one takes the picture from the reflected light (Figure 6). Then, the digital information was processed by the CAD system with a virtual propriety articulator. In this second part of the system, the operator was able to design directly the prothesis on the electronic model considering the dynamic movement of the jaw obtained virtually with the “Access Articulator”. And the last part of “Duret system” was a four-axis drilling machine (CAM system). With this prototype, Duret communicates in his paper, a precision obtained approaching 40µm with a speed of execution of 20 min per element (impression and placement of the prothesis). (6)

According to the author, the Duret system allowed all types of restoration such as crowns, inlays and even bridges. (23)(6)

At the same time as the development of the Duret system, in the 1980s, came the CEREC system (acronym for “Chairside Economical Restoration of Esthetic Ceramics” or “computer assisted CERamic REConstruction”) marketed in 1987 by Sirona dental system. This project was the result of a partnership between Dr Werner Mormann and engineer Marco Brandestini. (13)(7)(24)(25)

According to the author of the article "The CEREC system", the first CEREC system (CEREC 1) appeared in 1985 at the University of Zurich Dental School and it was only limited to inlay-type reconstructions with software that allowed a fairly basic design in 2D. (14)

It was not until 1988 that CEREC 1 saw its capacity for dental reconstruction increased with onlays and veneers. To achieve an optical impression, Dr. Mormman with the help of Dr Marco Brandestini used the principle of triangulation with the help of a light source projecting through a wire mesh at a parallax angle onto the preparation with a reception of light reflected to the sensor (CCD) with a specific angle. Lines deformations obtained, observed by the sensor, provides information on the depth of the preparation (principle of the active triangulation more developed below in 5.2). (7)(25)

Figure 9: CEREC 1 with Dr Mormann and Dr Brandestini from "The evolution of the CEREC system"

At the beginning of the year 1990, it is therefore possible to say that there were only 2 dental CAD / CAM systems with the possibility of taking an optical impression in the dental office (Chair-side) as we can see on the Table 1. This is confirmed by Francois Duret himself in an article written in 1991 which aimed to list all the CAD / CAM systems existing at that time. (6)

Indeed, the other CAD / CAM systems did not offer an optical camera. The data acquisition was done by means of "palpation" scan: the dentist himself had to make a temporary reconstruction of the prosthesis by means of a resin and this was copied by a machine equipped with a haptic sensor (more developed in the introduction). (6)(13)

These two systems had limited distribution because of their very high price ($200,000 for the Duret system and $ 35,000 for the CEREC 1 system).(6)

Until the 2010s, the CEREC system remained the only "chairside" CAD / CAM system marketed in the world (Table 1). It will undergo a succession of evolution as evidenced by the article "the CEREC system" and by Dr Werner himself in an article "The evolution of the CEREC system" published in the journal JADA. (14)(7)

By crossing the 2 articles previously cited, it is possible to describe the evolution of the CEREC system evolving in parallel with the improvement of the technology and the computing which will allow a succession of changes both in hardware and in software. (15)

The first CEREC system known as CEREC 1, although one of the first commercially available “chair-side” CAD/CAM systems, was very limited in the type of dental reconstruction proposed. Indeed, its optical impressions were limited to preparations for inlay, onlay and veneer reconstructions. Then, the following years were marked by software and hardware improvements, and in 1994 the CEREC 2 system was able to do much more than its predecessor: it added the possibility of making full crowns reconstruction. (7)(6)

Another major software change was the moving from 2D to 3D in 2003 with the CEREC 3 system, which made the system much easier to use and more intuitive for the dentist. In addition, it opened the door to other tools to check the occlusion with the antagonists, control of the vertical dimension, ... (24)(7)

The evolution of CEREC system has not stopped since two recent additions have been made:

- CEREC connect: Allows the optical impression to be communicated to the laboratory for reconstruction with the CEREC inLab system or for a more classical reconstruction such as metal fused ceramic crowns. (14)

- CEREC AC (Acquisition Unit): With a new optical camera that uses blue light instead of the previously used infrared (i.e. a shorter wavelength). This change allows for a much better capture resolution, which allows for more accurate reconstructions. In addition, several improvements in the optics, software and sensor have been made to improve the imaging treatment. According to the studies, it is possible to capture a quadrant of 5 teeth in less than 20s and a full arch in 60-90s. (14)(26)

After more than 35 years of development, the CEREC system has become one of the most marketed CAD / CAM systems in the world and allowing several types of reconstruction (crowns, inlays, onlays, bridges, ...). (14)

During the last decade, more manufactured come in the market of the iOS with system like E4D Dentist developed by D4D Technologies LLC in 2008, the iTero system developed by Cadent in 2006, the Lava C.O.S commercialized by 3M ESPE in 2008, … (see Table 1)

According to the article published in 2013 “Part 1: 3D intraoral scanner for restorative dentistry”, there are nowadays at least more than 10 iOS tools commercialized in dentistry. (16)

5.2 How the CAD works and what the different type of the optical scanner used?

Among the articles selected, 10 articles are related with the technologies used by the iOS to record the POI (developed in the introduction). After analysing, it is possible to notice 5 main technologies (Table 1):

- Interferometry Moiré: Used by Prof. Duret for his iOS prototype in the 1970s. Its working principle is already described above in the history section.
- Active triangulation
- Confocal laser microscopy
- Optical coherent tomography
- Active wavefront sampling (Active Wavefront Sampling)

It is important to notice that the ability to measure the object iOS distance or also called “depth value” (z-coordinate), after evaluation of the x and y coordinates from an image or video, is necessary to have a good 3D depth POI recognition. These different technologies are of course not used exclusively, in fact some IOS models can use a combination of the two technologies mentioned above to increase their efficiency and accuracy. (9)

5.2.1 Triangulation technics

By recombining the data in the table 1, it is possible to see that this is one is the most common method used by optical camera manufacturers. According to the article (8) and table 1, there are 2 triangulation techniques (passive and active).

The passive triangulation technique, also called “stereovision”, is based on an analysis of two stereo images obtained from the same object. To obtain such a result, a device consisting of 2 cameras which are connected to 2 different sensors whose positions are known and an orientation with respect to the target well defined as illustrated below (Figure 10):

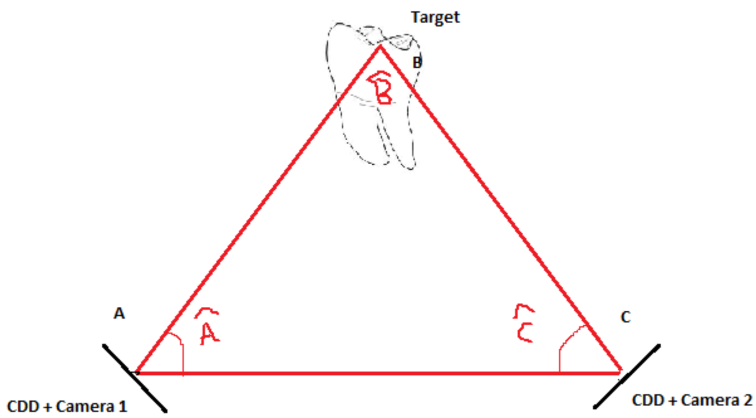


Figure 10: Passive Triangulation (own resources)

The position between the sensors and the target object will be determined by trigonometry calculations. Indeed, in the image above (Figure 10), it is possible to see a triangle formed between the 2 sensors (Distance known, AC) and the target object (point B). (13) In this example, the distance AB can be determined by this formula AB= AC x sin (C)/sin (A+C) where the angle A and C are known.

It should be noted that in the case of passive triangulation, only ambient light is used (no active camera). This kind of technique gives very good results in terms of accuracy compared to the active technique. However, only structures with high contrast will be detected (an additional camera can improve this disadvantage).(8)

The active triangulation technique consists of the same set-up as above, but this time a camera/sensor is replaced by a laser light source. With such a device, the laser, which is deflected by a mirror oriented at a defined angle to the target, is then reflected by the surface to be scanned and captured by a sensor. The trajectory drawn by the laser and the position of the mirror and the sensor form a triangle where the rules of trigonometry can be applied.(13)(8)

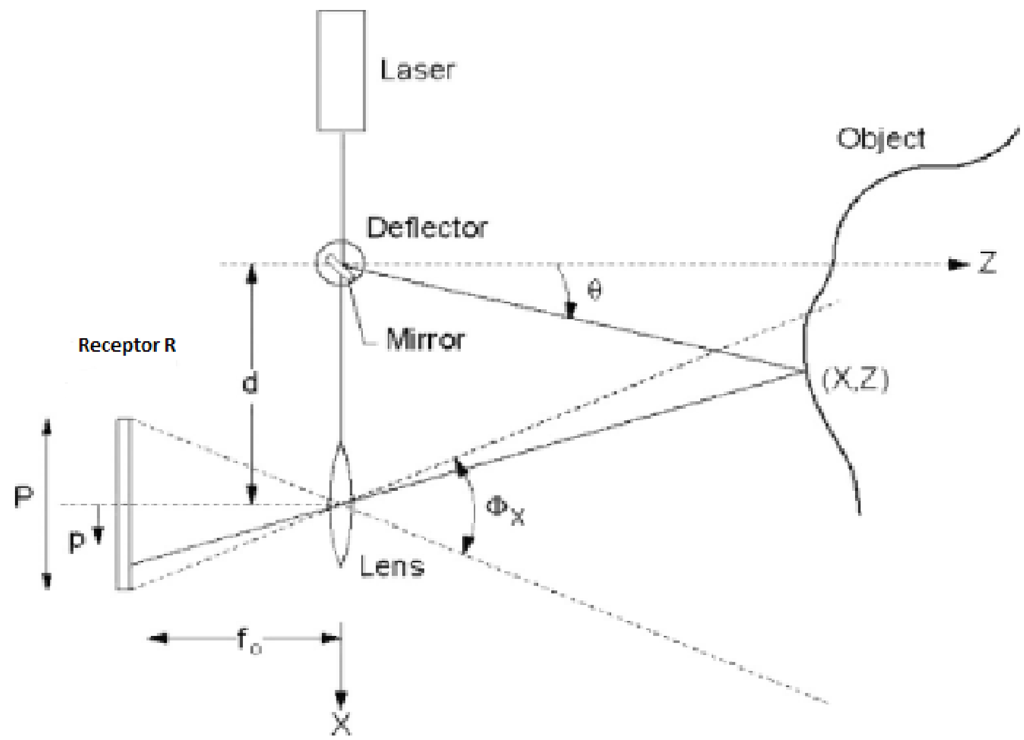


Figure 11: Active Triangulation from "Recent advances in dental optics - Part I: 3D intraoral scanners for restorative dentistry"

In the example above (Figure 11), the mirror is positioned at a well-defined angle so that the incident laser forms a known angle α with the straight-line representing distance IOS - target (Z). The reflected beam will be received by the sensor at an angle Ɵ which will be estimated by the position of the reflected laser on the sensor with respect to the center of the sensor (the sensor is positioned on the focal plane f0 of the lens of the receiver camera R).

With the distance between the receiver R and the mirror known, it will be possible to know Z by the same trigonometric rules as before.

The above example (Fgure11) is a triangulation by projection of a point; however, it is not applicable in the case of an optical impression in dentistry. For a good and fast 3D reconstruction it would require a multiple points projection on the whole surface of the target object. Therefore, the IOS uses a triangulation by projection of a mask (mesh projection). In this case, a light pattern (such as a grid) is projected onto the object and the deformations of this same pattern from the original one, will allow to find the geometry of the target object structure such as the cusps of a tooth for example (Figure 12). By this method we gain considerably in acquisition speed. (8)(16)

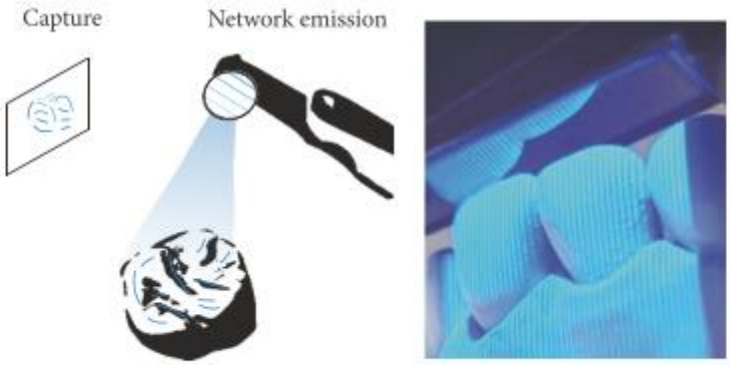


Figure 12:Active Triangulation with mesh projection from "Intraoral Scanner Technologies: A Review to Make a Successful Impression"

This kind of technology can be found in the CEREC and IOS models for example.

(16)(8)(22)(15)(27)

5.2.2 Confocal laser microscopy

According to the article (16) this other widely used method is a mixture of confocal microscopy, which appeared in 1961 with Marvin Minsky, and the appearance of lasers that came much later in the years 1980s.

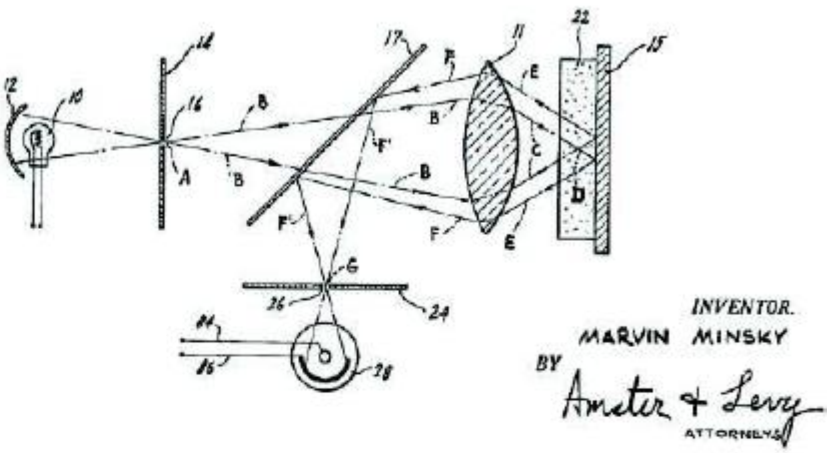


Figure 13: Confocal microscopy by the inventor Marvin Minsky

Confocal microscopy has an advantage for 3D reconstruction: it allows to have a clear image of a large sample. In optical microscopy, any image outside the optical plane of the system is blurred. In confocal microscopy, a focalized light (or laser (several projected points)) reflected from a specific depth level is recovered through a small aperture in front of the receiver. This "pinhole" only allows light to pass through the optical plane of the system (in-of-focus lights). The pinhole's aperture can be adjusted to change the focal length of the system, resulting in a sharp image. The higher the aperture, the smaller the depth of field (short focal length). (16)(8)(13)(9)

The different images or layers obtained at different depths of field are then reconstructed by a computer to obtain a 3D reconstruction of a tooth, for example. (16)(9)

This principle of operation can be found in the iTero model, the 3d progress model or the Trios model from 3Shape (Table1). (16)(15)

5.2.3 AWS (Active Wavefront Sampling)

The articles (16) (8) present a technique that is currently only used by 3M ESPE for its C.O.S model, which is called the non-collinear focusing/defocusing method or 3D-in motion technology by 3M ESPE itself.

Although it requires a preliminary powdering of the teeth to be scanned, this technique has several advantages such as the need for a single optical path to operate, and a reduction in the number of optics required as attested by the article (16) and the MIT thesis (18). This last advantage is very interesting because it allows the integration of the optical system in a smaller optical camera compared to its competitors.

This technique is mainly based on "depth from focus" imaging. To summarize, it must be taken into account that an object located on the focal plane F will appear as sharp on a sensor but if it moves away from it, it will appear as blurred as it is possible to see on the illustration below (Figure 14).(18)

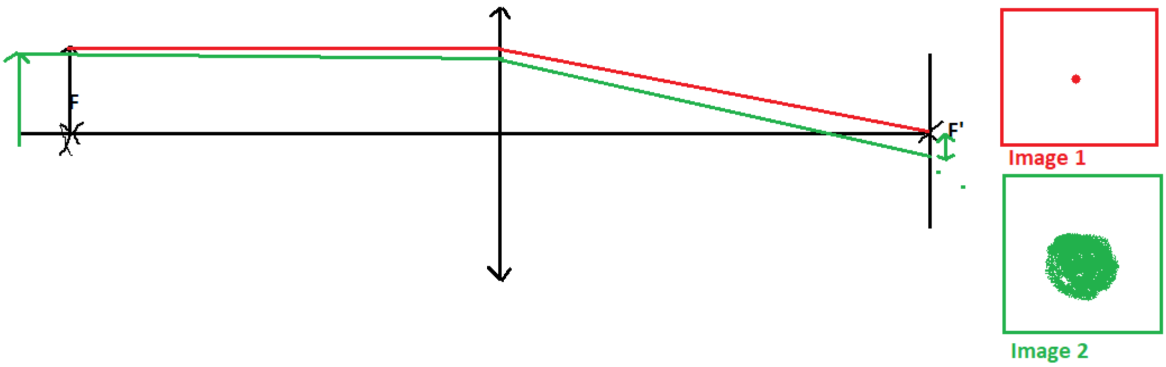


Figure 14: Image out of focus (own ressources)

A direct relationship can be demonstrated between the distance of the object-lens (focal plane of the lens) and the diameter of the blurred image.

However, the problem with such system is the possible overlap of the blurred images obtained from a complex structure like a tooth (multiple POIs with different distances to the focal planes). (16)(8)

To overcome this solution, an opaque mask with a small aperture eccentric to the optical axis in rotation with respect to it, will allow to obtain multiple blurred images recorded separately from different POIs.(16)

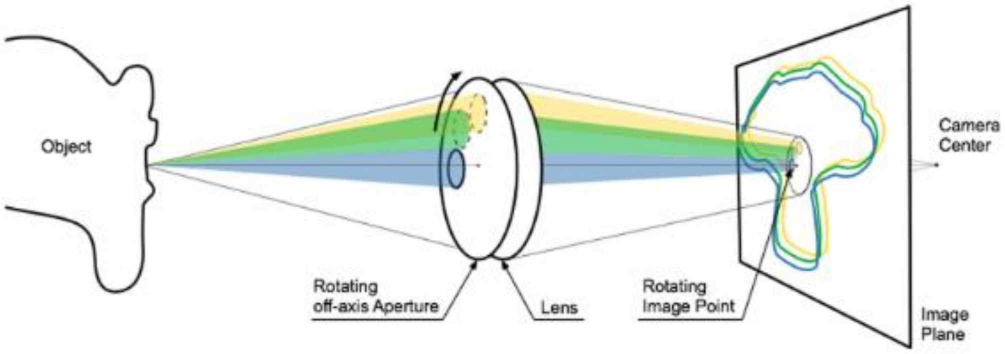


Figure 15: Active Wavefront Sampling principles from "Recent advances in dental optics - Part I: 3D intraoral scanners for restorative dentistry".

5.2.4 Optical coherent tomography

This is a technique used by the E4D Dentist system scanner (Table1). In this technique, the light interferometry will allow to obtain a 3D reconstruction by computer from several sections obtained thanks to the principle of the Michelson interferometer.(16)

As with Moiré interferometry, we will use interferometry but this time, a single light source (monochromatic laser) of coherent type (same phase) will be used to locate the depth of field of the different layers of the sample (Z coordinate of the POIs). (8)

To do this, a mono chromatic coherent light source such as a laser (light with a small wavelength spectrum of the same phase) will have to pass through a semi-reflective separating plate to divide it into 2 light rays of the same wavelength spectrum but of intensity I/2. These 2 rays will follow a different path and will then be reflected by 2 mirrors M1 and M2 (1 mirror for 1 light ray) in order to send the previously separated light rays back to the semi-reflecting plate which will then send the 2 rays back to the sensor. (16)(8)

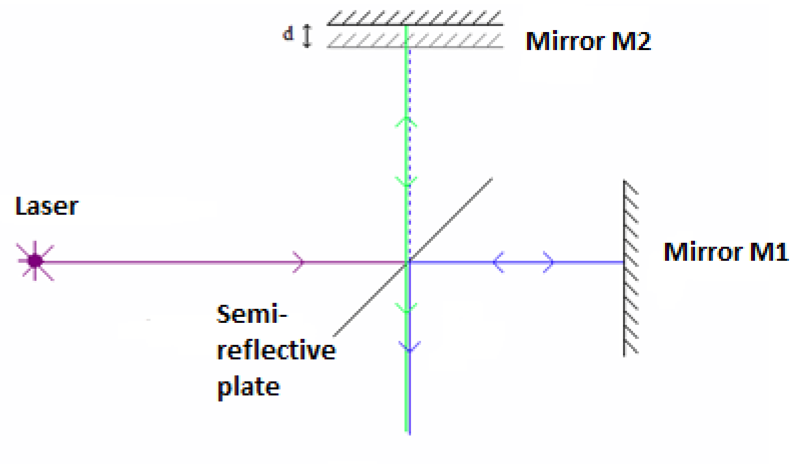


Figure 16: Michelson interferometer principles (own ressources)

Depending on the distance of the two mirrors from the semi-reflecting plate, an interference pattern will be obtained (so-called non-coherent light).

In the case of an optical camera, the sample will be in the place of mirror M1 and mirror M2 can move to obtain a precise interference pattern and thus obtain the object-iOS distance (Z coordinate).

5.3 What are the advantage and the disadvantage of the digital impression compared to the traditional approach?

The analyse of 7 scientific papers including 5 reviews (table 2), permit us to resume the common advantages and the disadvantages of the digital impression compared to the traditional approach with the classical materials such as the alginate and the addition silicone (PVS impression) in this table:

Advantage	**Disadvantage**
- Time efficiency. - Better communication with the patient and the dental technician. - Less discomfort for the patient. - Higher accuracy for the study model for the short span of restoration. - Less risk operator error	- Expensive. - Not adapted for the long span of restoration. - Difficulty to record the marginal ridge. - More time spent during the impression process.

About the ergonomic and the comfort patient, 4 reviews (4)(19)(12)(28) have found a better compliance from the patient with the using of the iOS. In fact, they point the time efficiency, a better breathing for patient during the process, and the non-use of materials that can be trigger of the nausea reflex. Also, one review (4) headlines the fact of the better communication with the patient because some of the model equipped with a touch screen permit a direct visualisation of the dental printing and give a first view of the future restauration/prothesis.

However, it should be noted that this conclusion is contradicted by a systemic review (21) which reported a much better patient comfort (71%) in the case of a full impression with a conventional PVS technique. The same study questions the conclusion on time saving on dental chair. Indeed, it shows an average time of 23 min for a full digital impression so much more than to traditional impression. (21)

For the communication with the lab 2 reviews are agreeing to say that a digital impression accompanied a 3D design of the prothesis permit a closer bound between the dentist and the dental technician. (4)(10)

Other advantage of the optical impression is based on less possible deformations linked on the suppression of the step operator dependant and the properties of the materials in the classical approach (loss of spatial stability of the alginate and PVS, contraction of the plaster during the pouring of the cast, ….). (19)(4)

In addition one paper (3), although with many methodological weaknesses, explores a hypothesis in favour of iOS. Its results seem to show a better accuracy in the case of impressions for crown preparations with a TOC <8° compared to more traditional approaches. This can be explained by the fact that an IOS has less problem to record the very frequent undercuts for preparations with a TOC of less than 10° (ideal case of retention and strength for a fixed prosthesis). (3)

About the disadvantages, the 3 reviews (4) (19) (20) have demonstrated the difficulty of the record the marginal ridge or deep preparation. This phenomenon can be explained per a mesh density too low. In fact, for some preparation such as the chamfer margins, the triangle formed per the POI registered can be too large.
Another article points the necessity of using gingival retraction for preparation close to the gingiva, because the iOS have not the properties of the classical materials of impression to displace the gingiva from the preparation.

Most of the article have also demonstrated the non-efficiency of the iOS regarding the full arch impression due to possible accumulation of error linked with the stitching of multiples scan. In fact, to record a full arch impression, the iOS will build a single digital model from multiple overlapping scan that will be combined with stitching algorithm. This process may induce deviation and discrepancies. (19)(20)(4)(5)(3)

Another problem highlighted by the article (19), is the loss of scanning accuracy for metallic type restorations such as inlay-core, or excessive saliva due to excessive reflections of captured light (a common problem of any light reflection-based system). This same reflection problem can be induced by structures producing shadow areas such as stepped preparations, sharp edges, proximal boxes, and as the article (4) attests this will also concern finishing lines. Indeed, light cannot pass through and especially for subgingival aesthetic preparations where light unlike physical materials (alginate and silicone) cannot move the gingiva from the finishing line and cannot register the non-visible areas either. (4)(19)

The last point to note according to 2 reviews: the very high costs of optical cameras at the present time. Indeed, in 2020, prices oscillate between 15 000 euros and 35 0000 euros in general. This can even reach 45,000 euros for the top of the range models. This is a serious obstacle, as the article (21) shows, because dental clinics with several seats are only equipped with one model and this can lead to organisational complications (impossibility of making several impressions simultaneously). Furthermore, the article (4) informs about additional costs sometimes not foreseen with iOS due to its maintenance (software upgrade). (4)(21)

6- Conclusion

- About the evolution of the intraoral scanner, it is possible to conclude after this research that there were 2 phases during its development.

  The first period between the 1970 and the 2010 was marked by the creation of the concept with Francois Duret with the use of the holography and the continuous development of the famous system CEREC with the active triangulation during all the decade 1990's with the association of Dr Mormman and Brandestini. In this period, the development of intraoral scanner was limited by the technology of the time. Plus, the high cost of construction associated with few functionalities impacted deeply its commercialization.

  The second phases of the development can be defined as the maturation of this technology. In fact, after the year 2010's, the imaging treatment improve a lot with the speed and the memory of the computer. That why, we observed more manufacturer in this field with more system CAD/CAM "chair-side" with more competitive price.

- All the IOS are composed on same component such as a handle camera with a CDD device, a computer, and a software. The difference between them is based on the technology to record the depth of the POIs (coordinate z) and the software used. The most technology used is the active triangulation introduced by CEREC 1, but it is now possible to find other technologies like the confocal laser microscopy, the AWS, the optical coherence tomography, or a combination of them. Each technology presents different advantages and disadvantages.

- After 40 years of development, intraoral scanners are more efficient and have more features compared to the first one developed in the 90s. They even have several advantages compared to so-called conventional impressions such as saving time for restoration (possibility of doing the construction of the prosthesis the same day as the impression taking for certain model), better acceptability on the part of the patient (in particular with those who have a gag reflex), better communication with the prosthetist (impression with more information with the possibility of previewing the prosthesis on the preparation), and a reduction in the risk of error (depending on the dentist and prosthetist).

  However, despite all these advancements, the IOS still has room for improvement in accuracy (especially in the case of sub-gingival preparation or patient with high quantity of saliva) or in its ability to take full arcade impressions. Despite a still very high cost, iOS will become more and more present in the dental office and the new improvements in image processing with IA (Intelligence Artificial) for example, will be able to correct the actual problem of deviation or accuracy loss in the case of full-arch impression.

7- Responsibility

Intraoral scanners are very recent technologies that have many advantages and even improvements in the daily practice of dentists for prosthetic rehabilitation treatments.

However, the dentist as a health professional has a duty to provide the best possible science-based treatment for the patient. Indeed, at this moment, although presenting good clinical results for some specific situations, they still present important gaps compared to non-digital impressions which are much less expensive, especially for complete impressions.

Another problem that this type of technology can bring is the risk of security of patient data (particularly when communicating DICOM files between the dental practice and the laboratory) and the dentist is responsible for protecting this data.

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Annexe

François DURET

L'EMPREINTE OPTIQUE OU LA CYBERNETIQUE ODONTOLOGIQUE

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La théorie de l'empreinte optique est une nouvelle façon de concevoir notre méthode de travail. Elles se veut essentiellement cybernétique, c'est-à-dire mécaniquement intelligente. Il est, certes, particulièrement difficile de définir l'intelligence sans faire référence au comportement humain; nous dirons simplement qu'il en est la limite supérieure et que la cybernétique odontologique apparaît comme transposition aux machines dites intelligentes de notre savoir-faire, pour nous libérer l'esprit d'un certain nombre de conceptions pratiques. La seule méthode pour reproduire une dent ou un maxillaire avec précision (200 à 500 microns au mieux) est l'empreinte négative à l'aide de matériaux plus ou moins élastiques, le profil étant constitué par la dent du patient et le négatif par l'empreinte elle-même. Cette méthode, utilisée depuis plus de 300 ans, n'a subi aucune modification fondamentale dans son objet. En effet, le principe de la saisie de la forme a toujours reposé sur le moulage par des pâtes'fixant' le volume étudié. Tout ce qui suivait n'était que l'aboutissement dirigé par ce premier acte. En fait, le véritable problème, c'est-à-dire le principe même de la méthode, a été oublié au travers des décennies. Il ne s'agissait plus pour nos chercheurs de corriger la saisie des formes, mais de perfectionner les pâtes d'empreinte... Pourtant, cette façon de procéder est fondamentalement mauvaise: la cause physique de l'imprécision du captage des données est liée aux variations d'énergie des sytèmes empreinte-négatif. Pour réduire ces variations d'échanges énergiques, il n'existe qu'une seule méthode: limiter les échanges énergétiques et, en particulier, les variations d'énergie internes. Ceci revient à conserver le plus possible d'enthalpie de l'ensemble considéré à une valeur fixée, action impossible par les méthodes classiques. Plus un système est simple, moins il est sensible aux variations d'énergie libre et de l'enthalpie. C'est pour cette simple raison que dès 1972, nous avons choisi le quantum énergétique, c'est-à-dire la saisie des formes par onde, comme base de travail.

HISTORIQUE

De 1972 à 1976, dans le laboratoire de J. DUMAS à LYON et J. THOUVENOT à TOURS, a été élaboré la théorie de l'empreinte optique comme suit:
— saisie de forme de la dent à l'aide de l'holographie

Les travaux ont été repris par un certain nombre de chercheurs, aux USA en particulier: YOUNG (1977), PRYPUTNIEWYCZ (1977) et BURSTON (1978). Il était pourtant particulièrement évident que l'holographie était une méthode trop sophistiquée pour le but à atteindre. C'est sans doute pour cette raison

AUSTIN PUBLISHING GROUP

Austin Journal of Orthopedics & Rheumatology

ISSN 2472-369X

Open Access

Review Article

Austin J Orthopade & Rheumatol. 2015; 2(3): 1021.

Intra-oral Scanners: A New Eye in Dentistry

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Received: August 18, 2015; **Accepted:** November 01, 2015; **Published:** November 17, 2015

Abstract

Today, intra-oral mapping technology is one of the most exciting new areas in dentistry since three-dimensional scanning of the mouth is required in a large number of procedures in dentistry such as orthodontics and restorative dentistry. Since the introduction of the first dental impressioning digital scanner in the 1980's, development engineers at a number of companies have enhanced the technologies and created in-office scanners that are increasingly user-friendly. It offers the clinician the ability to offer patients different appliances and fixed restorations of all types. The new technology has become easier to use for the clinician as well as more precise, and offers technological advances over earlier versions. These systems are capable of capturing 3D virtual images of tooth which can be used to create accurate master models on which the restorations can be made in a dental laboratory (dedicated impression scanning systems). The use of these products is rapidly increasing around the world and presents a paradigm shift in the way in which dental impressions are made. Several of the leading 3D dental digital scanning systems are presented and discussed in this article.

Keywords: Intra-oral scanner; Software; Record keeping

Introduction

Moritz Zimmermann

M. Zimmermann[a], A. Mehl[b], W. H. Mörmann[c], S. Reich[d]

Intraoral scanning systems – a current overview

Intraoralscanner: eine aktuelle Übersicht

Zusammenfassung

Innerhalb weniger Jahre hat sich das Angebot an intraoralen optischen Abformsystemen deutlich vergrößert. Die Möglichkeiten und das Potenzial der digitalen Abformung mit intraoralen optischen Abformsystemen sind heutzutage unumstritten. Zahlreiche Innovationen sowie Indikationserweiterungen in den Bereichen Kieferorthopädie und Implantologie lassen die intraoralen Scansysteme als äußerst vielversprechend und zukunftsträchtig erscheinen. Die digitale Abformung mittels Intraoralscannern ist der konventionellen Abformtechnik in manchen Punkten bereits deutlich überlegen. Die vielseitige Integration der digitalen Abformung in Diagnostik- und Therapiekonzepte im Rahmen eines „Healthcare-Pakets" für den Patienten erscheint besonders erwähnenswert. So bleibt mit Spannung zu sehen, wann die digitale Abformung – ähnlich wie bereits etablierte digitale Applikationen im alltäglichen Leben – ein selbstverständlicher Bestandteil der zahnärztlichen und zahntechnischen Tätigkeit sein wird. Innerhalb des vorliegenden Artikels wird eine Übersicht über die Vorteile und Einschränkungen der digitalen Abformung mit Intraoralscannern gegeben. Zudem liefert er eine Zusammenfassung sämtlicher heutzutage relevanter Intraoralscanner.

Schlüsselwörter: *digitale Abformung, Intraoralscanner, Übersicht*

Abstract

There is no doubt today about the possibilities and potential of digital impression-taking with the aid of intraoral optical impression systems, and the past few years have seen a considerable increase in the range of optical intraoral scanners available on the market. On the strength of numerous innovations and a wider range of indications in orthodontics and implantology, intraoral scanning systems appear to be a highly promising development for the future. Digital impression-taking with intraoral scanners has already shown itself in some respects to be clearly superior to conventional impression-taking. Particularly worthy of mention is the versatile integration of digital impressions into diagnostic and treatment concepts to provide a customizable healthcare solution for the patient. It remains exciting to look forward to future developments that will allow us to observe digital impression-taking – as with other digital applications already established in everyday life – becoming firmly established in the routine of dentistry and dental technology. This article presents an overview of the benefits and limitations of digital impression-taking using intraoral scanning systems, and includes a summary of all the relevant intraoral scanners available on the market at present.

Keywords: *digital impression, intraoral scanning, review*

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Inside Dentistry
April 2009
Volume 5, Issue 4

3D Digital Scanners: A High-Tech Approach to More Accurate Dental Impressions

Nathan S. Birnbaum, DDS, CAGS(Prosth); Heidi B. Aaronson, DMD; Chris Stevens, DDS; Bob Cohen, CDT

Ever since the introduction of the first digital scanner for making dental impressions in the 1980s, development engineers at a number of companies have enhanced the technologies and created in-office scanners that are increasingly user-friendly and produce precisely fitting dental restorations. These systems are capable of capturing three-dimensional (3D) virtual images of tooth preparations from which restorations may be directly fabricated (CAD/CAM systems) or can be used to create accurate master models for the restorations in a dental laboratory (dedicated impression scanning systems). The use of these products presents a paradigm shift in the way dental impressions are made. Several of the leading 3D dental digital scanning systems are presented and discussed in this article.

A Paradigm Shift in the Concept for Making Dental Impressions

The acquisition of an accurate negative copy of a prepared tooth or teeth and of the adjacent and opposing teeth and the establishment of a correct interocclusal relationship, as well as the conversion of this information into precise replicas of the dentition on which indirect restorations can be made, are the ultimate goals of the impression process in restorative dentistry.

The widely used techniques currently employed for obtaining elastomeric impressions and for creating gypsum models from those impressions have only been in use since 1937, when Sears introduced agar as an impression material for crown preparations.[1] The first elastomeric material specifically produced for the purpose of dental impression-making was Impregum™, a polyether material introduced by ESPE, GmbH in 1965.

Many dentists are reluctant to become involved with newer technologies in impression making because they either mistakenly believe that the elastomeric technique and materials have been around since time immemorial and are immutable, or that 3D digital scanners are too new a technology that is not yet "ready for prime time." In fact, elastomeric impression materials, with their many inherent problems,[2,3] have only been in use in dentistry for 72 years.

The evolution of the CEREC system

Werner H. Mörmann, Prof. Dr. med. dent.

ABSTRACT

Background and Overview. Early in 1980, the author anticipated the attraction of restoring posterior teeth with tooth-colored material. He conducted studies and developed the clinical concept of bonded ceramic inlays, at the same time raising the issue of the fast fabrication of the ceramic restorations. The author developed plans for in-office computer-aided design/computer-aided manufacturing (CAD/CAM) fabrication of ceramic restorations specifically to enable the dentist to complete one or multiple ceramic restorations chairside, in a single appointment. The initial concept comprised a small mobile CAD/CAM unit integrating a computer, keyboard, trackball, foot pedal and optoelectronic mouth camera as input devices, a monitor and a machining compartment. CEREC 3 (Sirona Dental Systems GmbH, Bensheim, Germany) divided the system into an acquisition/design unit and a separate machining unit. Three-dimensional software makes the handling illustrative and easy both in the office and in the laboratory.

Conclusions. It appears that the CEREC CAD/CAM concept is becoming a significant part of dentistry.

Clinical implications. Sound knowledge of adhesive bonding and diligent planning are essential for the successful integration of CAD/CAM into clinical dental offices.

Key Words. CEREC; ceramic restorations; chairside computer-aided design/computer-aided manufacturing; in-office computer-aided design/computer-aided manufacturing; block ceramic; bonded restoration.
JADA 2006;137(9 supplement):7S-13S.

ARTICLE 1

I had been teaching operative dentistry with amalgam and gold restorations at the Dental School of the University of Zurich for 10 years when, early in 1980, I anticipated the attraction of restoring posterior teeth with tooth-colored materials. At that time, we could not use direct composite fillings because of polymerization shrinkage, the resulting formation of a marginal gap, and lack of abrasion resistance. Nevertheless, I found it imperative that posterior teeth be restored durably in their natural color in the future.

On the basis of my own in vitro and in vivo studies with pressed and hot polymerized composite inlays, I developed the hypothesis that inlays made of tooth-colored material, inserted adhesively with resin-based composite as a luting agent, could solve the problem.[1] The

DISCLOSURE: Dr. Mörmann is co-developer of the CEREC 1 system (Sirona Dental Systems GmbH, Bensheim, Germany) and president of the Foundation for the Advancement of Computerized Dentistry, and he has been awarded research grant donations by Vita Zahnfabrik (Bad Säckingen, Germany) and Ivoclar Vivadent (Scaan, Liechtenstein).

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The CEREC system

25 years of chairside CAD/CAM dentistry

Dennis J. Fasbinder, DDS

In September 1985 at the University of Zurich Dental School, Mörmann[1] placed the first chairside ceramic restoration with the CEREC 1 system (Sirona Dental Systems, Charlotte, N.C.) by using computer-aided design/computer-aided manufacturing (CAD/CAM) technology. At the time, it was a revolutionary concept for restorative dentistry that an industrially made ceramic material could be fabricated chairside by using a milling device with the benefits of a direct restorative treatment modality. As with any new concept, there were many questions about the viability of such a radical restorative technique and its acceptance by dentists.

The year 2010 marks 25 years of chairside CAD/CAM experience in dental practice. The restorative materials and clinical technique have been studied extensively as they have evolved. In a recent search of the word "CEREC" on PubMed, I found 402 studies referenced.

In recognition of 25 years of CAD/CAM in the dental office, this supplement presents four articles that describe some of the latest techniques and innovative materials available for chairside CAD/CAM dentistry in 2010.

The CEREC system has evolved through a series of software and hardware upgrades since its introduction to the dental marketplace as the CEREC 1 system. There have been several significant changes in the system since its introduction. The separation of the milling chamber from the image capture and design hardware led to a significant improvement in clinical efficiency by allowing for simultaneous design of one restoration while milling a second one. The change from a two-dimensional design program to a three-dimensional (3-D) design program occurred as the speed and memory of computers improved. The introduction of the 3-D software substantially improved the immediate understanding of the 3-D program because dentists were able to view the designs in a way similar to what they were used to seeing with stone models. 3-D design also improved the clinical work flows of chairside system use. The most recent evolution, the CEREC Acquisition Center (Sirona Dental Systems) unit, has introduced a newly developed light-emitting diode (LED) camera called the Bluecam. This camera is based on a blue LED that replaces the infrared-emitting camera in the CEREC Acquisition Unit (Sirona Dental Systems) system. In the first article in this supplement, Poticny and Klim[2] discuss the Bluecam and other work-flow improvements for chairside delivery of ceramic restorations.

The evolution of the software and hardware for the CEREC system is mirrored by developments in the materials available. Ivoclar Vivadent (Amherst, N.Y.) introduced a lithium disilicate restorative material (IPS e.max CAD) that initially was designed to be used in the dental laboratory as a coping material that was more translucent than zirconia. It then became available in a variety of shades and several translucencies for use in esthetic full-contour, chairside restorations. Other available ceramic materials for chairside CAD/CAM require adhesive luting agents for bonding of the restorations to achieve clinical success. The enhanced strength of the

ABBREVIATION KEY. CAD/CAM: Computer-aided design/computer-aided manufacturing. **LED:** Light-emitting diode. **3-D:** Three-dimensional.

Mangano et al. BMC Oral Health (2017) 17:149
DOI 10.1186/s12903-017-0442-x

BMC Oral Health

RESEARCH ARTICLE Open Access

Intraoral scanners in dentistry: a review of the current literature

Francesco Mangano[1*], Andrea Gandolfi[2], Giuseppe Luongo[3] and Silvia Logozzo[4,5]

Abstract

Background: Intraoral scanners (IOS) are devices for capturing direct optical impressions in dentistry. The purpose of this narrative review on the use of IOS was to: (1) identify the advantages/disadvantages of using optical impressions compared to conventional impressions; (2) investigate if optical impressions are as accurate as conventional impressions; (3) evaluate the differences between the IOS currently available commercially; (4) determine the current clinical applications/limitations in the use of IOS.

Methods: Electronic database searches were performed using specific keywords and MeSH terms. The searches were confined to full-text articles written in English and published in peer-reviewed journals between January 2007 and June 2017.

Results: One hundred thirty-two studies were included in the present review; among them, 20 were previous literature reviews, 78 were in vivo clinical studies (6 randomized controlled/crossover trials, 31 controlled/comparative studies; 24 cohort studies/case series; 17 case reports) and 34 were in vitro comparative studies.

Conclusions: Optical impressions reduce patient discomfort; IOS are time-efficient and simplify clinical procedures for the dentist, eliminating plaster models and allowing better communication with the dental technician and with patients; however, with IOS, it can be difficult to detect deep margin lines in prepared teeth and/or in case of bleeding, there is a learning curve, and there are purchasing and managing costs. The current IOS are sufficiently accurate for capturing impressions for fabricating a whole series of prosthetic restorations (inlays/onlays, copings and frameworks, single crowns and fixed partial dentures) on both natural teeth and implants; in addition, they can be used for smile design, and to fabricate posts and cores, removable partial prostheses and obturators. The literature to date does not support the use of IOS in long-span restorations with natural teeth or implants. Finally, IOS can be integrated in implant dentistry for guided surgery and in orthodontics for fabricating aligners and custom-made devices.

Keywords: Intraoral scanners, Optical impressions, Accuracy, Time efficiency, Clinical use

Background

Intraoral scanners (IOS) are devices for capturing direct optical impressions in dentistry [1–3]. Similar to other three-dimensional (3D) scanners, they project a light source (laser, or more recently, structured light) onto the object to be scanned, in this case the dental arches, including prepared teeth and implant scanbodies (i.e. cylinders screwed on the implants, used for transferring the 3D implant position) [2, 3]. The images of the dento-gingival tissues (as well as the implant scanbodies) captured by imaging sensors are processed by the scanning software, which generates point clouds [3, 4]. These point clouds are then triangulated by the same software, creating a 3D surface model (mesh) [3, 4]. The 3D surface models of the dentogingival tissues are the result of the optical impression and are the 'virtual' alternative to traditional plaster models [4, 5].

Although IOS are becoming widespread in clinical dental practice, only a few reviews on the use of these devices are available in the literature [5–8].

The purpose of the present narrative review was therefore to:

- identify the advantages and/or disadvantages of using optical impressions compared to conventional impressions;

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Review > J Indian Prosthodont Soc. Jan-Mar 2020;20(1):27-37. doi: 10.4103/jips.jips_327_19. Epub 2020 Jan 27.

Accuracy of an intraoral digital impression: A review

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Affiliations + expand

PMID: 32089596 PMCID: PMC7008627 DOI: 10.4103/jips.jips_327_19

Free PMC article

Abstract

Intraoral scanners (IOSs) are used for capturing the direct optical impressions in dentistry. The development of three-dimensional technology and the trend of increasing the use of IOSs in dental office routine lead to the need to assess the accuracy of intraoral digital impressions. The aim of this review was to assess the accuracy of the different IOS and the effect of different variables on the accuracy outcome. An electronic search using PubMed with specific keywords to obtain potential references for review. A search of MEDLINE (PubMed) identified 507 articles. After title and abstract screening, 412 articles were excluded for not meeting the inclusion criteria and discarding duplicate references. Ninety-five articles were followed for full screening; only 24 articles were included in the final analysis. The studies indicated a variable outcome of the different IOS systems. While the accuracy of IOS systems appears to be promising and comparable to conventional methods, they are still vulnerable to inaccuracies.

Keywords: Accuracy; digital impression; intraoral scanner; optical impression.

Conflict of interest statement

There are no conflicts of interest.

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Review > Eur J Orthod. 2016 Aug;38(4):429-34. doi: 10.1093/ejo/cjw033. Epub 2016 Jun 7.

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Validity and reliability of intraoral scanners compared to conventional gypsum models measurements: a systematic review

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PMID: 27266879 DOI: 10.1093/ejo/cjw033

Abstract

Background: The development of 3D technology and the trend of increasing the use of intraoral scanners in dental office routine lead to the need for comparisons with conventional techniques.

Objective: To determine if intra- and inter-arch measurements from digital dental models acquired by an intraoral scanner are as reliable and valid as the similar measurements achieved from dental models obtained through conventional intraoral impressions.

Search methods: An unrestricted electronic search of seven databases until February 2015.

Selection criteria: Studies that focused on the accuracy and reliability of images obtained from intraoral scanners compared to images obtained from conventional impressions.

Data collection and analysis: After study selection the QUADAS risk of bias assessment tool for diagnostic studies was used to assess the risk of bias (RoB) among the included studies.

Results: Four articles were included in the qualitative synthesis. The scanners evaluated were OrthoProof, Lava, iOC intraoral, Lava COS, iTero and D250. These studies evaluated the reliability of tooth widths, Bolton ratio measurements, and image superimposition. Two studies were classified as having low RoB; one had moderate RoB and the remaining one had high RoB. Only one study evaluated the time required to complete clinical procedures and patient's opinion about the procedure. Patients reported feeling more comfortable with the conventional dental impression method.

Limitations: Associated costs were not considered in any of the included study.

Conclusions and implications: Inter- and intra-arch measurements from digital models produced from intraoral scans appeared to be reliable and accurate in comparison to those from conventional impressions. This assessment only applies to the intraoral scanners models considered in the finally included studies. Digital models produced by intraoral scan eliminate the need of impressions materials; however, currently, longer time is needed to take the digital images.

Registration: PROSPERO (CRD42014009702).

Funding: None.

Dental Materials Journal 2020; 39(1): 57–61

Review

The current clinical relevancy of intraoral scanners in implant dentistry

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Optical technology has provided a paradigm shift in implant dentistry. However, there is little information about the use of optical technology in implant dentistry, since this technology is relatively new and has been evolving under the current conditions. In the present narrative literature review, the effects of intraoral scanners (IOSs) use on accuracy and the operating time, as well as safety and patient perception, in implant dentistry were evaluated from the clinical perspective. The accuracy of digital scans with IOSs was comparable to the conventional impression techniques for single or partial prostheses, and the digital scans with IOSs are time efficient when taking impressions for single- or double-abutments. However, the accuracy and time efficiency are decreased for multiple implant scans or large-area scans with IOSs use. Patient satisfaction with and preference for IOSs scans are generally superior to those with conventional impression procedures.

Keywords: Digital dentistry, Intraoral scanner, Clinical relevancy

INTRODUCTION

The term "digital dentistry" first appeared in PubMed back in 1999[1]. In these last two decades, digital dentistry has spread widely in the prosthodontic fields. It has been applied to fixed partial dentures[2-4], complete dentures[5], and maxillofacial prostheses[6]. It has also contributed greatly, from treatment planning to the definitive prosthetic work, in implant dentistry[7]. Digital dentistry is a field with high future growth potential, though there are some issues that need to be addressed because the field is still evolving.

The essential step on the digital path is digitization of the dentition by digital scanning. Digitization of the dentition was first introduced using an indirect scan of the stone model, and then, recently, direct intraoral scanning, so-called digital impression, has come into the clinic in conjunction with CAD/CAM technology. Intraoral scanners (IOSs) could change the daily routine practice of both dentists and dental technicians. It has been suggested that IOSs may obviate the need for impression trays, impression materials, and stone casts, and shipping to a laboratory will no longer be required[8-11]. The electronic files can be digitally sent and stored saving, time, cost, and space. These fascinating advantages are considered to be quite useful in implant dentistry. Digital implant impressions with IOSs not only do not need impression trays and materials, but also impression copings, so that patients can avoid opening their mouths widely during the impression. Digital impressions can be achieved by optical acquisition for simply connected scan bodies instead of the screw tightening and loosening of impression copings[12]. Obviously, a higher impression accuracy is needed for implant-supported prostheses. Even so, no impression technique could achieve an absolute passive fit[13-15]. As for the conventional implant impressions with open or closed tray technique, despite the fact that deformation of the impression materials and expansion of the stone cast may result in the misfit of the prostheses, successful outcomes have been achieved in clinical practice[16-20]. The biologic tolerance of the bone around the implant could compensate for the misfit[21]. Therefore, a certain amount of misfit is accepted in daily clinical practice.

The aim of the current narrative literature review is to access whether IOSs can be used in implant prosthetic work. The accuracy and operating time with IOSs, as well as safety and patient perception, were evaluated from the clinical perspective.

ACCURACY OF IOSs IN IMPLANT DENTISTRY

Accuracy is defined as the "closeness of agreement between a measured quantity value and a true quantity value of a measurand", and it is expressed by trueness and precision[22,23]. Trueness represents the closeness of the measurement to the accepted reference value, whereas precision represents the closeness of repeated measurement of the same object. The precision of IOSs can be measured easily *in vivo* by repetitive captures of the object and assessment of their reproducibility, whereas the calculation of trueness is slightly difficult. A sophisticated scanner, such as an industrial coordinate measuring machine, is needed to obtain a reliable reference model. The trueness of IOSs is calculated by the closeness of agreement between the measurement result and a true value.

Several studies have compared accuracy with specific mention of trueness and precision of different IOSs in implant dentistry[24-28], as summarized in Table 1. The partial prosthesis and the full arch prosthesis in Table 1 were assumed to be a 3-unit implants-supported bridge and a 6-unit implant-supported bridge from molar to molar region, respectively. Table 1 shows the significant

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Received Aug 29, 2019: Accepted Sep 11, 2019
doi:10.4012/dmj.2019-285 JOI JST.JSTAGE/dmj/2019-285

Journal of prosthodontic research 64 (2020) 109–113

Contents lists available at ScienceDirect

Journal of Prosthodontic Research

journal homepage: www.elsevier.com/locate/jpor

Review

Accuracy and practicality of intraoral scanner in dentistry: A literature review

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ARTICLE INFO

Article history:
Received 8 May 2019
Received in revised form 17 July 2019
Accepted 22 July 2019
Available online 30 August 2019

Keywords:
Intraoral scanner
Desktop scanner
Digital impression
Digital dentistry

ABSTRACT

Purpose: The digitization of the dental field has been vigorously promoted in recent years. An impression using an intraoral scanner is considered to significantly change future dental treatment. The purpose of this review is to evaluate accuracy and practicality of various intraoral scanners and verification method of intraoral scanners.

Study selection: This review was based on articles searched through the MEDLINE and PubMed databases. The main keywords that were employed during the search were "Oral Scanner, Intraoral Scanners, Desktop Scanner, and Digital Impression".

Result: It was reported that illuminance and color temperature affected trueness and precision of intraoral scanners. The repeatability of intraoral scanners indicated the possibility of producing fixed prostheses within the range of being partially edentulous. It is considered difficult to use intraoral scanners in fabricating cross-arch fixed prostheses. However, with intraoral scanners, it may be considered possible to fabricate mouth guards and dentures equivalent to those of desktop scanners. Current intraoral scanner scans are considered more comfortable than traditional impressions that use irreversible hydrocolloid and elastomeric impression materials.

Conclusion: Since the intraoral scanner is an evolving device, further improvement in accuracy is expected in the future. In addition, verification of the accuracy of intraoral scanners must be conducted accordingly.

1. Introduction

The most significant change in the dental field in recent years is, without a doubt, the development of digital dentistry [1–5]. Regarding the fabrication of prostheses, with computer-aided design-computer-aided manufacturing (CAD-CAM) systems, it became possible to mill frameworks designed by a computer and to use aesthetic materials such as alumina and zirconia ceramics, which cannot be cast [6–11]. More recently, fabrication of prostheses using three-dimensional (3D) printing has also been reported [12–17]. In clinical application of final impressions, it has also become possible to employ an intraoral scanner as an alternative to conventional impressions using a vinyl polysiloxane material [11,18–26]. The advantages of digital impressions using an intraoral scanner include it being effective for patients with strong vomiting reflexes, and it being possible to overwrite only the part where the impression is not clear. When considering remaking and polymerizing, it was reported that total clinical treatment time was reduced [27–29]. Recently, data of patients can be transmitted to dental technicians using the Internet, therefore, there is no longer any need to send stone models. Thus, there is no risk of the model breaking in transit. In the field of orthodontics, intraoral scanners are considered to be a paradigm shift as an alternative to irreversible hydrocolloid and polyvinyl siloxane impressions [30]. Most orthodontic treatments require long periods of treatment, and the first diagnostic model needs to be stored during the said period. The digital models acquired from intraoral scanners do not occupy any physical space as in conventional gypsum models, and there is no doubt that the digital model obtained by the intraoral scanner is effective in terms of securing storage space.

Also, digital dentistry, especially digital models, has several benefits, such as quick access to 3D diagnostic information, and transfer of digital data for communication with specialists [30–33]. Intraoral scanners have many advantages as compared to

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https://doi.org/10.1016/j.jpor.2019.07.010
1883-1958/

European Journal of Prosthodontics and Restorative Dentistry (2018) 26, 101-121

Accuracy of Intraoral Scanners: A Systematic Review of Influencing Factors

Keywords

Digital
Impression
Precision
Trueness
Virtual

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Received: 21.08.2017
Accepted: 08.05.2018

doi: 10.1922/EJPRD_01752Abduo21

ABSTRACT

Digital impressions by intraoral scanning (IOS) have become an increasingly popular alternative to conventional impressions. This systematic review aimed to evaluate the accuracy of the available IOS systems for dental impressioning, and to identify the influencing factors on accuracy. The literature search was completed to retrieve all the studies that investigated the IOS accuracy when used to scan teeth. A total of 2305 studies were initially obtained. After applying the inclusion criteria, 32 studies were suitable for the analysis. The following systems were included in the review: Cerec Bluecam, Cerec Omnicam, Cadent iTero, Lava C.O.S, Lava True Definition, TRIOS, TRIOS Color, E4D, Planscan, MHT, Carestream 3500 and Zfx IntraScan. In comparison to conventional impressions, the IOS systems can be reliably used for diagnostic purposes and short-span scanning. However, for whole arch scanning, the IOS is susceptible for more deviation. The studies indicated variable outcome of the different IOS systems. While the accuracy of IOS systems appears to be promising and comparable to conventional methods, they are still vulnerable to inaccuracies. For prosthesis fabrication, the IOS accuracy is enhanced by reducing the span of scanning, and ensuring the scanned surfaces exhibit minimal irregularities.

INTRODUCTION

Dental impression is a routine procedure that is required in many disciplines of dentistry to record the oral tissues. The generated casts are used for diagnostic purpose, treatment planning, or prosthesis and appliance fabrication. In order for the impression to serve its purpose, it has to accurately represent oral tissues of the patient. Inaccurate impression will lead to prosthesis misfit which will eventually cause cement dissolution, loss of prosthesis retention, and rendering the tooth prone to biological problems such as caries.[1,2] In addition, imprecise surface details will prevent precise articulation and occlusion establishment.[3]

Although the conventional impression has been the standard of practice for many decades, it is associated with material preparation, ongoing cost, technical time, potential patient discomfort, and requirements of high clinical skills.[4,5] Regardless of the material and technique, any conventional impression is associated with an inevitable degree of error which is attributed to the number of steps and materials manipulation.[4-6] For example, all impression materials are prone to dimensional distortion through the setting procedure.[6,7] As the impression is removed from the patient's mouth, unavoidable deformation will occur with removing the impression from the undercut areas. Likewise, pouring the impression will further contribute to the distortion during the setting of the stone material. Yet, the potential accuracy problems are offset by the familiarity of taking the impression and pouring it with dental stone.[6]

Computer-Aided Design in Restorative Dentistry

3

Guillermo Pradíes Ramiro, Cristian Abad Coronel, Alberto Ferreiroa Navarro, Bassam Hassan, and Faleh Tamimi

Abstract

As 3D printing, computer-aided machining, and optical scanners keep improving and are becoming more accessible, design software is rapidly becoming the next frontier in digital dentistry. Rapid prototyping technologies in dentistry were initially operated with generic software that was not specifically designed for dental applications. This was very inefficient and a limiting factor for digitalization of dentistry. The arrival of specialized software for different dental applications has made digital dentistry a reality by making it efficient and bringing it to its full potential. This chapter addresses the different types of software that has been developed for restorative dentistry. This includes software for fixed, removable, and implant prosthodontics as well as software for treatment planning.

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Evolution of the Software and Hardware in CAD/CAM Systems used in Dentistry

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ABSTRACT

The computer-aided design/computer-aided manufacturing (CAD/CAM) systems were introduced into dentistry in 1970s. This technology has evolved rapidly that, starting from a single crown to full mouth, rehabilitation is possible in a single day now. This article reviews the history, evolution, components, and various materials used for fabrication of prosthesis. It also evaluates popular CAD/CAM systems, its limitations, future evolvement, and also the dental considerations while using them.

Keywords: CAD/CAM systems, Cerec system, Digitalization tool, Evolution of CAD/CAM, Milling in CAD/CAM.

How to cite this article: Zarina R, Jaini JL, Raj RS. Evolution of the Software and Hardware in CAD/CAM Systems used in Dentistry, Int J Prev Clin Dent Res 2017;4(4):284-291.

Source of support: Nil

Conflict of interest: None

INTRODUCTION

Computer-aided design (CAD) and computer-aided manufacturing (CAM) have become an increasingly popular part of dentistry over the past 25 years.[1] The CAD/CAM technology was developed to solve three challenges. One of the challenges was to fabricate posterior restorations with sufficient strength. The second challenge was to create restorations with a natural appearance. The third challenge was to make restoration easier, faster, and more accurate.[2] With recent versions of CAD/CAM systems it is possible to make half-arch impressions in 40 seconds and full-arch impressions in just 2 minutes. The CAD/CAM also makes designing and fabrication faster that a full-contour crown takes just 6 minutes to mill. Even by experienced technicians it takes multiple days to finish conventional restorations.[3-5]

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HISTORY AND EVOLUTION OF DENTAL CAD/CAM SYSTEMS

1970s saw rapid progress being made in computer-assisted processing technology in various industries and this was reflected in the field of dentistry also. Nickel-chromium alloys became a substitute for gold alloys in 1980s due to increase in the price of gold. But, metal allergies became a problem, especially in northern Europe, and a transition to allergy-free titanium was proposed. The precision casting of titanium was still difficult at that time.[6] There was a strong requirement for an alternative technique. Three pioneers in particular who contributed to the development of dental CAD/CAM systems are Duret, Moermann, and Anderson. Duret developed the Sopha® system, which had an impact on the later development of dental CAD/CAM systems. He produced the first dental CAD/CAM restoration in 1983 and demonstrated his system at the French Dental Association's International Congress in November 1985 by creating a posterior crown restoration for his wife in less than an hour.[5] Sopha system was developed by Duret.[3] Dr Moermann developed the CEREC® system, which was a chairside CAD/CAM. The emergence of this system was very innovative because it allowed same day ceramic restorations. This was a turning point and it spread the term CAD/CAM.[6] The third is Dr Andersson, the developer of the Procera® system in 1983. Procera® system had central processing center with satellite networking centers under this unit. Rekow[7] used photographs and high-resolution scanners to capture the data to mill restorations by a five-axis machine.[6]

COMPONENTS OF CAD/CAM SYSTEM

Digitalization Tool/Scanner

Geometrical data will be transformed into digital data by a digitalization tool to process in a computer. The digitizing accuracy is a major factor, which has an influence on the fit of fixed restoration. Currently, the data acquisition is either performed directly in the patient's mouth (intraoral) or indirectly after taking an impression and fabricating a master cast (extraoral). Triangulation is a procedure by which three-dimensional data will be collected by the computer.[8] Digitalization can be contact digitalization (Fig. 1)[8] or optical digitalization (Fig. 2).[8] A

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

journal homepage: www.elsevier.com/locate/optlaseng

Recent advances in dental optics – Part I: 3D intraoral scanners for restorative dentistry

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ARTICLE INFO

Keywords:
Intraoral scanner
Digital dental impressions
Triangulation
Confocal microscopy
Optical coherence tomography

ABSTRACT

Intra-oral scanning technology is a very fast-growing field in dentistry since it responds to the need of an accurate three-dimensional mapping of the mouth, as required in a large number of procedures such as restorative dentistry and orthodontics. Nowadays, more than 10 intra-oral scanning devices for restorative dentistry have been developed all over the world even if only some of those devices are currently available on the market. All the existing intraoral scanners try to face with problems and disadvantages of traditional impression fabrication process and are based on different non-contact optical technologies and principles. The aim of this publication is to provide an extensive review of existing intraoral scanners for restorative dentistry evaluating their working principles, features and performances.

1. Background

Three-dimensional scanning of the mouth is required in a large number of procedures in dentistry such as restorative dentistry and orthodontics. The aim of the 3D mapping of the oral cavity is to create *digital impressions*.

Restorative dentistry is of course the main field that require the application of very accurate 3D intraoral scanners. For the realization of any dental prosthesis it is necessary to realize three-dimensional mathematical models of the dentition, performing a reverse engineering procedure. Then the prosthesis can be realized by means of CAD/CAM systems.

At present, according to the traditional work flow, this procedure starts at the dentist's office, and the steps leading to prosthesis's creation are as follows:

- the dentist captures the traditional impression by means of impression trays and impression materials;
- the dentist sends the impression tray to the dental laboratory;
- the laboratory's technician pours plaster inside the tray;
- after the hardening he scans the plaster model to have the 3D virtual digital model of the full arch;
- the technician can design the prosthesis by means of CAD/CAM systems and send the file to a milling machine;
- the milling machine produces the prosthesis;
- the prosthesis is applied by the dentist and refined inside the patient's mouth to verify and adjust the occlusion.

Basically, the 3D digital model is used to design the prosthesis and as an input to the program of the milling machine referring to CAD/CAM systems. It can also be used to perform surgery simulations or to build plastic models of the teeth by means of rapid prototyping techniques.

The whole traditional process is often slow and affected by errors. Furthermore, although the traditional impression taking process is very cheap, it is certainly bothering for the patient and, at the present state of the art, definitively obsolete.

By means of devices here described, the dentist can scan the teeth in vivo and he can directly create the virtual 3D model of the dentition. This allows bypassing the dental laboratory for a lot of steps.

According to the state of the art, there are three kinds of workflows in restorative dentistry. The traditional workflow has been described above; it is the oldest and is illustrated in Fig. 1.

Abbreviations: AFI, accordion fringe interferometry; AWS, active wave-front sampling; CAD/CAM, computer aided design/computer aided manufacturing; CLSM or LSCM, confocal laser scanning microscopy; HIPAA, health insurance portability and accountability act; LASER, light amplification by stimulated emission of radiation; LED, light emitting diode; MEMS, micro electro-mechanical system; NA, numerical aperture; OCT, optical coherence tomography; OBJ, alias wavefront technologies file format; PLY, polygon file format or Stanford triangle format; PMT, photo-multiplier tube; SLA, stereo-lithography; S/N or SNR, signal-to-noise ratio; USB, universal serial bus

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0143-8166/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.optlaseng.2013.07.017

Please cite this article as: Logozzo S, et al. Recent advances in dental optics – Part I: 3D intraoral scanners for restorative dentistry. Opt Laser Eng (2013), http://dx.doi.org/10.1016/j.optlaseng.2013.07.017

THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Influence of abutment tooth geometry on the accuracy of conventional and digital methods of obtaining dental impressions

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ABSTRACT

Statement of problem. Direct (intraoral) and indirect (desktop) digital scanning can record abutment tooth preparations despite their geometry. However, little peer-reviewed information is available regarding the influence of abutment tooth geometry on the accuracy of digital methods of obtaining dental impressions.

Purpose. The purpose of this in vitro study was to evaluate the influence of abutment tooth geometry on the accuracy of conventional and digital methods of obtaining dental impressions in terms of trueness and precision.

Material and methods. Crown preparations with known total occlusal convergence (TOC) angles (−8, −6, −4, 0, 4, 8, 12, 16, and 22 degrees) were digitally created from a maxillary left central incisor and printed in acrylic resin. Each of these 9 reference models was scanned with a highly accurate reference scanner and saved in stereolithography (STL) format. Then, 5 conventional polyvinyl siloxane (PVS) impressions were made from each reference model, which was poured with Type IV dental stone scanned using both the reference scanner (group PVS) and the desktop scanner and exported as STL files. Additionally, direct digital impressions (intraoral group) of the reference models were made, and the STL files were exported. The STL files from the impressions obtained were compared with the original geometry of the reference model (trueness) and within each test group (precision). Data were analyzed using 2-way ANOVA with the post hoc least significant difference test (α=.05).

Results. Overall trueness values were 19.1 µm (intraoral scanner group), 23.5 µm (desktop group), and 26.2 µm (PVS group), whereas overall precision values were 11.9 µm (intraoral), 18.0 µm (PVS), and 20.7 µm (desktop). Simple main effects analysis showed that impressions made with the intraoral scanner were significantly more accurate than those of the PVS and desktop groups when the TOC angle was less than 8 degrees (P<.05). Also, a statistically significant interaction was found between the effects of the type of impression and the TOC angle on the precision of single-tooth dental impressions (F=2.43, P=.002). Visual analysis revealed that the intraoral scanner group showed a homogeneous deviation pattern across all TOC angles tested, whereas scans from the PVS and desktop scanner groups showed marked local deviations when undercuts (negative angles) were present.

Conclusions. Conventional dental impressions alone or those further digitized with an extraoral digital scanner cannot reliably reproduce abutment tooth preparations when the TOC angle is close to 0 degrees. In contrast, digital impressions made with intraoral scanning can accurately record abutment tooth preparations independently of their geometry. (J Prosthet Dent 2016;■:■-■)

Direct digital methods of obtaining dental impressions were introduced into the dental field in the 1980s.[1] These systems evolved rapidly because of improvements in computing processing power, graphic rendering, and display screens that are now capable of capturing and storing high quality 3-dimensional (3D) virtual images of tooth preparations or dental casts from which restorations can be fabricated.[2] Also, a number of companies offer intraoral scanners that are increasingly user-friendly, perceived as pleasant for the patient,[3,4] accurate when recording short-span areas,[5-9] time efficient,[10] and capable of producing well-fitting restorations.[11] However, among

Intraoral scanner provided by the Japanese branch in Kyoto of 3Shape Copenhagen, Denmark. Previously presented as a poster and awarded first prize at the Annual Meeting of the Korean Academy of Esthetic Dentistry, Seoul, South Korea, December 2015.
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Accuracy of an intraoral digital impression: A review

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Abstract Intraoral scanners (IOSs) are used for capturing the direct optical impressions in dentistry. The development of three-dimensional technology and the trend of increasing the use of IOSs in dental office routine lead to the need to assess the accuracy of intraoral digital impressions. The aim of this review was to assess the accuracy of the different IOS and the effect of different variables on the accuracy outcome. An electronic search using PubMed with specific keywords to obtain potential references for review. A search of MEDLINE (PubMed) identified 507 articles. After title and abstract screening, 412 articles were excluded for not meeting the inclusion criteria and discarding duplicate references. Ninety-five articles were followed for full screening; only 24 articles were included in the final analysis. The studies indicated a variable outcome of the different IOS systems. While the accuracy of IOS systems appears to be promising and comparable to conventional methods, they are still vulnerable to inaccuracies.

Keywords: Accuracy, digital impression, intraoral scanner, optical impression

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Received: 04th September, 2019, **Revision:** 30th October, 2019, **Accepted:** 2nd January, 2020, **Publication:** 27th January, 2020

INTRODUCTION

Progress in digital dentistry has not only popularized the concepts of computer-aided design (CAD) and computer-aided manufacturing (CAM) but also created the provision for more efficacious and predictable therapeutic outcomes.

Obtaining three-dimensional images have accentuated the accuracy of the conventional prosthetic options and also provides for the virtual definition of various treatment strategies and to digitally design and fabricate varied types of restorations. Based on the type of tissue scanned, various principles and technologies have been developed and are being applied. The predicaments associated with conventional impression procedures have further highlighted the applications of intraoral scanners (IOSs). The intraoral digital scanning has been perceived as a more rapid and convenient technique from the perspective of both the dentists and the patients.[1]

Digital intraoral scanning has provided numerous benefits such as real-time visualization, easy repeatability, selective capture of the relevant areas, no need to disinfect and clean dental impressions and impression trays, cast pouring, no wear of the model, rapid communication and availability.[2-8]

Many CAD-CAM systems are available in the market for chairside digital impression and prosthesis fabrication.[9-12] Different IOSs by the numbers of company are increasing

Access this article online

Quick Response Code:

Website: www.j-ips.org

DOI: 10.4103/jips.jips_327_19

How to cite this article: Aswani K, Wankhade S, Khalikar A, Deogade S. Accuracy of an intraoral digital impression: A review. J Indian Prosthodont Soc 2020;20:27-37.

updates

Impression Materials and Techniques

22

Jenna Trainor, Andrew Keeling, and Robert Wassell

22.1 Learning Points

This chapter will emphasise the need to:

- Ensure your technician can feedback on defective impressions
- Choose an appropriate impression material based on an understanding of its properties
- Wash and disinfect impressions before sending them to the laboratory
- Identify impression defects and have strategies to remedy them
- Differentiate between impression techniques for cement- and screw-retained implant crowns
- Decide on what technical basis to buy a digital impression scanner.

22.2 Introduction

'First impressions count', thought the fourth-year student waiting endlessly for an impression to set. Then heartsink, after a cursory glance the teacher reminded him 'Inaccurate impressions lead to poorly fitting restorations'. That's how it is at dental school. In practice, it is up to you.

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Hindawi
Journal of Healthcare Engineering
Volume 2017, Article ID 8427595, 9 pages
https://doi.org/10.1155/2017/8427595

Review Article

Intraoral Scanner Technologies: A Review to Make a Successful Impression

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Received 24 January 2017; Accepted 19 June 2017; Published 5 September 2017

Academic Editor: Md. A. R. Ahad

To overcome difficulties associated with conventional techniques, impressions with IOS (intraoral scanner) and CAD/CAM (computer-aided design and manufacturing) technologies were developed for dental practice. The last decade has seen an increasing number of optical IOS devices, and these are based on different technologies; the choice of which may impact on clinical use. To allow informed choice before purchasing or renewing an IOS, this article summarizes first the technologies currently used (light projection, distance object determination, and reconstruction). In the second section, the clinical considerations of each strategy such as handling, learning curve, powdering, scanning paths, tracking, and mesh quality are discussed. The last section is dedicated to the accuracy of files and of the intermaxillary relationship registered with IOS as the rendering of files in the graphical user interface is often misleading. This overview leads to the conclusion that the current IOS is adapted for a common practice, although differences exist between the technologies employed. An important aspect highlighted in this review is the reduction in the volume of hardware which has led to an increase in the importance of software-based technologies.

1. Introduction

Since the eighteenth century, conventional impression techniques have been used to register the three-dimensional geometry of dental tissues. Nevertheless, volumetric changes of impression materials and expansion of dental stone seem error-prone, and thus the process requires the services of an excellent dental laboratory [1–3]. To overcome these difficulties, impression with IOS (intraoral scanner) was developed for dental practice [4]. The implementation of the IOS device in dental practices coincided with the development of CAD/CAM (computer-aided design and manufacturing) technology in dentistry, with numerous advantages for practitioners. Nowadays, IOS and CAD/CAM provide easier planning of treatment, case acceptance, communication with laboratories, reduced operative time, storage requirements, and reduced treatment times [5–7]. The last decade has seen an increasing number of optical IOS, and these are based on different technologies; the choice of which may impact on clinical use [6].

To allow the practitioner to make an informed choice before purchasing or renewing an IOS, this article is divided in three distinct parts. The first presents the different technologies employed by the current IOS for the capture of image and the generation of a digital file by the software, the second

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ScienceDirect

Procedia Engineering 100 (2015) 1174 – 1181

Procedia Engineering

www.elsevier.com/locate/procedia

25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014

Development of High Speed and High Accuracy 3D Dental Intra Oral Scanner

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Abstract

3D digitization technology, commonly known as Intra oral scanning method is a modern approach than traditional impression methods in dentistry. Utilization of 3D digitization results in accurate mapping of oral cavity and eliminates number of procedures for making dental prosthesis. This paper unveils design of 3D dental oral scanner with software integration is proposed for high speed and accuracy. The main parts of the system are Intra-Oral Scanning (IOS) hardware, CPU and display monitor. The IOS hardware is designed using non-contact optical technologies based on the principle of confocal laser scanner microscopy results in high speed scanning. The light intensity is detected by photo-detection device, transforming the light signal into an electrical one which is recorded by a computer and can be reconstructed. The software is designed using merging of active triangulation method, surface reconstruction and Image processing tools, results in high accurate 3D image of oral cavity, which will be displayed on the monitor screen.

Peer-review under responsibility of DAAAM International Vienna

Keywords: 3D digitization; prosthesis; Intra-Oral Scanning; Confocal laser scanner microscopy; Surface reconstruction

1. Introduction

Three-dimensional scanning of an oral cavity in Orthodontics and restorative dentistry is required for an accurate mapping which sequels in the elimination of long procedures. The main goal of using this 3D digitization

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Peer-review under responsibility of DAAAM International Vienna
doi:10.1016/j.proeng.2015.01.481

Digitalization in Restorative Dentistry

2

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Abstract

Digitalization is the first step involving a digital restorative dentistry workflow. Although the digitalization process was initially confined to CAD/CAM (computer-aided design/computer-aided manufacturing) dental procedures, nowadays a much wider range of dental procedures have been revolutionized by their ongoing digitalization. Digitalization consists basically of converting any physical 2D or 3D volume into an electronic information language codified in terms of only two possible digits (0 or 1) normally contained in an informatic file.

The number of digitalized procedures and devices that have been incorporated into restorative dentistry is substantially growing. Digital photograph cameras,

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F. Tamimi, H. Hirayama (eds.), *Digital Restorative Dentistry*,
https://doi.org/10.1007/978-3-030-15974-0_2

DENTAL MATERIALS 28 (2012) 3–12

Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: www.intl.elsevierhealth.com/journals/dema

The future of dental devices is digital

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ARTICLE INFO

Article history:
Received 24 October 2011
Accepted 24 October 2011

Keywords:
Dental devices
CAD–CAM
Intra-oral scanners
Subtractive machining
Additive processing
FDM
SLA
SLM
Inkjet printing

ABSTRACT

Objectives. Major changes are taking place in dental laboratories as a result of new digital technologies. Our aim is to provide an overview of these changes. In this article the reader will be introduced to the range of layered fabrication technologies and suggestions are made how these might be used in dentistry.

Methods. Key publications in English from the past two decades are surveyed.

Results. The first digital revolution took place many years ago now with the production of dental restorations such as veneers, inlays, crowns and bridges using dental CAD–CAM systems and new improved systems appear on the market with great rapidity. The reducing cost of processing power will ensure that these developments will continue as exemplified by the recent introduction of a new range of digital intra-oral scanners. With regard to the manufacture of prostheses this is currently dominated by subtractive machining technology but it is inevitable that the additive processing routes of layered fabrication, such as FDM, SLA, SLM and inkjet printing, will start to have an impact. In principle there is no reason why the technology cannot be extended to all aspects of production of dental prostheses and include customized implants, full denture construction and orthodontic appliances. In fact anything that you might expect a dental laboratory to produce can be done digitally and potentially more consistently, quicker and at a reduced cost.

Significance. Dental device manufacturing will experience a second revolution when layered fabrication techniques reach the point of being able to produce high quality dental prostheses. The challenge for the dental materials research community is to marry the technology with materials that are suitable for use in dentistry. This can potentially take dental materials research in a totally different direction.

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0109-5641/$ – see front matter © 2011 Academy of Dental Materials. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.dental.2011.10.014

CAD/CAM in-office technology

Innovations after 25 years for predictable, esthetic outcomes

Daniel J. Poticny, DDS; James Klim, DDS

Innovations and improvements to the CEREC Acquisition Center (AC) with Bluecam system (Sirona Dental Systems, Charlotte, N.C.) and to the materials supporting it have made it possible for dentists to produce esthetic restorations rapidly that are reliable and predictable for a wide range of applications. The CEREC system was introduced in 1985 and was the first to use the chairside computer-aided design/computer-aided manufacturing (CAD/CAM) concept. Another CAD/CAM system, E4D Dentist (D4D Technologies, Richardson, Texas), was introduced in 2008. CEREC AC and E4D Dentist are capable of producing almost any type of single-unit ceramic or composite restoration and have contributed to the growth of in-office CAD/CAM. Because Sirona was the originator of this technology and nearly all of the global clinical evidence regarding CAD/CAM systems is about CEREC AC, in this article, we focus on innovations in CEREC AC and the materials that support its use.

Since 1985, more than 27,000 CEREC units have been installed for in-office use in more than 50 countries. Dentists have placed more than 20 million restorations produced with these units. CAD/CAM is part of many dental schools' curricula. CEREC AC's laboratory counterpart (CEREC inLab, Sirona Dental Systems) is used routinely by 4,500 dental laboratories worldwide, and 7.5 million restorations are produced annually with CEREC AC and inLab (written communication, J. Bizzell, marketing manager, clinical CAD/CAM, Sirona Dental Systems, April 2010). Although CAD/CAM is innovative, it differs from traditional treatment and manufacturing methods and has been one of the most critically examined restorative dental procedures despite its record of success. The results of a 2001 review of the literature showed that restorations made with CAD/CAM performed better than any other restorative material and equivalent to cast gold for restorations of the same type.[1] On the basis of the number of

ABSTRACT

Background. The in-office application of computer-aided design/computer-aided manufacturing (CAD/CAM) has evolved continually across 25 years, and material enhancements made in conjunction with this evolution have improved the speed and precision with which dentists can place high-quality, esthetic restorations for almost every dental application.

Methods. The authors present an overview of the CEREC Acquisition Center (AC) with Bluecam system (Sirona Dental Systems, Charlotte, N.C.) and available materials.

Results. On the basis of the growth of CAD/CAM, the manufacturer has made substantial improvements to all aspects of the CEREC AC system—including hardware, software and materials—during the past 25 years.

Conclusion. Dentists can create laboratory-grade restorations in their offices with little disturbance to work-flow patterns. This is possible, because of innovations to the system that make CAD/CAM feasible for most dental practices.

Key Words. CAD/CAM; work flow; ceramics; lithium disilicate.

JADA 2010;141(6 suppl):5S-9S.

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The Use of CAD/CAM in Dentistry

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KEYWORDS

• CAD/CAM • CEREC • E4D • iTero • Lava COS
• Dental laboratory

Computer-aided design (CAD) and computer-aided manufacturing (CAM) have become an increasingly popular part of dentistry over the past 25 years.[1] The technology, which is used in both the dental laboratory and the dental office, can be applied to inlays, onlays, veneers, crowns, fixed partial dentures, implant abutments, and even full-mouth reconstruction. CAD/CAM is also being used in orthodontics.

CAD/CAM technology was developed to solve 3 challenges. The first challenge was to ensure adequate strength of the restoration, especially for posterior teeth. The second challenge was to create restorations with a natural appearance. The third challenge was to make tooth restoration easier, faster, and more accurate. In some cases, CAD/CAM technology provides patients with same-day restorations.

Dentists and laboratories have a wide variety of ways in which they can work with the new technology. For example, dentists can take a digital impression and send it to a laboratory for fabrication of the restorations or they can do their own computer-aided design and milling in-house.

When laboratories receive a digital impression, they can create a stone model from the data and either continue with traditional fabrication or rescan the model for milling. Alternatively, the laboratory can do all of the design work directly on the computer based on the images received.

This article discusses the history of CAD/CAM in dentistry and gives an overview of how it works. It also provides information on the advantages and disadvantages, describes the main products available, discusses how to incorporate the new technology into your practice, and addresses future applications.

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Dent Clin N Am 55 (2011) 559–570
doi:10.1016/j.cden.2011.02.011 dental.theclinics.com

The CEREC system
25 years of chairside CAD/CAM dentistry

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In September 1985 at the University of Zurich Dental School, Mörmann[1] placed the first chairside ceramic restoration with the CEREC 1 system (Sirona Dental Systems, Charlotte, N.C.) by using computer-aided design/computer-aided manufacturing (CAD/CAM) technology. At the time, it was a revolutionary concept for restorative dentistry that an industrially made ceramic material could be fabricated chairside by using a milling device with the benefits of a direct restorative treatment modality. As with any new concept, there were many questions about the viability of such a radical restorative technique and its acceptance by dentists.

The year 2010 marks 25 years of chairside CAD/CAM experience in dental practice. The restorative materials and clinical technique have been studied extensively as they have evolved. In a recent search of the word "CEREC" on PubMed, I found 402 studies referenced.

In recognition of 25 years of CAD/CAM in the dental office, this supplement presents four articles that describe some of the latest techniques and innovative materials available for chairside CAD/CAM dentistry in 2010.

The CEREC system has evolved through a series of software and hardware upgrades since its introduction to the dental marketplace as the CEREC 1 system. There have been several significant changes in the system since its introduction. The separation of the milling chamber from the image capture and design hardware led to a significant improvement in clinical efficiency by allowing for simultaneous design of one restoration while milling a second one. The change from a two-dimensional design program to a three-dimensional (3-D) design program occurred as the speed and memory of computers improved. The introduction of the 3-D software substantially improved the immediate understanding of the 3-D program because dentists were able to view the designs in a way similar to what they were used to seeing with stone models. 3-D design also improved the clinical work flows of chairside system use. The most recent evolution, the CEREC Acquisition Center (Sirona Dental Systems) unit, has introduced a newly developed light-emitting diode (LED) camera called the Bluecam. This camera is based on a blue LED that replaces the infrared-emitting camera in the CEREC Acquisition Unit (Sirona Dental Systems) system. In the first article in this supplement, Poticny and Klim[2] discuss the Bluecam and other work-flow improvements for chairside delivery of ceramic restorations.

The evolution of the software and hardware for the CEREC system is mirrored by developments in the materials available. Ivoclar Vivadent (Amherst, N.Y.) introduced a lithium disilicate restorative material (IPS e.max CAD) that initially was designed to be used in the dental laboratory as a coping material that was more translucent than zirconia. It then became available in a variety of shades and several translucencies for use in esthetic full-contour, chairside restorations. Other available ceramic materials for chairside CAD/CAM require adhesive luting agents for bonding of the restorations to achieve clinical success. The enhanced strength of the

ABBREVIATION KEY. CAD/CAM: Computer-aided design/computer-aided manufacturing. **LED:** Light-emitting diode. **3-D:** Three-dimensional.

Received: 09th October 2014 Accepted: 28th January 2015 Conflicts of Interest: None

Source of Support: Nil

Review Article

Assessment of Chair-side Computer-Aided Design and Computer-Aided Manufacturing Restorations: A Review of the Literature

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How to cite the article:
Baroudi K, Ibraheem SN. Assessment of chair-side computer-aided design and computer-aided manufacturing restorations: A review of the literature. J Int Oral Health 2015;7(4):96-104.

Abstract:

Background: This paper aimed to evaluate the application of computer-aided design and computer-aided manufacturing (CAD-CAM) technology and the factors that affect the survival of restorations.

Materials and Methods: A thorough literature search using PubMed, Medline, Embase, Science Direct, Wiley Online Library and Grey literature were performed from the year 2004 up to June 2014. Only relevant research was considered.

Results: The use of chair-side CAD/CAM systems is promising in all dental branches in terms of minimizing time and effort made by dentists, technicians and patients for restoring and maintaining patient oral function and aesthetic, while providing high quality outcome.

Conclusion: The way of producing and placing the restorations made with the chair-side CAD/CAM (CEREC and E4D) devices is better than restorations made by conventional laboratory procedures.

Key Words: chair-side restoration, computer-aided design and computer-aided manufacturing, digital dentistry

Introduction

The idiom "CAD/CAM" in dental technology is an abbreviation for "computer-aided design" and "computer-aided manufacturing," used to improve the design and creation of dental restorations including crowns, veneers, inlays and onlays, fixed bridges, implants, dentures, and orthodontic appliances. Early efforts of this technology were in the mid-1980s. Dr. Mörmann developed CEREC system; an innovative approach to make same day restorations in the dental clinic at the chair-side.[1] Historically, the CEREC System (Sirona) was the first chair-side CAD/CAM system in dentistry and is currently available in its third product generation. In 2006, Mörmann pointed out that the concept of CEREC CAD/CAM is becoming an important part of dentistry.[2]

CAD/CAM Components

The CAD/CAM systems consist of three major components. The first component is a digitalization tool/scanner, which converts geometry to digital information that can be processed by the computer. The second component is software, which processes information, depending on the application, provides information and data of the product intends to manufacture. The third component is a milling device/production technology that converts the information into the specific product.[2]

CAD/CAM Systems

The available advanced CAD/CAM systems can be divided into the following three groups based on their production methods:[3]

- In office system: Where a dentist digitally scans the prepared tooth, creates restorations chair-side, and then seats it within a single appointment.
- In lab system: Where laboratories could scan models made from physical impressions and use CAD/CAM to produce restorations.
- Centralized production: Where a dentist captures chair-side digital impressions then sent data via the internet to the laboratory.

The current existing in-office systems with chair-side milling machines are the CEREC from (Sirona Dental; Charlotte, NC) and E4D from (D4D Technologies; Richardson, TX). Chair-side digital impression systems with transfer of images to the laboratory include the iTero, CEREC and Lava C.O.S. systems. The scanned data can be exported to a laboratory (via CEREC AC Connect or E4D Sky) to have more complicated or advanced restorations fabricated.[3]

Chair-side CAD/CAM Materials

Several of materials are available for chair-side CAD/CAM restorations, which achieved predictability and longevity. All blocks are either monochromatic or polychromatic form for chair-side CAD/CAM restorations. Studies have proved their predictability and longevity. These materials include esthetic and high-strength ceramics, composite resins, and nanoceramics, which facilitate handling and finishing. Innovations in the CEREC AC system involving the use of

3D printing in dentistry

A. Dawood,*[1] B. Marti Marti,[1] V. Sauret-Jackson[2] and A. Darwood[3]

IN BRIEF

- Discusses the latest technologies in 3D imaging and printing that can be applied in dentistry.
- Suggests these technologies could be used in daily practice.

PRACTICE

3D printing has been hailed as a disruptive technology which will change manufacturing. Used in aerospace, defence, art and design, 3D printing is becoming a subject of great interest in surgery. The technology has a particular resonance with dentistry, and with advances in 3D imaging and modelling technologies such as cone beam computed tomography and intraoral scanning, and with the relatively long history of the use of CAD CAM technologies in dentistry, it will become of increasing importance. Uses of 3D printing include the production of drill guides for dental implants, the production of physical models for prosthodontics, orthodontics and surgery, the manufacture of dental, craniomaxillofacial and orthopaedic implants, and the fabrication of copings and frameworks for implant and dental restorations. This paper reviews the types of 3D printing technologies available and their various applications in dentistry and in maxillofacial surgery.

INTRODUCTION

The term 3D printing is generally used to describe a manufacturing approach that builds objects one layer at a time, adding multiple layers to form an object. This process is more correctly described as additive manufacturing, and is also referred to as rapid prototyping.[1,2]

3D printing technologies are not all new; many modalities in use today were first developed and used in the late 1980s and 1990s[3] the author first treated a patient with the help of 3D printing in 1999 (Fig. 1).

The term '3D printing', however, is relatively new, and has captured the public imagination. A great deal of hype surrounds the use of 3D printing which is hailed as a disruptive technology that will forever transform manufacturing. We have seen headlines in the international press describing the use of 3D printing to produce everything from fashion wear and architectural models to armaments (Fig. 2). However, the reality is different; 3D printed underwear would today be uncomfortable and 3D printed guns are dangerous – to the individual firing them. While we are very many

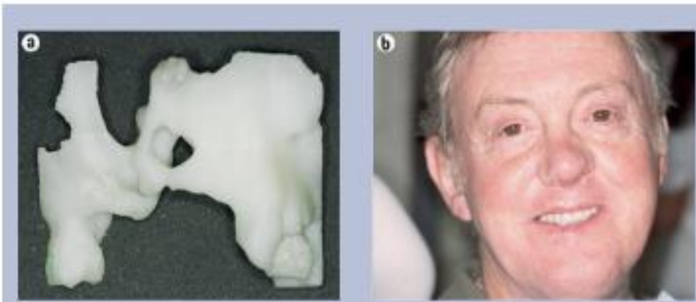

Fig. 1 The first patient treated by the author with the help of 3D printing in 1999. (a) Frontal view of the 3D printed medical model, printed with FDM technology, which shows the complex anatomy of the patient's cleft palate, before implant placement. (b) A recent image of the patient with implant supported bridgework in place

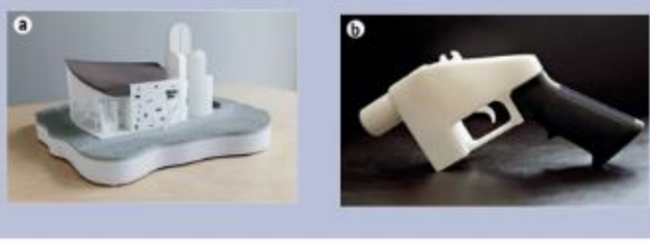

Fig. 2 (a) A 3D printed colour plaster architectural model of one of the most iconic examples of twentieth-century religious architecture designed by Le Corbusier. Model printed by digits2widgets.com. Photograph Chris Sullivan. (b) 3D printed gun. Production file controversially disseminated on the internet by American Cody Wilson, produced by digits2widgets.com for London's Victoria and Albert Museum collection

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Refereed Paper
Accepted 6 October 2015
DOI: 10.1038/sj.bdj.2015.914
©British Dental Journal 2015; 219: 521–529

Dental CAD/CAM systems

A 20-year success story

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The stage was set for exciting advances in dentistry in the 1950s and 1960s when prototypes of computer-aided design (CAD) and computer-aided manufacturing (CAM) were introduced into industrial settings.[1] In those applications, the geometry of the "parts" was simpler than that generally needed for dental restorations, but the same techniques could be applied to creating dental crowns.

Early dreamers like Mörmann,[2] Duret and colleagues[3] and me[4] were intrigued by the possibilities. But the road was far less smooth than any of us imagined. Computing power was limited; a gigabyte drive was unheard of, yet design of the complex geometries of crowns was computationally intensive. CAM systems were large, and the thought of having a desktop milling machine was laughable. Equipment companies perceived that dental CAD/CAM systems would be like cameras for which revenue would be driven by selling the materials like film. Simultaneously, the material companies perceived that the systems were equipment and beyond the scope of their product line. Perseverance, however, paid off. The dreamers continued to work, and CAD/CAM systems are now part of everyday dentistry.

In this supplement, you will read about the success of one of the systems that emerged as an effective in-office automated system known as the CEREC system (Sirona Dental Systems GmbH, Bensheim, Germany), though much of what you read will apply to any CAD/CAM system. The CEREC system has been available commercially for 20 years, is used by more than 17,000 dentists and in 28 dental schools in the United States, and has produced approximately 12 million restorations. In the first article of this supplement, Mörmann[5] chronicles the evolution of his idea into a series of increasingly robust systems.

At first blush, the thought of machining a brittle material like dental ceramics was ridiculous. But as Giordano[6] describes in the second article of this supplement, innovations in materials created esthetic materials that could withstand potential damage introduced by CAD/CAM operations. When created with an in-office CAD/CAM system, esthetic restorations provided in a single appointment are a reality.

But can an automatically produced restoration fabricated in the dental office perform as well and deliver the same esthetics as those created by skilled artist technicians? In the third article of this supplement, Fasbinder[7] reviews the literature pertaining to performance of CEREC-generated restorations. He provides insight into the types of restorations that could be produced over time and the successful fit, esthetics and survival of ceramic restorations produced in the dental office.

While thousands of dentists have incorporated CAD/CAM systems into their offices, there still are many dentists who have not. In the fourth article of this supplement, Trost and colleagues[8] summarize the practice management considerations, providing guidance for clinicians to make informed decisions about incorporating the technology into their own practices. While this article focuses on decisions relating to the CEREC system, the same kinds of considerations will apply to future in-office systems. In this month's issue of JADA, Strub and colleagues[9] have summarized how CEREC's successes have catalyzed the development of other systems.

Without question, the dreams of automation have had an irreversible impact on dentistry. With in-office systems, esthetic,

CAD/CAM imaging in dentistry

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CAD/CAM (computer-assisted design/computer assisted manufacturing), although devised 20 years ago, has only been available for routine dental practice for 2 years. As a supplement to the conventional methods for making dental prostheses, CAD/CAM will have profound effects on the dental profession. CAD/CAM will improve versatility, accuracy, and cost effectiveness and will be a part of routine dental practice by the beginning of the 21st century.

Current Opinion in Dentistry 1991, 1:150–154

A dental prosthesis is designed to reconstruct, partially or totally, the portions of the oral-facial complex using manufactured products. For over 200 years, the fabrication process has undergone constant evolution leading to progressively more excellent results, but requiring rather awkward operations. Traditional methods, such as making the impression, pouring the cast, waxing, and casting, remain rather fundamental. Dental CAD/CAM (computer-assisted design/computer-assisted manufacturing) offers an extraordinary opportunity to introduce into dentistry the most modern techniques from physical science and mathematics. Although devised 20 years ago, CAD/CAM has only been available for routine dental practice for 2 years. A review of the evolution of dental CAD/CAM will indicate how this new technology has grown and demonstrate some of its capabilities. Although CAD/CAM currently has daily application, the first results indicate substantial future development that will have a profound effect on the dental profession.

Description of CAD/CAM

Dental CAD/CAM is the application of computer-assisted design and manufacture to dentistry. To this has been added a first step of capturing information, analogous to making an impression. CAD/CAM systems are technically complex instruments whose operation involves three distinct steps: gathering information, designing the restoration, and fabricating the restoration.

The first step: collection of information

The first step, which for a long time has been the specialty of dental CAD/CAM, is the collection of the maximum amount of intraoral information in association with certain diagnostic and therapeutic elements. This guarantees correct software function and the creation of an individualized prosthesis.

After preparation of the area to be treated, the dentist makes the optical reading or measurement using an electromechanical or electrooptical capture device, either directly in the mouth, or indirectly on a cast. Most CAD/CAM methods use the metrological properties of the laser beam for measuring, and those of the charged coupled device camera for reading. Even though some methods substitute the use of a micropalpation device for the camera, or use a second charged coupled device instead of the laser, these systems remain quite similar for the most part. The laser or "structured" lights [1] can be represented by the projection of a fine fringe or one of several screens whose superimposition allows one to obtain particular physical phenomena, such as Moire, and assures three-dimensional recognition of the object. Irrespective of the method of imaging, this measurement leads to the three-dimensional capture of a cloud or pattern of points representative of the object and referenced in space. This does not differ much from the traditional method, in which the stone cast serves as a storage of information, and does not require any prior knowledge of the relative position of each point that constitutes the surface. The second part of this first step consists of indicating on the digitized object and reconstructing on the video screen a certain number of points and information whose specific identification is crucial to the fabrication of the prosthesis (contact areas, physical boundaries, identification of occlusal determinants, and others). This operation, conducted by the practitioner, will be followed by calculation of the surface topography and correlation of multiple views if more than one image has been made.

Abbreviations

CAD—computer-assisted design; **CAM**—computer-assisted manufacturing.