

Dental Impressions Using 3D Digital Scanners: Virtual Becomes Reality

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Abstract: The technologies that have made the use of three-dimensional (3D) digital scanners an integral part of many industries for decades have been improved and refined for application to dentistry. Since the introduction of the first dental impressioning digital scanner 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 able to produce precisely fitting dental restorations. These systems are capable of capturing 3D virtual images of tooth preparations, from which restorations may be fabricated directly (ie, CAD/CAM systems) or fabricated indirectly (ie, dedicated impression scanning systems for the creation of accurate master models). The use of these products is increasing rapidly 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.

THE CONCEPT OF IMPRESSION MAKING

The most critical step in the process of fabricating precisely fitting fixed or removable dental prostheses is the capture of an accurate impression of prepared or unprepared teeth, dental implants, edentulous ridges, or intraoral landmarks or defects. Unless a wax or resin pattern is made directly on the teeth, on the edentulous ridges, or in the defects, which is a time-consuming and generally impractical effort, the dentist or auxiliary must achieve an exact duplication of the site so that a laboratory technician, usually at a remote location, can create the restoration on a precise replica of the target site.

Traditionally, the paradigm for transferring the necessary information from the patient's oral cavity to the technician's laboratory bench has been to obtain an accurate negative of

the target site, from which the technician is able to fabricate an accurate gypsum positive duplicating the original intraoral situation. The advent of highly innovative and accurate impressioning systems based on new technologies has created a paradigm shift in the concept for impression making. These systems are poised to revolutionize the way in which dental professionals already are and will continue making impressions for indirect restorative dentistry.

FROM BITES TO BYTES: A BRIEF HISTORY OF IMPRESSIONING IN DENTISTRY

Impression making for restorative dentistry is a relatively recent concept in the millennia-old history of restorative dentistry. The earliest physical proof or record of prosthetic treatment to replace missing teeth goes back to Etruscan times, approximately 700 BC in which teeth were carved from ivory and bone and affixed to adjacent teeth

with gold wires. It was not until 1856, when Dr. Charles Stent perfected an impression material for use in the fabrication of the device that bears his name for the correction of oral deformities, that documentation exists of the use of an impression material other than beeswax or plaster of Paris, which had inherent problems, respectively, of distortion or difficulty of use, for creating an oral prosthesis.¹

The first use of an elastomeric material for capturing impressions of tooth preparations, as well as other oral and dental conditions, was not until 1937, when Sears introduced agar as an impression material for crown preparations.² In the mere 71 years that elastic impression materials have been in use, numerous formulations have been developed, all of which have exhibited particular shortcomings

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in the goal of obtaining precise reproduction of the oral structures.

The reversible hydrocolloid agar and the irreversible hydrocolloid alginate exhibit poor dimensional stability because of the imbibition or loss of water, respectively, when sitting in wet or dry conditions, as well as in having low tear resistance. The Japanese embargo on the sale of agar to the United States during World War II spurred research into the development of alternative elastomeric impression materials. The polysulfide rubber impression material introduced in the late 1950s, originally developed to seal gaps between sectional concrete structures,³ overcame some of the problems of the hydrocolloids. Nevertheless, polysulfide rubber was messy, possessed objectionable taste and odor, had long setting times intraorally, and underwent dimensional change after the impression was removed from the mouth, as a result of continued polymerization with the evaporation of water and shrinkage toward the impression tray, leading to dies that were wider and shorter than the teeth being impressed.⁴ This problem was overcome somewhat by the use of custom trays that allowed for 4 mm of uniform space for the material and by pouring up the impression within 48 hours.³

The introduction in 1965 of the polyether material Impregum™ by ESPE, GmbH as the first elastomeric impression material specifically developed for use in dentistry afforded the profession a material with relatively fast setting time, excellent flowability, outstanding detail reproduction, adequate tear strength, high hydrophilicity, and low shrinkage. The material is still in use today in several formulations, although it exhibits problems with objectionable odor and taste, high elastic modulus (stiffness) often leading to difficulty in removing impressions from the mouth, and the requirement to pour up models within 48 hours because of absorption of water in very humid conditions, which can lead to impression distortion.⁴

Condensation cure silicone impression materials subsequently were developed, but these also suffered from problems with dimensional accuracy. The creation of addition silicone vinyl polysiloxane impression materials solved the issues of dimensional inaccuracy, poor taste and odor, and high modulus of elasticity, and offered excellent tear strength, superior flowability, and lack of distortion even if models were not poured quickly. The biggest drawback of the polysiloxane impression materials, however, is that they are hydrophobic, which can lead to the inability to capture fine

detail if problems with hemostasis and/or moisture control occur during impression making.

In addition to the many problems inherent in the accuracy of the elastomeric materials themselves, further distortions can occur by mistakes made in the mixing of the materials or in the impression-making technique, the use of nonrigid impression trays,⁵ the transfer of the impression to the dental laboratory (often subjecting the impressions to variable temperatures in everything from delivery vehicles to post office sorting rooms to the holds of cargo jets), the need for humidity control in the dental laboratory to assure accuracy in the setting of the gypsum model materials, etc. Newer technologies that allow for the use of digital scanners for impression making are indeed a welcome development. Digital impression making does not require patients to sit for as long as 7 minutes with a tray of often foul-tasting and malodorous "goop" in their mouths, requiring that they open uncomfortably wide, often gagging. Further, these devices help calm dentists' anxieties about economic and time considerations when deciding to remake inadequate impressions.

Advances in computerization, optics, miniaturization, and laser technologies have enabled the capture of dental impressions. Three-dimensional (3D) digitizing scanners have been in use in dentistry for more than 20 years and continue to be developed and improved for obtaining virtual impressions. The stressful, yet critical task of obtaining accurate impressions has undergone a paradigm shift.

The computer-aided design/computer-aided manufacture (CAD/CAM) dental systems that are currently available are able to feed data obtained from accurate digital scans of teeth directly into milling systems capable of carving restorations out of ceramic or composite resin blocks without the need for a physical replica of the prepared, adjacent, and opposing teeth. With the development of newer high-strength and esthetic ceramic restorative materials, such as zirconia, laboratory techniques have been developed in which master models poured from elastic impressions are digitally scanned to create stereolithic models on which the restorations are made. Even with such high-tech improvements, it is evident that such second-generation models are not as accurate as stereolithic models made directly from data obtained from 3D digital scans of the teeth provided by dedicated 3D scanners designed for impression making. This article outlines the features of two CAD/CAM systems and two dedicated 3D impressioning digital scanners that have been gaining in popularity in this emergent field of dentistry.



Figure 1 The CEREC 3 imaging unit. As a CAD/CAM system, the product also includes a separate, newly upgraded milling unit, the MC XL.



Figure 2 The CEREC 3 camera. The new software used in the system includes a camera crosshair, which makes the optical impression easier and more predictable.



Figure 3 For dentists preferring a complete chair/systems arrangement, the CEREC 3 is now included as part of the CEREC Chairline integrated unit.

CAD/CAM SYSTEMS

CAD/CAM technology has been in use for a half century. It originated in the 1950s with numerically controlled machines feeding numbers on paper tape into controllers wired to motors positioning work on machine tools. It advanced in the 1960s with the creation of early computer software that enabled the design of products in the aircraft and automotive industries. The introduction of CAD/CAM concepts into dental applications was the brainchild of Dr. Francois Duret in his thesis written at the Université Claude Bernard, Faculté d'Odontologie in Lyon, France in 1973, entitled "Empreinte Optique" (Optical Impression). He developed a CAD/CAM device, obtained a patent for it in 1984,⁶ and brought it to the Chicago Midwinter Meeting in 1989. There, he fabricated a crown in 4 hours as attendees watched. In the meantime, in 1980, a Swiss dentist, Dr. Werner Mörmann and an electrical engineer, Marco Brandestini developed the concept for what was to be introduced in 1987 by Sirona Dental Systems LLC (Charlotte, NC) as the first commercially viable CAD/CAM system for the fabrication of dental restorations—CEREC®.

CEREC

The CEREC® 3 system (Figure 1), an acronym for Chair-side Economical Restoration of Esthetic Ceramics, was a bold effort to combine a 3D digital scanner (Figure 2) with a milling unit to create dental restorations from commercially available blocks of ceramic material in a single appointment. One-appointment direct dental restorations eliminated the need for multiple visits, as well as for temporization and all of its inherent problems. The CEREC system uses computer-assisted technologies, including 3D digitization, the storage of the data as a digital model, and proprietary CEREC 3D software that proposes a restoration shape based on biogeneric comparisons to adjacent and opposing teeth, and then enables the dentist to modify the design of the restoration. After this is accomplished, the data is transmitted to a milling machine, the latest version of which, CEREC inLab® MC XL, is capable of milling a crown in as little as 4 minutes from a block of ceramic or composite material. The most current version of the CEREC 3 acquisition unit is integrated into a total chair/systems unit, the CEREC Chairline (Figure 3).

With this system, the impressing process necessitates achieving adequate visualization of the margins of the tooth preparation by proper tissue retraction or troughing and

hemostasis. The entire area being impressed needs to be coated completely with a layer of biocompatible titanium dioxide powder to enable the camera to register all of the tissues. This is true not only for digital scanning, but also for conventional elastomeric impressions as well.

Several image views then are made from an occlusal orientation assuring capture of the tooth or teeth being restored, as well as of the adjacent and opposing teeth. Next, the preparation is shown on a touch screen that enables the dentist to view the prepared tooth from every angle and to focus on magnified areas of the preparation. The "die" is "cut" on the virtual model, and the finish line is delineated by the dentist directly on the image of the die on the monitor screen. Then, the CAD biogeneric proposal of an idealized restoration is presented by the system, and the dentist is given the opportunity to make adjustments to the proposed design using a number of simple and intuitive on-screen tools (Figure 4).

After the dentist is satisfied with the proposed restoration, he or she mounts a block of homogeneous ceramic or composite material of the desired shade in the milling unit and proceeds with fabrication of the physical restoration. The use of color-coded tools during the design stage of the process to determine the degree of interproximal contact helps to assure finished restorations that require minimal, if any, adjustments before cementation.

E4D Dentist

D4D Technologies LLC (Dallas, TX), an acronym for Dream, Design, Develop, Deliver, introduced the E4D Dentist™ CAD/CAM system in early 2008, after an extended period of beta-testing and fine-tuning to assure a quality product. It consists of a cart containing the design center (computer and monitor) and laser scanner (Figure 5), a separate milling unit, and a job server and router for communication. The scanner, termed the IntraOral Digitizer, has a shorter vertical profile than that of the CEREC system, so the patient is not required to open as wide for posterior scans.

Of significance, the E4D Dentist does not require the use of a reflecting agent, such as titanium dioxide powder, to enable the capture of fine detail on the target site. Other CAD/CAM systems create a digital "gypsum" model on which the restoration is made. While the E4D Dentist can create such models when the scanner is used on either actual gypsum models or elastomeric impressions, it creates a more accurate and informative model when scanning is done with the IntraOral Digitizer (Figure 6).

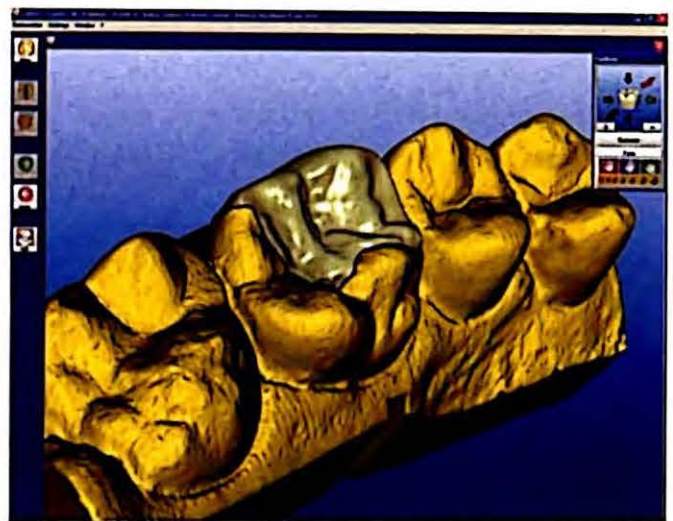


Figure 4 A screen shot of an onlay restoration proposed by the software library. User-friendly tools permit refinement of the restoration before milling.

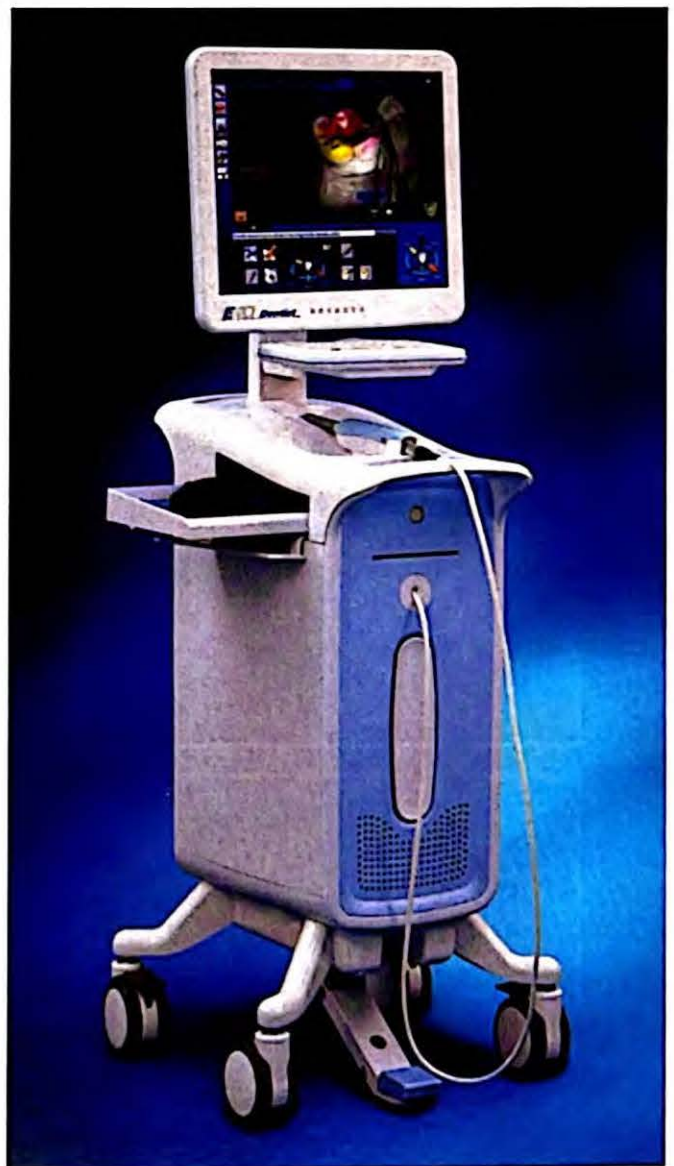


Figure 5 The E4D imaging unit. The CAD/CAM system also includes a separate milling unit.

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The ICEverything™ (ICE) feature of the system's Denta-Logic™ software takes actual pictures of the teeth and gingiva before treatment and after tooth preparation, as well as an occlusal registration. As successive pictures are taken, they are wrapped around the 3D model to create the ICE model. The 3D ICE view makes margin detection simpler to achieve (Figure 7). The touch screen monitor enables the dentist to view the preparation from various angles to assure its accuracy.

The design system of the E4D Dentist is capable of auto-detecting and marking the finish line on the preparation. After the dentist approves this landmark, the software uses its Autogenesis™ feature to propose a restoration, chosen from its anatomical libraries, for the tooth to be restored (Figure 8).

As with the CEREC system, the operator is provided with a number of highly intuitive tools to modify the restoration proposal. After the final restoration is approved, the design center transmits the data to the milling machine. Using blocks of ceramic or composite mounted in the milling machine, and with the aid of rotary diamond instruments that can replace themselves when worn or damaged, the dentist can fabricate the physical restoration.

DEDICATED IMPRESSION SCANNING SYSTEMS

Dedicated 3D digital dental impression scanners eliminate several time-consuming steps in the dental office, including

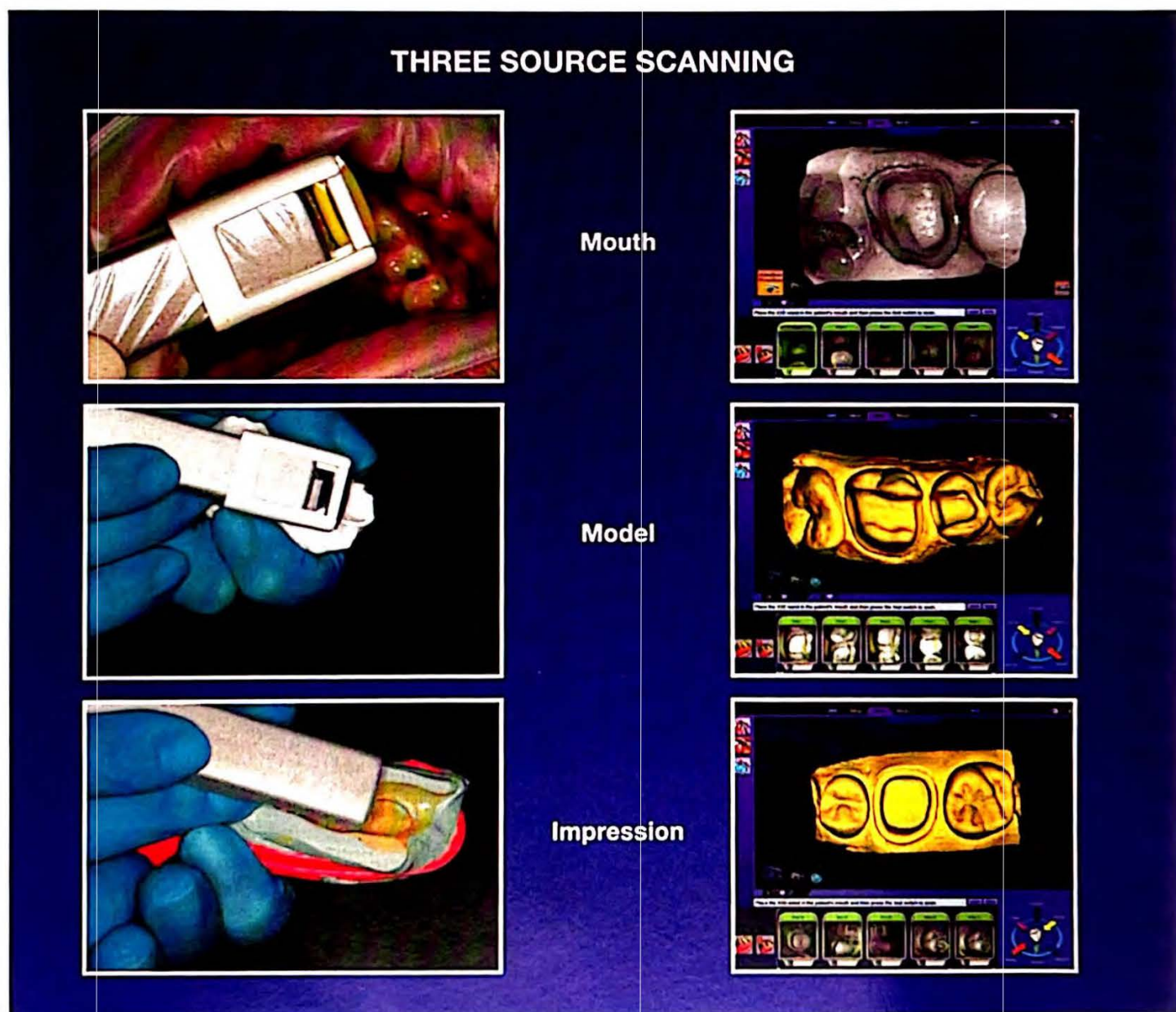


Figure 6 The IntraOral Digitizer, which does not require the use of a reflecting powder to capture images, can be used to scan teeth, models, or elastomeric impressions.

tray selection, dispensing and setting of materials, disinfection, and shipment of impressions to the laboratory. In addition, the laboratory saves time by not having to pour base and pin models, cut and trim dies, or articulate casts. With these systems, the final restorations are produced in the laboratory, but they are fabricated on models created from the data in the digital scans, as opposed to gypsum models made from physical impressions. Patient comfort, treatment acceptance, and education are added benefits. Digital scans can be stored on computer hard drives indefinitely, whereas conventional models, which may chip or break, must be stored physically, which often requires extra space in the dental office.

iTero

The iTero™ digital impression system (Cadent, Carlstadt, NJ) was introduced in early 2007, following 5 years of intensive research and beta-testing. Based on the theory of "parallel confocal," the iTero scanner emits a beam of light through a small hole, and any surface within a certain distance will reflect the light back toward the wand. The iTero device projects 100,000 beams of red light, and within one third of a second, the reflected light is converted into digital data. There is no need for the use of a reflecting agent, such as titanium dioxide powder, as the laser is able to reflect off all oral structures.

The iTero system includes a computer, monitor, mouse, integrated keyboard, foot pedal, and scanning wand organized on a well-designed mobile cart (Figure 9). Disinfection consists of replacing the disposable sleeve on the handheld scanner (Figure 10). The end of the scanner that enters the mouth has the tallest vertical profile of the systems reviewed in this article (Figure 11), and thus requires wider mouth opening by the patient.

Voice prompts guide the dentist in taking a series of scans of the patient's teeth and occlusal registration. The images are captured on the monitor by stepping on the foot pedal. The image on the screen is similar to a viewfinder on a camera, which allows the dentist to position the camera correctly while looking at the screen. As this is not a continuous scan and no powdering is necessary, the dentist may remove the scanner from the mouth to dry or rinse fluids as necessary.⁷ Individual images may be retaken to ensure capture of adequate detail. If the preparation must be modified, the quadrant needs to be rescanned after all adjustments are complete.⁸



Figure 7 3D ICE view of a prepared tooth derived from the ICEverything feature of the DentaLogic software from pre- and postoperative scans.

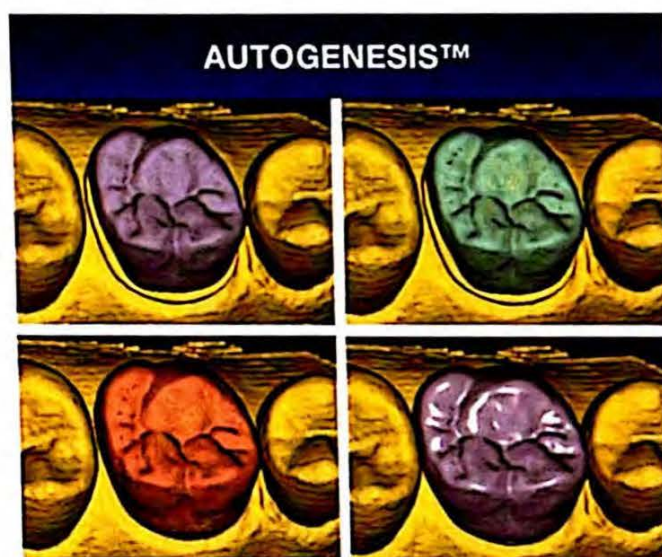


Figure 8 The Autogenesis feature of the E4D system proposes a restoration, which can be enhanced by the operator with simple onscreen tools before milling.

After all scans (at least 21) are completed, the dentist steps on the foot pedal and, within a few minutes, the digital model is displayed on the monitor (Figure 12). Using a wireless mouse, the dentist can rotate the model on the screen to confirm that the preparations are satisfactory before temporizing the teeth and sending the scans to the laboratory. Voice prompts again are very helpful in assuring that such necessities as proper occlusal tooth reduction for the intended crown type have been achieved.

All patient data and laboratory prescriptions are input into the computer before the scanning procedure. Digital data are sent wirelessly to Cadent, where the digital impression is

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Figure 9 The iTero 3D digital impression system. Scan data of preparations are e-mailed wirelessly to Cadent for creation of the model, which then is sent to the laboratory for the restoration.



Figure 10 iTero's handheld digital scanner does not require the use of a titanium dioxide reflecting agent to capture digital images of hard and soft tissues.

refined and a hard plastic model is milled. Cadent then returns the model to the local dental laboratory, which completes the final restoration.⁹

Lava C.O.S.

The Lava™ Chairside Oral Scanner (C.O.S.) was born out of the research of Professor Doug Hart and Dr. János Rohály

at the Massachusetts Institute of Technology. The Lava C.O.S. was created at Brontes Technologies Inc (Lexington, MA) and was acquired by 3M ESPE (St. Paul, MN) in October 2006. The product was launched officially at the Chicago Midwinter Meeting in February 2008.

The method used for capturing 3D impressions involves active wavefront sampling (AWS), which enables a 3D-in-Motion technique. This technique incorporates revolutionary optical design, image processing algorithms, and real-time model reconstruction to capture 3D data in a video sequence and model the data in real time. Other digital impressioning scanners use triangulation and laser approaches, which rely on the warping of a laser or light pattern on an object to obtain 3D data. In so doing, these methods are relatively slow and have the downside of distortion and optical illusion. By using AWS, however, the LAVA C.O.S. captures scanned images quickly (approximately twenty 3D data sets per second, or close to 2,400 data sets per arch) in video mode and creates a highly accurate virtual on-screen model instantaneously.¹⁰

The Lava C.O.S. unit consists of a mobile cart (Figure 13) containing a computer, a touch screen monitor, and a scanning wand (Figure 14), which has a 13.2-mm wide tip and weighs 14 oz (about the size of a large power toothbrush). The end of the scanner that enters the mouth is the smallest of the systems reviewed in this article. The camera at the tip of the wand (Figure 15) contains 192 light-emitting diodes (LEDs) and 22 lenses. There is no need for a keyboard or mouse, as the monitor displays a keyboard for all data input. Disinfection involves a simple wipe down of the monitor with an intermediate-level surface disinfectant designed for use on nonporous surfaces and replacement of the plastic sheath on the wand.

Whereas the Cadent iTero does not require any powdering and the CEREC requires heavy powdering, the Lava C.O.S. requires only enough powdering to allow the scanner to locate reference points. Therefore a very light dusting of powder is required, and is produced using the powdering gun provided with the unit.

Following preparation of the tooth and gingival retraction (if necessary), the entire arch is dried thoroughly and lightly dusted with powder. The dentist begins scanning by pressing either a button on the scanning wand or the start key on the touch screen monitor. A pulsing blue light emanates from the wand head as a black and white video of the teeth appears instantaneously on the monitor. Starting on

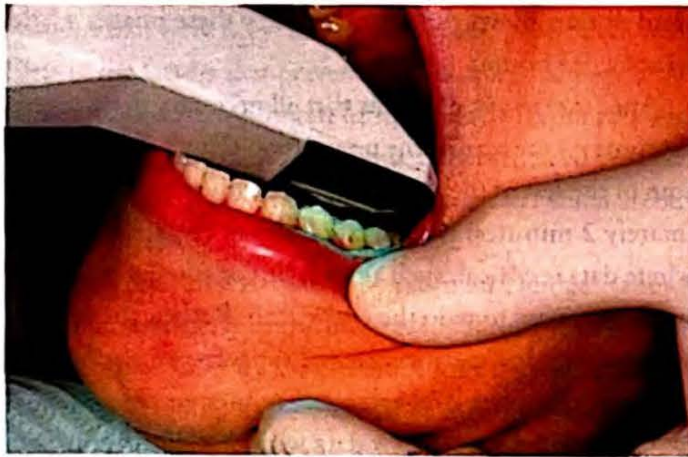


Figure 11 iTero's scanner is used intraorally to capture individual 3D images as the dentist follows voice prompts to assure accurate scanning and occlusal clearance.

the occlusal surface of any posterior tooth, the dentist guides the wand forward over the occlusal surfaces of the sextant being scanned, and then rotates the wand so that the buccal surfaces are captured.

The wand then is moved posteriorly, capturing all the buccal surfaces with some overlap of the occlusal. After he or she reaches the most posterior tooth, the dentist begins scanning the lingual surfaces of all the teeth in the sextant. The "stripe scanning" is completed when the dentist returns to scanning the occlusal of the starting tooth, ie, "closing the loop." If any sudden movement occurs, the image automatically pauses and the dentist can continue by returning to any surface that has been previously scanned. The software recognizes data that is already in the computer and resumes scanning without the need for pressing any buttons. Additionally, the software can distinguish between surfaces that are intended to be scanned (ie, teeth and attached gingiva) and extraneous data (ie, tongue, cheeks, etc).

As the teeth are scanned, they turn bright white on the monitor, and any areas that remain in red need to be scanned for more detail. To help the dentist maintain the wand at a proper distance from the teeth, a target appears on the monitor to indicate whether the wand is too close or too far away from the teeth. With the help of these on-screen guides, the dentist can modify the continuous scan without pausing, withdrawing the wand, or restarting the scan.

After scanning the preparation and adjacent teeth, the dentist pauses the scan and evaluates the result on the monitor. He or she is able to rotate and magnify the view on the screen, and also switch from the 3D image to a 2D view of the exact images captured by the camera during the scan. A

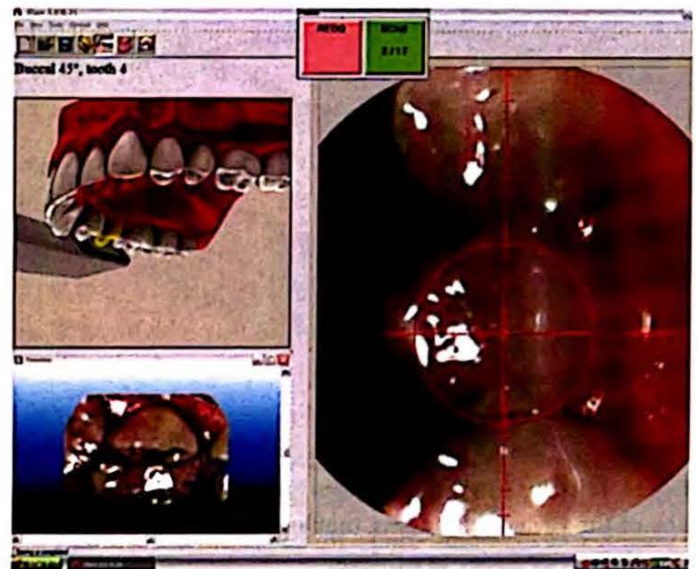


Figure 12 Typical screen shot of a prepared arch, which may be viewed at any angle using the wireless mouse.

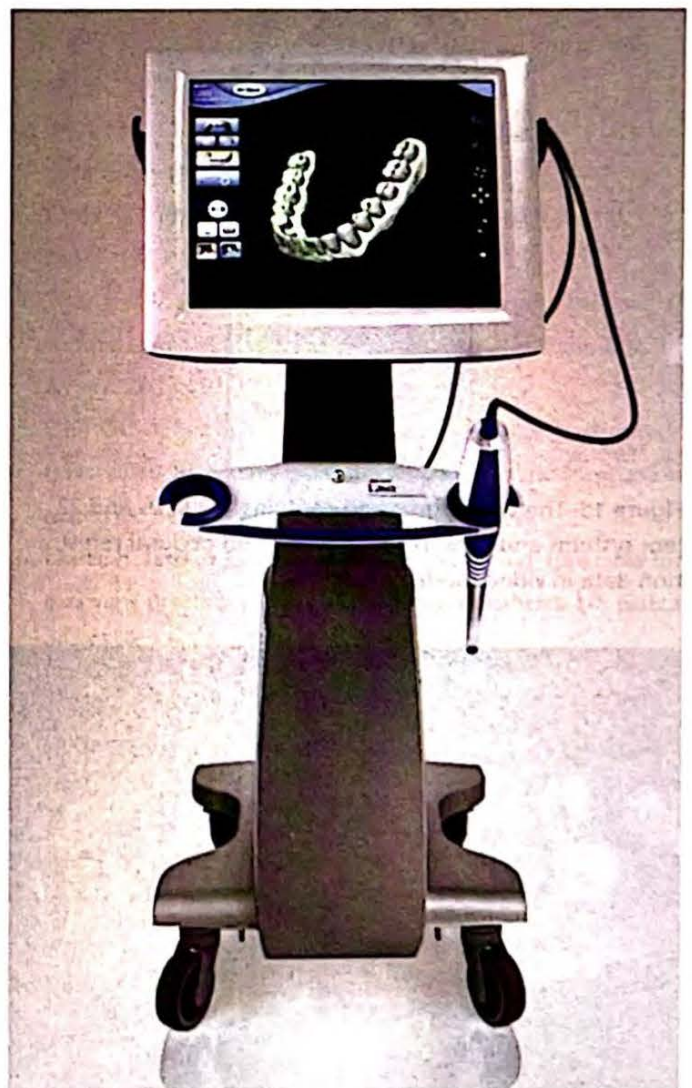


Figure 13 The Lava Chairside Oral Scanner (C.O.S.). Note the absence of a keyboard because data entry and laboratory prescriptions are done onscreen.



Figure 14 The Lava C.O.S. camera has the smallest wand of any of the reviewed systems, making access to all parts of the oral cavity easier to achieve.



Figure 15 The tip of the wand contains 192 LEDs and 22 lens systems and captures impression and occlusal registration data in video mode.



Figure 16 Typical screen shot of a prepared tooth. In addition to the image shown, the dentist and laboratory technician can view it in stone cast mode or with 3D glasses.

third option allows the dentist to view these images while wearing 3D glasses.

After the dentist confirms that all necessary details were captured on the scan of the preparation (Figure 16), a quick scan of the rest of the arch is obtained, which takes approximately 2 minutes. If there are holes in the scan in areas where data is critical, such as cusp tips or contact points, it is not necessary to redo the entire scan. Rather, the dentist simply scans that specific area and the software patches the hole. The software uses reference points on the scanned images to integrate the new data with that of the previous scans; therefore, it is crucial to have some overlap when scanning new data.

After the opposing arch is scanned, the patient is instructed to close into maximal intercuspal position. The buccal surfaces of the teeth on one side of the mouth are powdered, and a 15-second scan of the occluding teeth is captured. The maxillary and mandibular scans then are digitally articulated on the screen.

After all the scans have been reviewed for accuracy, the dentist uses the touch screen monitor to complete an on-screen laboratory prescription. The data is sent wirelessly to the laboratory technician, who then uses customized software to cut the die and mark the margin digitally. 3M ESPE receives the digital file where it is ditched virtually, and the data is articulated seamlessly with the operative, opposing, and bite scans. At the model manufacturing facility, a stereolithography model is generated, and is sent to the laboratory (along with a Lava coping if the restoration is to be a Lava crown), where the technician creates the final restoration. Despite the name of the system, it is not dedicated only to the creation of Lava crowns, as all types of finish lines may be reproduced on the stereolithography dies, allowing for any type of crown to be manufactured by the dental laboratory.

LEARNING CURVE

All of the 3D digital impressing systems reviewed in this article have the potential to produce restorations with improved marginal fit over that of traditional elastomeric impressions, based on the fact that the master die is created from digital data obtained from the tooth preparation, rather than from a second- or third-generation impression or model. The success of the CEREC system over the past 21 years in convincing many dentists worldwide to engage in new technologies bodes well for the future of all of the

systems that have been and will continue to be developed. One of the factors that prevent dentists from "taking off the blinders" and attempting to introduce new techniques and instruments into their dental practices is the fear that the learning curve is too great and that "you can't teach an old dog new tricks."

Recent research advanced by Norman Doidge¹¹ shows that neuroplasticity in the brain exists throughout the human lifespan and that the cerebral cortex is capable of constantly undergoing improvements in cognitive functioning. This means that any task that requires highly focused attention or the mastery of new skills helps to improve the mind, especially memory. Admittedly, learning to use any of the digital scanners discussed in this article means acquiring new skills and mastering new techniques, which will take some time and patience. The bottom line, however, is that the end result of developing the ability to use these new technologies will empower dentists to learn more about the dentistry they perform and enable them to provide their patients with well-fitting restorations.

THE ECONOMICS

The cost of all the systems presented, ranging from just over \$20,000 to well over \$100,000, may appear prohibitive for many, if not most, small dental practices. Nevertheless, when all of the attendant costs of traditional impression-making are taken into account, including the frequent need to remake impressions or even remake restorations as a result of the shortcomings of the older techniques and materials, and considering the improved quality of restorations made possible by the newer digital systems, the 3D digital impressioning systems become more appealing. The lease programs offered through most CAD/CAM system manufacturers have brought using this technology into the realm of profitability for practices producing more than 14 indirect restorations a month.

Notwithstanding the ethical dilemma of dentists' providing indirect ceramic restorations when simpler and less expensive composite restorations are achievable simply to justify the lease expenses of an expensive digital system, the use of new and better technology to improve the quality of dentistry is an advantage that well-educated patients are becoming increasingly more willing to accept, even at a higher cost. The technology of 3D digital impression scanning has advanced to a level at which it can no longer be ignored. Virtual has become a reality.

ACKNOWLEDGEMENTS

The authors would like to thank Michael Dunn and Gabe Foster of Sirona Dental Systems LLC; Dr. Gary Severance and Lee Culp of D4D Technologies LLC; Tim Mack and Mike Walsh of Cadent; and Dr. János Rohály, Brian Keenan, and Tara Mingardi of 3M ESPE/Brontes Technologies, for their help in providing information which was critical to the content of this article.

DISCLOSURE

Dr. Birnbaum and Dr. Aaronson use the 3M ESPE Lava C.O.S. system for digital impressioning in their practice. Dr. Aaronson is employed on a part-time basis as a consultant for the 3M ESPE Lava C.O.S. system.

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