

Intraoral Digital Impression Technique: A Review

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Abstract

With the techniques of computer-aided design and computer-aided manufacturing (CAD/CAM) being applied in the field of prosthodontics, a concept of intraoral digital impressions was put forward in the early 1980s. It has drawn comprehensive attention from dentists and has been used for dental prosthesis fabrication in a number of cases. This new digital impression technique is expected to bring about absolute digitization to the mode of prosthodontics. A few published articles have indicated that dental prostheses fabricated from intraoral digital impressions have exhibited remarkable advantages over those from conventional impressions in several respects. The present review discusses intraoral digital impression techniques in terms of the following aspects: (1) categories and principles of intraoral digital impression devices currently available; (2) operating characteristics of the devices; and (3) comparison of the manipulation, accuracy, and repeatability between intraoral digital impression and conventional impression.

With electronic technology, digital technology, and advanced manufacturing technology being applied in the field of dentistry, digitization in diagnosis and treatment has become a major trend in prosthodontics. Computer-aided design and computer-aided manufacturing (CAD/CAM) have been employed in the fabrication of restorations, especially ceramic crowns and fixed dental prostheses (FDPs), since the 1980s.¹ A few published articles have indicated that dental prostheses fabricated from intraoral digital impressions have exhibited remarkable advantages over those from conventional impressions in several respects.²⁻⁴

Many CAD/CAM systems are now available for design and production of restorations based on conventional silicone impressions.⁵ In these cases, a plaster cast is made from the silicone impression and is sent for extraoral scanning, where the plaster cast is fixed on the extraoral scanner platform. Although the accuracy of extraoral scanning is adequate, the intraoral outline depictive process of a conventional impression is hard to perfectly reproduce due to the deformation of impression materials and plaster. Therefore, the inadequate precision of plaster casts is not optimal for completing CAD/CAM procedures. In

contrast, direct intraoral digital impressions can avoid errors more than a conventional impression can. Additionally, this saves time for making conventional impressions and plaster models and lowers the cost of materials. Recent developments in the field of intraoral digital impression offer great progress. Several outstanding intraoral scanning systems were generated during the past two decades. An increasing number of fixed prostheses are now manufactured with intraoral digital impressions, which have become a pivotal part of the digitization of prosthodontics.⁶

CAD/CAM systems are composed of three major parts: (1) a data acquisition unit, which collects the data from the region of the preparation teeth and neighboring structures and then converts them to virtual impressions (an optical impression is created at this moment directly or indirectly); (2) software for designing virtual restorations anchored in virtual impressions and setting up all the milling parameters; and (3) a computerized milling device for manufacturing the restoration with solid blocks of the chosen restorative material.⁶ The first two parts of the system play roles in the CAD phase, while the third is responsible for the CAM phase.

CAD/CAM systems can be divided into two types based on digital data sharing capacity: open and closed.⁷ Closed systems offer all CAD/CAM procedures, including data acquisition, virtual design, and restoration manufacturing. All the steps are integrated in the unique system. There is no interchangeability between different systems. Open systems allow the adoption of original digital data by other CAD software and CAM devices.

There are still several obstacles and deficiencies to address in intraoral digital impressions. Some systems need a layer of powder spray on the tooth surface, and the inhomogeneous powder thickness may slightly transfigure the tooth outline. Another major problem is scanner displacement during the scanning process, which may affect scanning accuracy.

This article reviews the characteristics of some major intraoral digital impression devices currently available, and focuses on categories, principles, and operation. We also discuss the differences between intraoral digital and conventional impressions.

Categories, principles, and operating characteristics

The main intraoral digital impression systems currently available on the market include CEREC, Lava C.O.S. system, iTero, E4D, and TRIOS. They vary from each other in terms of key features such as working principle, light source, the necessity of powder coat spraying, operative process, and output file format.

CEREC system

The CEREC 1 system (Sirona, Bensheim, Germany) was brought to market in 1987 together with the Duret system as the first intraoral digital impression and CAD/CAM device.⁸ This system is designed with the concept of “triangulation of light,” in which the intersection of three linear light beams is focused on a certain point in 3D space.¹ Surfaces with uneven light dispersion adversely reduce the accuracy of scans. Therefore, adoption of an opaque powder coating of titanium dioxide is required for producing uniform light dispersion and increasing scan accuracy.⁹

Currently, the most prevalent CEREC system is its fourth-generation product, known as CEREC AC Bluecam. It captures images using a kind of visible blue light emitted from an LED blue diode as its light source. The CEREC AC Bluecam can capture one quadrant of the digital impression within 1 minute and the antagonist in a few seconds. The newest CEREC system, CEREC AC Omnicam, was brought to market in 2012. The Omnicam imaging technique is a style of continuous imaging, where consecutive data acquisition generates a 3D model, whereas Bluecam imaging is a single image acquisition. Omnicam can be used for a single tooth, quadrant, or full arch, but Bluecam can only be applied for a single tooth or quadrant. Powder-free scanning and precise 3D images with natural color are the most prominent features of Omnicam. The powder-free feature has particular benefits for a larger scanning area.¹⁰

Tooth surfaces with uneven light dispersion adversely reduce the accuracy of scans. Accordingly, it is wise to make an opaque powder coating of titanium dioxide before scanning to induce uniform light dispersion and improve scan efficacy.¹¹ When

digitally scanning, the dentist holds the scanner and aims the camera towards the scanned area. The camera tip should be a few millimeters away from the tooth surface or should just slightly touch the surface.⁶ The dentist is asked to slide the camera head over the teeth in a single direction gently so as to generate the successive data into a 3D model. This seamless scanning process can express a notable depth of field. In addition, the scan can be interrupted and resumed at any time by the operator. A new technology of shake detection system can ensure the 3D images are only captured when the camera is stable and still, so it can avoid any possible inaccurate data due to shaking or trembling of the operator’s hand.⁶

When scanning is complete, the preparation can be shown on the monitor and looked over from any angle. The virtual die is cut on the effective model, and the finish line is outlined by the dentist directly on the die image. Then, a CAD system “biogeneric” proposes an idealized restoration design to let the dentist makes adjustments using a number of on-screen tools. Once satisfied with the restoration, the dentist can mount a block of ceramic or composite material with the desired shade in the milling unit and start to produce the physical restoration. During the design stage, color-coded tools determine the degree of interproximal contact and ensure the finished restorations require minimal adjustments, if any, before cementation. The dentist can either capture the teeth digitally and fabricate a restoration in a single visit, or can transfer the data to the dental laboratory by CEREC Connect[®], which can in turn select the restoration design virtually and mill it in the laboratory.¹⁰

This type of intraoral scanner can be used for single crowns, veneers, inlays, onlays, and implant-supported FDPs. For crowns over implants, the prepared abutment can be directly scanned,⁶ or a scan body seated on the implant can be scanned by the dentist. A scan body is a plastic coping with markers that provide 3D registration of the implant location.¹²

The CEREC system is a closed system, exporting the digital impression data as a proprietary format file that works on Sirona’s supporting CAM devices such as CEREC MC and CEREC In-Lab. The CEREC MC is a chairside milling unit that can provide single-appointment treatments. Earlier, the CEREC chairside milling unit was not capable of milling FPDs and some high-strength ceramic materials. Therefore, these types of cases had to be milled through CEREC In-Lab. With recent developments in CEREC devices, the CEREC MC X and CEREC MC XL combined with CEREC AC Omnicam can be used for a majority of indications and materials, including FPDs and zirconium oxide.⁹

Lava C.O.S. system

Lava[™] C.O.S. (Lava Chairside Oral Scanner; 3M ESPE, Seefeld, Germany) is an intraoral digital impression device invented in 2006 and brought to market in 2008. It works under the principle of active wavefront sampling.¹³ This principle refers to obtaining 3D data from a single-lens imaging system. Three sensors can capture clinical images from diverse angles simultaneously and generate surface patches with in-focus and out-of-focus data by proprietary image-processing algorithms.¹⁴ Twenty 3D datasets can be captured per second, embodying over 10,000 data points in each scan.² This allows

the system to produce a precise scan out of 2400 more datasets (or 24 million data points). The manufacturer states that the high data redundancy ascribed to many overlapping pictures ensures the highly accurate image quality.²

The Lava C.O.S. has the smallest scanner tip—only 13.2-mm wide. The scanner sends out pulsating visible blue light as light source and works with a mobile host computer and a touch-screen display.⁶

Similar to CEREC AC Bluecam, the Lava C.O.S. also requires a powder coating spray on the tooth surface before scanning. After the mouth is rinsed and air dried, the particular powder (Lava™ powder for chairside oral scanner; 3M ESPE) is sprayed on the tooth surface to form a homogeneous layer. In the progress of scanning, the dentist should start with the posterior tooth area and move the camera forward, ensuring both buccal and lingual sides are captured.¹⁰ The Lava C.O.S. can display the images seized in the mouth on the touch screen at the same time. With real-time visibility, dentists can immediately see if they are receiving enough information from the preparation. Once it is confirmed that all necessary details were captured on the preparation scan, a quick scan of the rest of the arch is required. If the display shows a critical missing or blurry area in the scan, the dentist simply needs to rescan this specific area, and the software will be amended automatically.¹⁰ The dentist then scans the opposite arch in the same manner. Finally, a scan from the buccal side with the patient in occlusion is taken, and the system will articulate the maxillary and mandibular teeth automatically to create a bite record.¹⁵

After reviewing all the scans, the dentist can fill out an on-screen laboratory prescription. The data are wirelessly transferred to the laboratory, where a technician cuts the die accordingly and digitally marks the margin with customized software. The digital data are virtually ditched after being transferred to 3M ESPE. Afterward, the data is normatively articulated with the opposing and bite scans.¹⁰

A stereolithography (SLA) model is created by the manufacturer and delivered to the laboratory. Despite the different system name, it is not dedicated solely to the creation of Lava crowns and FDPs. All types of finish lines may be reproduced on the SLA dies, which allows any type of crown to be manufactured by the dental laboratory.¹⁰

In most cases, the Lava C.O.S. also exports data files in a proprietary formatted manner, which can be designed and manufactured only by its supporting CAD software and CAM device. Scanning of implant cases is accomplished by Biomet 3i (Palm Beach Gardens, FL). It uses a healing cap (Encode; Biomet 3i) attached to the implant before taking an optical impression. After data acquisition, Biomet 3i can mill the abutment. The alternative option is to deliver the data to Dental Wings software (DWOS). The compatibility with other software makes Lava C.O.S. a semi-open system.⁶

iTero system

Cadent Inc (Carstadt, NJ) introduced iTero to the market in 2007. The iTero system captures intraoral surfaces and contours by laser and optical scanning based on the principle of parallel confocal imaging.¹⁶ A total of 100,000 points of laser light at 300 focal depths of the tooth structure can be obtained

during one scan. These focal depth images are separated at the level of approximately 50 μm , allowing the camera to acquire precise data of tooth surfaces.¹⁷ Parallel confocal scanning with the iTero system can capture all structures and materials in the mouth without coating teeth with scanning powders.⁶ This system uses red laser as a light source and consists of a host computer, a mouse, a keyboard, a screen, and a scanner.¹⁵

When the prepared tooth is finished by rinsing, retraction, hemostasis, and air drying, the dentist puts the scanner over the tooth and starts the scan process. Scans over prepared teeth should involve the following areas: occlusal, lingual, buccal, and interproximal contacts of the adjacent teeth. If any shake is detected, the system requires a rescan. After completion, a 45° angle view from buccal and lingual directions of the remaining teeth in the arch and opposite arch are achieved. Eventually, a buccal scan of the patient's centric occlusion is obtained. The system will carry out a virtual bite registration instantly.¹⁸

According to Birnbaum et al,¹⁰ "once the digital impression has been completed, the clinician can select from a series of diagnostic tools to evaluate the preparation and complete the impression. The occlusal reduction tool shows in vivid color how much clearance has been created in the preparation for the restoration selected by the clinician. A margin line tool is available to assist in viewing the clearly defined margin. Once the clinician has completely evaluated all aspects of the digital impression, adjustments, if any, are made at that time and a few additional scans will register the changes that were made to the prepared tooth."^{10,19}

The completed digital impression is conveyed to the Cadent facility and the dental laboratory through a HIPAA-compliant wireless system. Upon laboratory review, the digital files are output to a model by Cadent. The model is milled from a proprietary blended resin and is pinned, trimmed, and articulated according to the clinician-created digital impression. The precision of milled models and dies is secured by Cadent industrial 5-axis milling machines.¹⁰

Cadent models have a unique feature. Among them, one model can be used as either a working model or soft-tissue model. By ditching the dies effectively, the dies and models are precisely developed, and the inaccuracies of hand trimming are eradicated. Then, the definitive restoration is specifically processed at the laboratory using the digital prescription.²⁰

iTero is an open system in the treatment of crowns, FPDs, veneers, implants, aligners, and retainers. It exports digital image files as an STL format, which can be shared by any other lab equipped with a CAD/CAM system. For an optical impression of the implant position, iTero partners with Straumann, which has contributed considerable enhancement for clinical circumstances with implants in recent years. In these cases, Straumann applies implant components according to CAD software DWOS which works on the digital impression data from iTero.¹⁶ A specific transfer is attached at the superior surface over the implants with three spheres, allowing the correct implant positioning. The iTero System camera is thereafter placed over the implant, and the digital impression data is gained in the same way as described previously. As an open system, iTero is compatible with software that accepts STL images, such as DWOS.^{6,16}

E4D system

The E4D system was developed by D4D Technologies, LLC (Richardson, TX) under the principle of optical coherence tomography and confocal microscopy. It uses red laser as a light source and micromirrors to vibrate 20,000 cycles per second. E4D's high-speed laser formulates a digital impression of the prepared and proximal teeth to create an interactive 3D image.²¹ The laser technology traps images from every angle. The software builds a library of images. The image library can wrap around a precise virtual model in seconds. This system also functions as a powder-free intraoral scanning device. It includes a cart with the design center (computer and monitor), laser scanner head, and a separate milling unit.

When scanning the prepared tooth, the dentist places the intraoral scanner above the tooth while holding down the foot pedal. After centering the target area on the screen and focusing on the images, the pedal is released, and the images are secured. The scanner must be held a specific distance from the surface being scanned. This is achieved with the assistance of rubber-tipped "boots" extending from the head of the scanner. In this manner a series of pictures from necessary angles is captured. The system will integrate these images into a complete 3D impression automatically. Unlike the systems described above, the occlusal relationship is not obtained by scanning the closing mouth from the buccal direction. Instead, it is created with trimmed impression material and placed on top of the prepared tooth afterward. The scanner captures a combination of the registration material and the adjacent teeth free of material coverage. This data is applicable for drawing occlusal heights of restorations in following the CAD procedure.¹⁰

The 3D digital impression data can be exported as a proprietary format or a STL format. For the proprietary closed format, the data is sent to specific DentaLogic software for CAD work. The E4D design system can autodetect and label the finish line on the preparation. Once a landmark is marked by the dentist, the Autogenesis™ featured computer starts to select a proposed restoration from its anatomical libraries for the related tooth. Moreover, the operator will modulate the proposed restoration with numerous simple tools.¹⁰

After the definitive restoration is authorized, the design center will transmit the data to the milling machine. With mounted ceramic or composite blocks in the milling machine and rotary diamond instruments, which have advantages in replacement of worn or damaged parts, the dentist is able to complete the restoration fabrication.¹⁰

The E4D system file can also be converted to an STL file by paying a fee to D4D Technology. Thus, the digital impression data can be used by other CAD/CAM systems, and the E4D system can be considered as a semi-open device.

Like the CEREC AC Bluecam and Omnicam systems, the E4D system can work with a chairside-milling device. That means this system can also function as a "single-visit treatment" and provide high-strength ceramic prostheses or composite even for minimally prepared teeth.²²

TRIOS system

In 2010, 3Shape (Copenhagen, Denmark) launched a new type of intraoral digital impression system, TRIOS, which was presented to market in 2011. This system works under the princi-

ple of ultrafast optical sectioning and confocal microscopy. The system recognizes variations in the focus plane of the pattern over a range of focus plane positions while maintaining a fixed spatial relation of the scanner and the object being scanned. Furthermore, a quick scanning speed of up to 3000 images per second reduces the influence of relative movement between scanner probe and teeth.²¹ By analyzing a large number of pictures obtained, the system can create a final digital 3D model instantly to reflect the real configuration of teeth and gingival color. Similar to the iTero and E4D systems, the TRIOS intraoral scanner is a powder-free device in the scanning process.

The TRIOS system boasts an essential trait, "the variation of the focal plane without moving the scanner in relation to the object being scanned."²¹ According to Logozzo et al,²¹ "The focal plane should be continuously varied in a periodic fashion with a predefined frequency, while the pattern generation means the camera, the optical system, and the object being scanned are fixed in relation to each other. Further, the 3D surface acquisition time should be small enough to reduce the impact of relative movement between probe and teeth. The scanning system has the property of telecentricity in the space of the object being scanned and it is possible to shift the focal plane while maintaining telecentricity and magnification."²¹

The operation of TRIOS is relatively simple. The dentist can hold the scanner at a range of distances to the tooth. Either closely over the tooth or 2 to 3 cm away will not affect the focus and the capturing of images.²¹ The 3D profiles of teeth and gingiva are generated simultaneously, while the dentist moves the scanner gradually above them. After scanning the upper and lower teeth, a buccal scan can be taken when the patient closes into an intercuspal position. The system of the host computer will implement a digital registration to create a 3D occlusion relationship.

TRIOS includes two parts: TRIOS® Cart and TRIOS® Pod. The TRIOS® Pod offers better mobility and flexibility due to its simple construction with a handheld scanner only and its compatibility with other computers or iPad.²¹ For both the TRIOS® Cart and the TRIOS® Pod scanner, clinics can choose either a TRIOS® Standard or a TRIOS® Color solution program. The latter is capable of capturing and demonstrating the teeth and soft-tissue images in real color. The TRIOS system can provide service in a broad range of indications including crowns, FPDs, veneers, inlays, onlays, implants, and orthodontic cases. With the development of TRIOS® Color, it is expected that the patients with a removable partial denture or complete denture will be intraorally scanned directly in the future.²¹

The TRIOS system is an open system that can export 3D data as an STL file or a proprietary file. The STL file can work together with other CAD/CAM systems. The proprietary encrypted file can only be designed by 3Shape's specific CAD software and 3Shape Dental System™. Additionally, TRIOS is a professional digital impression acquisition and CAD system, and does not include a CAM milling device.²¹

In addition to the five systems described above, other digital impression systems are available. A brief summary of key features of various intraoral digital scanners is presented in Table 1.²¹

Besides the regular use of the intraoral digital impression systems mentioned above, other functions should be mentioned. Some types of intraoral scanner, such as E4D Dentist™ can

Table 1 Essential characteristics of intraoral digital impressions systems currently available

Intraoral scanner	Company	Working principles	Light source	Imaging type	Necessity of coating	In-office milling	Output format
CEREC AC	Sirona Dental System GmbH (Bensheim, Germany)	Active triangulation and optical microscopy	Visible blue light	Multiple images	Yes	Yes	Proprietary
iTero	Cadent Inc (Carstadt, NJ)	Parallel confocal microscopy	Red laser	Multiple images	None	No	Proprietary or selective STL
E4D	D4D Technologies, LLC (Richardson, TX)	Optical coherence tomography and confocal microscopy	Laser	Multiple images	Occasionally	Yes	Proprietary
Lava™ C.O.S.	3M ESPE (St. Paul, MN)	Active wavefront sampling	Pulsating visible blue light	Video	Yes	No	Proprietary
IOS Fastscan	IOS Technologies, Inc (San Diego, CA)	Active triangulation and Schleimpflug principle	Laser	3 images	Yes	No	STL
MIA3D	Densys Ltd (Migdal Ha'Emek, Israel)	Active stereophotogrammetry	Visible light	2 images	Yes	No	ASCII
DPI-3D	Dimensional Photonics International, Inc (Wilmington, MA)	Accordion fringe interferometry (AFI)	Wavelength 350 to 500 nm	Multiple images	None	No	STL
3D Progress	MHT SpA (Verona, Italy)-MHT Optic Research AG (Niederhasli, Switzerland)	Confocal microscopy and moiré	Not disclosed	3 images	Occasionally	No	STL
DirectScan	Hint-Els GmbH (Griesheim, Germany)	Stereoscopic vision	Not disclosed	Multiple images	Not disclosed	No	Not disclosed
TRIOS	3Shape A/S (Copenhagen, Denmark)	Confocal microscopy	Not disclosed	Multiple images	None	No	Proprietary or STL

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