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 flowabilty, and lack of distortion even if models were not poured quickly. The biggest drawback of the poly-

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 impression-

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

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 Chairside 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 impressioning process necessitates achieving adequate visualization of the margins of the tooth 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).

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

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

The ICEverything™ (ICE) feature of the system's DentaLogic™ 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 autodetecting 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

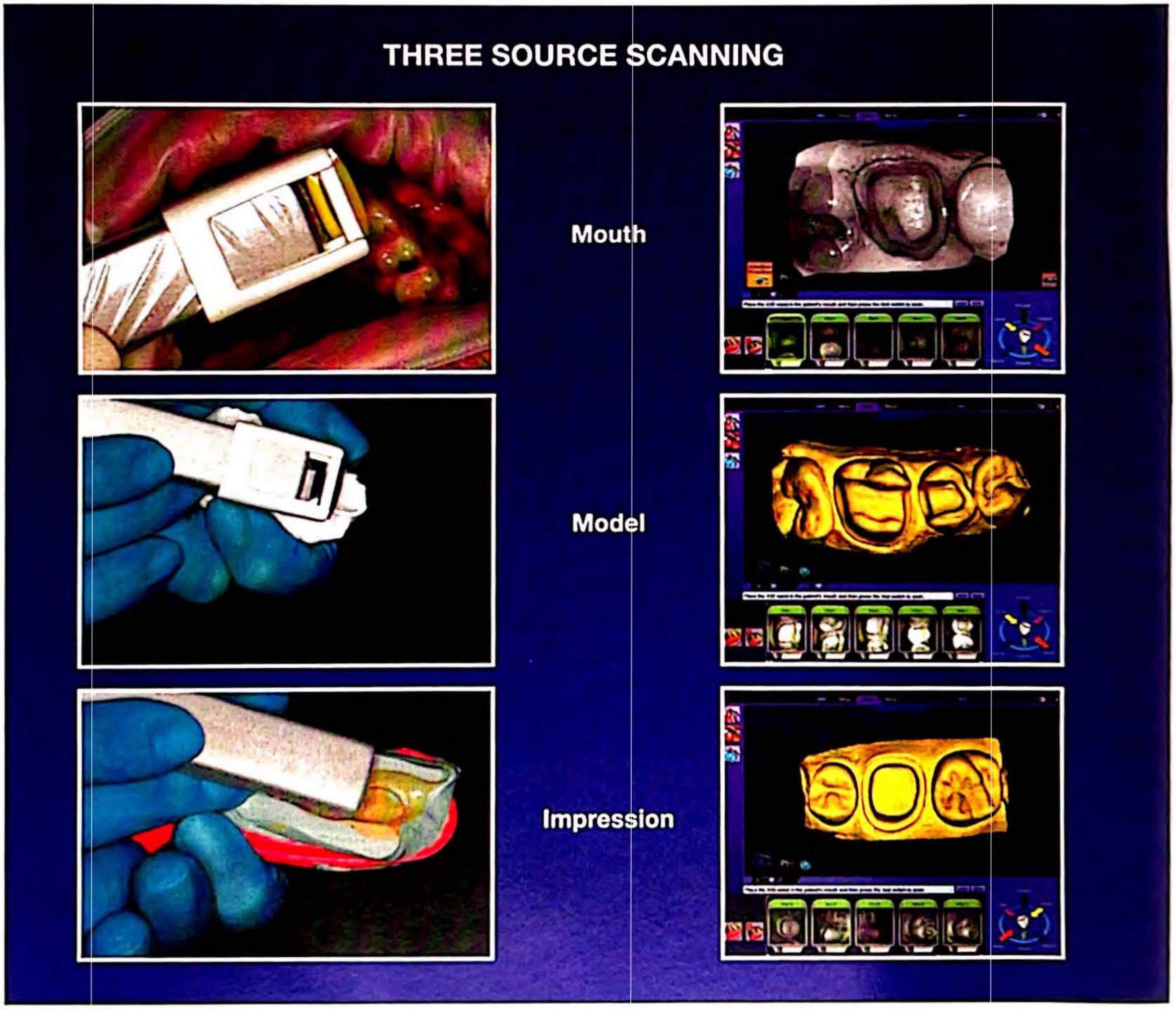

Figure 6 The IntraOral Digitizer, which does not require the use of a reflecting powder to capture images, can be used to scan

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