The Evolving Impressions of Digital Dentistry
How CAD/CAM technology continues to drive innovation

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ABSTRACT
The introduction of chairside and laboratory-based computer-aided design/computer-aided manufacturing (CAD/CAM) technology in dentistry has radically changed the way in which dentists approach the restorative workflow. As the CAD/CAM industry is evolving, new scanners, design software, and mills or printers are being introduced regularly. New materials are under development and existing software continues to be updated. Now more than ever, it is important to understand what each system has to offer and which can best meet the needs of an individual practice. Consideration must be given to price point, training, perceived benefits of digital scanning, laboratory, and total office integration.

CAD/CAM technology is not a new concept. As early as 1970, Duran explored how digital technology could be incorporated into dentistry, and in 1987, Mormann introduced the first chairside CAD/CAM system, CEREC 1, to the dental market. At the time, the system was limited only to ceramic inlay restorations.\(^1,2\) Today, Sirona (www.sirona.com) offers two different cameras and three different mills, as well as a stand-alone digital impression device, offering a digital solution for every type of material available on the market. Although Sirona is often considered the pioneer of CAD/CAM technology, in the past 5 years, a number of competitive technologies have entered the market. The introduction of these competitors has brought with it not only more choices, but also more confusion and indecision for the individual consumer, who is faced with so many different options.

Traditional vs. Digital Impression Techniques
Accurate impressions depend on proper technique and materials. Elastomeric impression materials (polyethers, polyvinyl siloxanes, and hybrids) are popular because of their excellent physical and mechanical properties, including precise detail reproduction, high elastic recovery, and dimensional stability.\(^3\) The decision to use one over the other varies among clinicians and is based upon personal preference. Although it is clear that elastomeric materials have improved over the years, their use continues to present some challenges. Traditional impression techniques involve multiple steps, making errors more prevalent both in the hands of clinicians and laboratory technicians.\(^4\) Patient comfort is also a concern due to tray fit, taste of material, and set time of the impression material. Consequently, digital impressions were introduced to overcome some of the obstacles seen with...
traditional impression materials and techniques. Clinical studies have also shown that indirect restorations fit more accurately when a digital impression is taken as opposed to a traditional impression.5,6

In digital impressions, intraoral scanners are used to create a digital image of the patient’s teeth, eliminating the need for traditional impression materials, as well as increasing patient comfort and decreasing anxiety.7 Using either a laser or video, digital impressioning acquires an image with a digital scanning device that optically records the patient’s dentition and bite relationship. Light is projected from the tip of the scanner, and a camera collects data, which are further manipulated to produce a digital model of the patient’s dentition. Current systems use different light source technologies, including laser, structured (striped) light, or LED illumination. Some systems require the use of titanium dioxide powder as a contrast medium, whereas others do not. Data collection methods, strategies, and size of scanner head may vary between scanners, but each procedure culminates in a digital model of the patient’s dentition.

Digital Impressioning vs. In-Office CAD/CAM Systems

Digital systems available for the dental office can be broken into two markets: digital impressioning systems and in-office CAD/CAM systems. Regardless of the system being used, all start with the capture of a digital impression.

Digital impressioning systems allow the use of digital scans in place of physical impression materials. There is no need to change preparation, retraction, or isolation technique. The only difference is that instead of taking a physical impression with impression materials, a scanner wand is used intraorally to record a digital image of the preparation. After scanning, the clinician reviews the digital image to ensure that all relevant areas are captured as well as to confirm that occlusal clearance is sufficient. A benefit of digital impressions is that they can be reviewed instantly and at significantly greater magnification than is available with loupes or even microscopes. If there is a problem with the scan, the clinician can make changes and re-scan if necessary.8 Once the clinician is satisfied with the preparation and digital scan, the data file is electronically transmitted to the dental laboratory along with a prescription. Virtually any type of restoration can be created using a digital impression, from all-ceramic crowns to gold inlays.

Once the scan is received, the dental laboratory or its manufacturing partner uses special software to identify preparation margins and digitally mark and trim the dies. At that point, 3-dimensional (3D) printed or milled models can then be produced for the laboratory to use in fabricating the restoration if desired. These models can be used to fabricate restorations using both digital and traditional methods and materials. An interesting new twist with digital impressions and monolithic milled or pressed restorations is the option for laboratories to produce model-less restorations. This cuts down on turnaround time and laboratories generally charge less for the restoration.9

As can be seen by the number of new scanner systems recently brought to market, the field of digital impressions is rapidly growing. Companies such as 3M ESPE and Align Technologies have introduced and subsequently refined their technologies in the past 5 years. 3M ESPE’s newest scanner, the 3M™ True Definition Scanner (www.3mespe.com), has a smaller wand, costs less, and now has open architecture, allowing several CAD software brands to use the file for design. Recently, 3M ESPE announced milling strategies compatible with the E4D® Design Center and Mill (www.e4d.com) and TS150™ In-Office Milling Solution (IOS Technologies, Inc; www.ios3d.com), enabling clinicians

<table>
<thead>
<tr>
<th>SCANNER (MANUFACTURER)</th>
<th>POWDER REQUIRED</th>
<th>IN-OFFICE MILLING OPTIONS</th>
<th>TYPE OF CAPTURE</th>
<th>LAB FABRICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apollo DI (Sirona)</td>
<td>Yes</td>
<td>None</td>
<td>Continuous capture</td>
<td>Sirona Connect</td>
</tr>
<tr>
<td>CEREC® AC (Sirona)</td>
<td>Yes</td>
<td>MC, MC X, or MCXL</td>
<td>Laser image point &amp; click</td>
<td>Sirona Connect</td>
</tr>
<tr>
<td>CEREC® AC with Omnicam (Sirona)</td>
<td>No</td>
<td>MC, MC X, or MCXL</td>
<td>Continuous capture</td>
<td>Sirona Connect</td>
</tr>
<tr>
<td>CS 3500 (Carestream Dental)</td>
<td>No</td>
<td>CS3000</td>
<td>Laser image point &amp; click, light guided</td>
<td>CS Connect</td>
</tr>
<tr>
<td>E4D® NEVO™ (E4D Technologies)</td>
<td>No</td>
<td>E4D® Design Center and Mill</td>
<td>Continuous capture</td>
<td>E4D Sky™, participating lab</td>
</tr>
<tr>
<td>IOS FastScan® (IOS Technologies)</td>
<td>Yes</td>
<td>TS150™ In-Office Milling Solution</td>
<td>Laser scan &amp; click</td>
<td>Participating lab</td>
</tr>
<tr>
<td>iTero® (Align Technologies)</td>
<td>No</td>
<td>None</td>
<td>Laser image point &amp; click</td>
<td>Any lab</td>
</tr>
<tr>
<td>TRIOS® (3Shape)</td>
<td>No</td>
<td>Biolase GALAXY BioMill™</td>
<td>Continuous capture</td>
<td>Participating lab</td>
</tr>
<tr>
<td>3M™ True Definition Scanner (3M ESPE)</td>
<td>Yes</td>
<td>E4D Design Center and Mill, TS150™ In-Office Milling Solution</td>
<td>Video capture</td>
<td>Participating lab</td>
</tr>
</tbody>
</table>

TABLE 1
Digital Impression and CAD/CAM Systems
an in-office milling option with a 3M ESPE scanner at a significantly lower cost than competitor in-office milling systems. In the past year, other digital impression systems such as CS 3500 from Carestream Dental (www.carestreamdental.com), TRIOS from 3Shape, and IOS FastScan (IOS Technologies, Inc) have also been introduced. Available digital impression and CAD/CAM systems are listed in Table 1.

Chairside CAD/CAM
Chairside CAD/CAM systems include both a scanner and a mill for fabricating a restoration. With these systems, clinicians can scan, design, and mill a full-contour restoration in-office. As seen with designated digital impressioning systems, a digital scan is taken of the preparation. Instead of electronically sending the data file to a dental laboratory for fabrication, the clinician is able to design the restoration chairside using software included in the CAD/CAM system. When fabricating a chairside restoration, the clinician can choose a crown, inlay, onlay, or veneer. Most of these software systems offer design options ranging from copying pre-existing tooth conditions to choosing from a library of proposals based on morphological details of adjacent teeth. These software programs offer a multitude of tools to modify the proposed restoration, including tools to adjust interproximal contacts, height of contour, occlusion, and other characteristics. Depending on the material, restorations may be customized using stain and glaze and then fired in a porcelain oven, giving the dentist more creative freedom and control. The finished restoration can be cemented during the same appointment. Patient responses to these types of systems are generally positive due to the quick turnaround of their indirect restoration; in most cases, no temporary is required.

The advantages of chairside CAD/CAM systems are numerous; however, these systems are significantly greater in cost than a scanner alone, and require extensive training for the entire staff (Table 2). To attract clinicians who only want to use digital impressioning without milling, companies offer dentists an option to purchase the scanner without the mill, which provides additional options in materials and lowers the total investment. To choose which system is best for a particular office, a review of the type of restorative materials routinely used is a good start. If the majority of indirect restorations are ceramo-metal based, digital impressions may be the way to go. However, true return on investment can be achieved if an office is using all-ceramic materials routinely, especially in the posterior region.

Open vs. Closed Architecture
There are two important categories of digital impression systems in terms of data files created during scanning: open and closed architecture. Open-architecture files, typically termed STL files, are not dependent on the manufacturer, and can be used in virtually any design software to fabricate a final restoration. For example, data obtained by an “open” scanner can be designed and milled (CAD/CAM) with many different systems, regardless of manufacturer. For laboratories that are skilled in customizing their own settings or configurations, open architecture offers more potential business opportunities.

For example, a laboratory with an open-architecture digital impression system may become an outsourcing partner for other laboratories or choose to integrate new interfaces with emerging CAD software platforms. Open-architecture systems allow individual dentists to work with several different laboratories and maximize the potential of their investment with options such as implant restorations and orthodontics.

Closed-system software architecture collects and manipulates data modules by the same manufacturer, offering laboratory owners security and a one-stop shop for resolving problems. One company controls both the CAD and CAM configurations, knows the milling unit’s performance specifications and capabilities, and is able to adapt the CAD and CAM software accordingly. For example, using Sirona Connect, participating Sirona Connect laboratories can receive files from any CEREC® device, design and mill on an InLab system (Sirona), and deliver a restoration to a dentist using CEREC. For laboratories that do not want to immerse themselves in all the new technologies and software from each different manufacturer, closed-architecture systems generally do a great job of taking the user by the hand from start to finish. The production process from scan to design to milling is made easy.

Optimizing Clarity and Exposing the Margin
Management of soft tissue during the preparation and impression-taking stages is critical for the success of the final impression, for both traditional and digital methods. Although supragingival margins are the most effective way to achieve clear visualization of the margin, in many situations, this is difficult. Scanners are not magic wands; they can only read what they can see. Therefore, a great deal of attention needs to be placed on soft tissue management to ensure the camera has an unobstructed view of the margin, as the scanner cannot distinguish debris and soft tissue from sound tooth structure (Figure 1 and Figure 2).

There are three ways to effectively manage and displace the soft tissue: mechanically, chemically, and surgically. The most popular technique is to mechanically displace gingival tissue with the use of retraction cord. Retraction pastes can also be used to mechanically displace tissue. Chemicals such as ferric sulfate or aluminum chloride can be applied as hemostatic agents to shrink soft tissue around the preparation.
Lasers are becoming more popular as a surgical method of managing tissue. Lasers are used to trough around the preparation, allowing visualization of the margin and providing homeostasis as well.

Material Selection
As materials evolve, there is a continual push toward strong yet esthetic restorations.

**TABLE 3**
Examples of Available Chairside CAD/CAM Blocks

<table>
<thead>
<tr>
<th>IPS E.MAX® CAD (IVOCLAR VIVADENT)</th>
<th>Lithium disilicate</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPS EMPRESS CAD (IVOCLAR VIVADENT)</td>
<td>Leucite glass ceramic</td>
</tr>
<tr>
<td>LAVA™ ULTIMATE (3M ESPE)</td>
<td>Resin nanoceramic</td>
</tr>
<tr>
<td>OBSIDIAN (GLIDEWELL LABORATORIES)</td>
<td>Lithium silicate ceramic</td>
</tr>
<tr>
<td>VITABLOCS® MARK II/REALLIFE/TRILUXE FORTE (VIDENT)</td>
<td>Fine-structure feldspar ceramic</td>
</tr>
<tr>
<td>VITA ENAMIC® (VIDENT)</td>
<td>Ceramic-polymer hybrid</td>
</tr>
</tbody>
</table>

Silica-based ceramics (feldspathic porcelains, leucite-reinforced ceramics, lithium disilicate ceramics) offer the most esthetic option, whereas zirconia provides higher strength. One clear advantage of chairside CAD/CAM restorations is that the solid manufactured block is made under ideal conditions, and furthermore, is free of porosities. Historically, material options for in-office milling were limited to weaker feldspathic monolithic blocks. Today, clinicians have material options resulting in a three- to 11-fold increase in flexural strength. Depending on the milling unit, there are many material choices now available in CAD/CAM blocks, including feldspathic porcelain, nano-ceramics, lithium disilicate, and more (Table 3). Zirconia blocks are also available, but unless the office has a sintering oven and a laboratory-grade mill, these materials are generally laboratory fabricated.

Practitioners also have the opportunity to enhance esthetics after milling by staining and glazing for customized shades. Early-generation materials were limited to monochromatic shades, and were not ideal for anterior restorations. Today, multi-layered translucent blocks are available, allowing clinicians the option of fabricating anterior restorations. Using chairside systems for anterior restorations in not for everyone; it requires experience and confidence with custom staining/glazing.

Due to its high strength and versatility, zirconia is gaining popularity as a restorative material. When zirconia was first introduced to the market, it was primarily used as a framework for single crowns and bridges (in place of metal). Similar to the fabrication of a porcelain-fused-to-metal crown, the zirconia framework is layered with a ceramic, providing a strong and esthetic restoration. The success of zirconia as a strong framework led to the development of a full-contour restoration. Advances in translucency have made monolithic zirconia a widely accepted and used choice due to a minimal need for tooth preparation (similar to cast gold), low cost, and ability to be used in multi-unit restorations. As zirconia continues to develop as a more translucent material, it may very well be a viable option for all regions of the mouth.

Laboratory Relationship
Doctors who acquire a digital impression system must evaluate their relationship with their dental laboratory. The prospect of losing this relationship can be a strong deterrent for potential CAD/CAM users who may not fully understand the extent to which they can maintain a partnership with their laboratory. Adopting CAD/CAM technology into a practice, even at the highest level, does not have to mean an end to the doctor-laboratory relationship. On the contrary, the integration of digital scanning technology can enhance this partnership and even save time and reduce remake rates for the laboratory.

The use of CAD/CAM systems opens doors to the use of other technologies, including 3D printing in the dental lab. Whereas a mill is a subtractive device because it uses material, 3D printing is considered an additive device. Some types of 3D printing use special powdered substrates that can include metal or plastic. This additive property allows...
several units to be produced simultaneously rather than adding time with each additional coping, die, etc. This technology can be used in a broad spectrum of applications, including fabrication of aligners, patterns for fixed prosthodontics, surgical guides, removable dentures, and models (Figure 3). Traditionally, laboratory crown work has required detailed model work that includes removable dies for checking margins and building porcelain. Today’s 3D printers are capable of producing models for dental laboratories and milling centers. Technology in this area continues to advance, offering ever-increasing opportunities for the laboratory/practice partnership to evolve.21

Integration
Integrating CAD/CAM technology into a dental practice takes commitment and effort, and the learning curve involved with digital impression should not be underestimated. If an office plans to make the switch to digital, having a team that is 100% committed will help ensure success, as well as having a laboratory to communicate with during the transition.22

An overlooked consideration when purchasing in-office CAD/CAM systems is the time and cost of training team members. Although most systems include some training in the purchase price, and all offer technical support over the phone and/or online, it is important to note that proficiency will take time. A highly skilled dental assistant or an in-office laboratory technician can efficiently finish a case in-office, but only with adequate training, which can be extensive and time consuming. Once the desired level of expertise is achieved, however, assistants can complete the design and fabrication of the restoration, thus freeing the dentist’s time. State dental boards have yet to clarify or regulate assistant usage of digital impression devices. Clinicians must make their own decisions following state laws and guidelines.

Summary
Over the past 5 years, CAD/CAM has developed at a rapid pace, and it is likely that integration of different systems will become the industry norm. Smaller intraoral scanners that require no cart are already appearing on the market, as well as those that do not require contrast medium (powder). Interdisciplinary case planning is evolving while integrating both cone-beam scans and implant-planning software for custom abutment and crown design. Digital dentures, partials, splints, and sleep appliances are appearing on the market in various configurations. One thing is certain—CAD/CAM is changing the way clinicians look at dentistry, from material selection to technique.

References

FIG. 3
(3.) Printed 3D models prior to cleaning.