RESTORATIVE

The Evolution of Digital Dentistry and the Digital Dental Team

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The room was filled with tension and excitement as the lights were slowly dimmed in the auditorium. The next 2 hours offered a glimpse of the future of dentistry. The topic was something out of a science-fiction novel, and it instilled in the audience a sense of awe, wonder, and just a touch of fear. As the auditorium lights came up, everyone sat in stunned silence as they contemplated all the possibilities offered by the presenter: dentistry going digital.

That presentation was given more than 20 years ago by one of digital dentistry's pioneers, Francois Duret, on the application of computer-assisted design/computer-assisted manufacturing (CAD/CAM) technology for restorative dentistry. While it took slightly longer than anticipated to integrate into the daily practice of dentistry, the new millennium seemed to include the catalysts for change in digital dentistry, as more than 10 different CAD/CAM systems have now been introduced as solutions for restorative dentistry.

Dentistry has cautiously welcomed this influx of technology that was promised so long ago. Based on technology adopted from aerospace, automotive, and even the watch-making industry, this technology is now being accepted due to its advantages of increased speed, accuracy, and efficiency without a compromise in quality. Today's chairside and laboratory-based CAD/CAM systems, such as Procera (Nobel Biocare), Lava (3M ESPE), Cercon (DENTSPLY Ceramco), CEREC (Sirona), and E4D (D4D Technologies), just to name a few, are being used to design and manufacture metal, alumina, and zirconia frameworks, as well as all-ceramic and composite full-contour crowns, inlays, and veneers. All the restorations manufactured in this way may be stronger, fit better, and have the possibility to be as or more aesthetic than restorations fabricated using traditional methods.

REDEFINING ROLES AND RELATIONSHIPS

The primary role of the dentist, dental team member, and dental technician in indirect restorative dentistry is to copy perfectly all functional and aesthetic parameters, as defined by nature, into a restorative solution. It is an architect-builder relationship. Throughout the entire restorative process—from the initial consultation through treatment planning, provisionalization (if needed), and final placement—the communication routes between the clinician and the laboratory technician require a complete transfer of information. This includes any information pertaining to existing, desired, and realistic situations and expectations, to and from the clinical environment. Functional components, occlusal parameters, phonetics, and aesthetic requirements are just some of the essential types of information that are necessary for the technician to successfully complete the fabrication of excellent functional and aesthetic restorations.

The primary and conventional tools of communication between the dentist and the technician are photography, written documentation, and impressions of the patient's existing dentition, clinical preparations, and opposing dentition. From this information, models are created and mounted on an articulator that simulates the jaw movements of the mandible.

As restorative dentistry evolves into the digital world of image capture, computer design, and creation of dental restorations through robotics, our perceptions and definitions of the dental laboratory must also evolve. First, in order to fully understand this concept, we must clearly define what a laboratory is. At first thought, we might say that a laboratory is the place where dentists send patient impressions, which the laboratory then processes into restorations to be sent back to the dentist for adjustment and delivery. This definition does seem to fit well with the traditional concept of a dentist-laboratory workflow. However, just as the Internet has forever changed the landscape of communication through related computer technology, the possibility of using CAD/CAM restoration files electronically has provided the catalyst for a significant change in the

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Figure 1. Dental operatory with a clinical CAD/CAM unit.

Figure 2. The D4D Dentist System.

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way we view and structure the dentist-laboratory (or doctor-technician) relationship.

Let us first imagine that our laboratory is not a place, does not have walls, and exists only in the talents of the partners in the restorative process: the dentist, his or her auxiliaries, and the dental technician. The equipment that we use to create the restoration may be located next to the chair, in an in-office laboratory area, remotely, or any or all of the above. Our "laboratory" is actually nothing more than a workflow, which is flexible to the degree that our abilities, access, and equipment will allow. The primary decision becomes where the hand-off from one partner to another should occur. Moreover, dentists who have the ability to optically scan (intraorally) for impressions, and who often choose CAD/CAM restorations as the best treatment option for their patients, have enhanced freedom as to where we believe the hand-off to the technician partner should occur. The laboratory is no longer a place, but rather, to a large degree, it is a virtual and fluid entity.

In some instances, it makes sense for the dentist to work independently and to prepare, design, and finish the restoration chairside in a single visit with the obvious advantages a clinical CAD/CAM system has to offer (Figure 1). These might include less complex restorations or fewer numbers of restoration for the same patient that do not require any special characterization other than perhaps stain and glaze or polish. Other times, it is advantageous to engage the services of the restorative partner, a dental technician, because he or she possesses the skill, and perhaps more importantly, the time, to create restorations that either demand more complex characterization or can be more efficiently created in an indirect manner.

THE DIGITAL PROCESS

The first successful introduction of CAD/CAM into dentistry was in 1982 with the introduction of the CEREC 1 (Sirona) chairside system. The fundamental principle of this system's concept was to capture electronically a preparation's image and then use software to interpolate the information and create a digital model. A virtual restoration design was then suggested and, after user-defined parameters were set, the restoration design was milled from a ceramic block and seated, all in one appointment. Subsequent software and hardware upgrades with the introduction of the CEREC 2, CEREC 3, and CEREC 3D systems (Sirona) focused primarily on improvements in user-friendliness, accuracy, material, and milling options.

The introduction of the E4D Dentist System (D4D Technologies) in 2008 (Figure 2), along with its accompanying DentaLogic software and Autogenesis libraries, became the first computerization model to accurately present a real 3-D virtual model and take into consideration the occlusal effect of the opposing (antagonistic) dentition along with the ability to design multiple teeth at the same time. It essentially takes a complex occlusal scheme and its parameters, condenses the information, and displays it in an intuitive format. This allows any dental professional with a basic knowledge of dental anatomy and occlusion to make modifications to the design and then send it to the automated milling unit. The introduction of the E4D Dentist System effectively automated some of the more mechanical and labor-intensive laboratory procedures (waxing, investing, burnout, casting, and pressing) involved in the conventional fabrication of a dental restoration, thus allowing the dentist, dental assistant, or dental technician to create functional dental restorations with a consistent, precise method (Figures 3 to 5).

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THE CHAIRSIDE DENTAL DESIGNER

Taking complicated dental design software and packaging it into a logical and recognizable format has expanded the opportunities of dental professionals other than clinicians to contribute to the restorative process.

Through educational initiatives, E4D offers a chairside dental designer (CDD) opportunity that expands the auxiliary's role with scanning principles, designing guidelines, and predictive milling practices and strategies. This allows the team to maximize productivity and efficiency in the restorative process. Based upon state and provincial guidelines and the delegation of the clinician, a properly trained and utilized CDD (or dental assistant) can reduce the doctor's restorative procedural time by 50%. Additionally, CAD/CAM courses are offered regularly to dental assistants wanting to maximize their contributions to the chairside restorative process with CAD/CAM dentistry.

THE WAY IT *WAS*

In the conventional indirect restorative process, the procedure began with the usual steps: the clinician prepared the case according to the appropriate preparation guidelines, took impressions, and then sent these and other critical pieces of information to the laboratory. In the laboratory, the impression was poured, the models mount-

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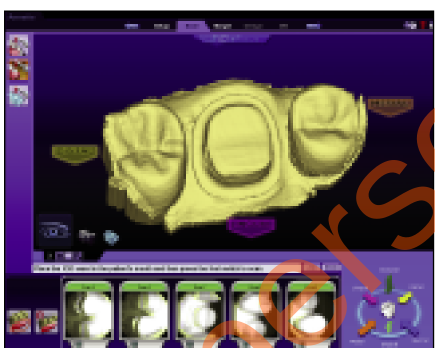

Figure 3. Digital working model.

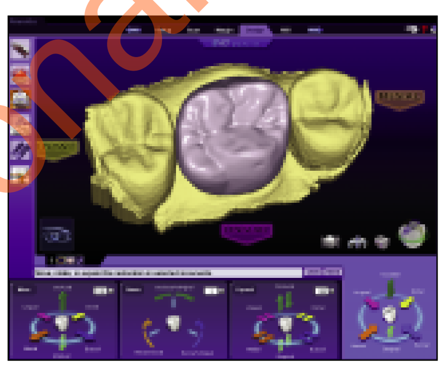

Figure 4. Digital restoration on model.

Figure 5. CAD/CAM-created restoration.

Figure 6. Preoperative condition of teeth Nos. 30 and 31.

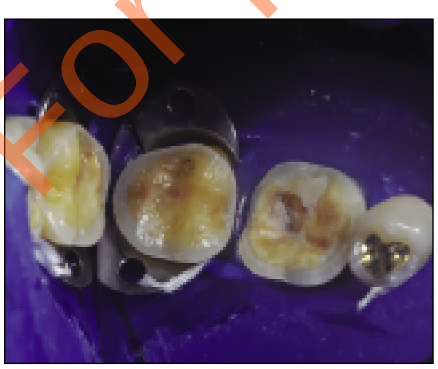

Figure 7. CAD/CAM all-ceramic onlay preparations.

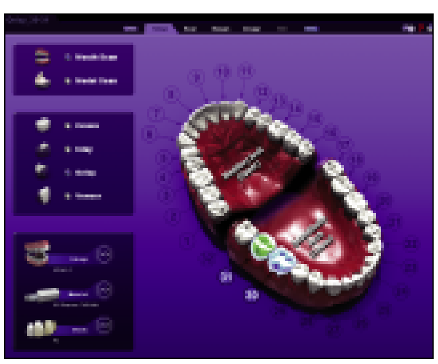

Figure 8. The data file in the E4D CAD/CAM system.

Figure 9. Digital model proposal.

Figure 10. Digital onlay design.

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ed, and the dies trimmed. These models were then used to fabricate appropriate restorations: layered, pressed, milled, cast, or in various combinations of these processes. Even though this application offered many advantages to the doctor-technician team, it still required the taking of an intraoral impression using conventional techniques along with the conventional laboratory procedures to create the traditionally created dental restorations.

In this article, we would like to go to the next phase in the evolution of the doctor-technician working relationship.

THE WAY IT *WILL BE*: A CASE REPORT

A 48-year-old male patient presented with a missing cast-gold restoration on tooth No. 31 and a fractured ceramic onlay on tooth No. 30 (Figure 6). He possessed a negative medical history and good oral hygiene with resultant periodontal health. Digital radiography was used to diagnose decay, which was undermining the existing and previous restoration. His teeth were asymptomatic. Treatment options of a gold onlay, a porcelain-fused-to-metal crown, or CAD/CAM (single appointment) ceramic onlays were considered and discussed with the patient. In these areas, while a gold onlay certainly is an excellent and prudent choice, properly placed CAD/CAM-milled onlays have also been extremely successful when proper preparation and occlusal design is employed.[1] The patient was appointed for a single prep-and-seat appointment. Upon arrival, his right mandibular quadrant was anesthetized. The existing ceramic restoration was removed, and both teeth were prepared for the all-ceramic onlays following accepted CAD/CAM glass-ceramic preparation guidelines (Figure 7): adequate clearance, rounded internal aspects, and supragingival butt-joint margins.

THE E4D DIGITAL PROCESS

An individual file is created within the DentaLogic software for each patient. The operator can input the patient's name or record number and the appropriate tooth number(s) to be treated and entered. (Up to 7 restorations can be designed and restored at the same time with the E4D Dentist System.) Then, the type of restoration anticipated is checked (full crown, veneer, inlay/onlay). Additional preferences include material choices (IPS Empress CAD or IPS e.max CAD [Ivoclar Vivadent], Paradigm MCXL or C [3M ESPE]) and the preferred shade. System defaults that can be set ahead of time or changed per patient/case are as follows: preferred contact tightness, occlusal contact intensity, and the virtual die space. (The virtual die space defines the internal fit of the final restoration to the die/preparation.)

Since the E4D Dentist System scans tooth structure, impressions (alginates included), or a stone model without applying a powdered contrasting agent prior to scanning, the system requires the user to enter the method of scan (intraoral/mouth or extraoral/impression or model). All of this information can be entered prior to patient treatment or changed at any time, should the actual treatment differ from what was originally planned (Figure 8).

Once the preparation has been completed, the intraoral scans are completed. In this case, a static bite registration will be taken primarily positioned on the mesial of the premolar, as well as a series of scans to capture the entire preparation and neighboring areas.

A static bite registration was created by injecting a blue, resilient bite registration material (Virtual Bite [Ivoclar Vivadent]) onto the preparations while having the patient occlude. (This particular bite registration has metallic additives to allow for scanning without powdering for those systems that require powder. The E4D Dentist System can be used with any bite registration material.) The IntraOral

Once the images of the preparation, neighbors, and bite registration are captured, the computer then has all the information it needs to prepare the working model—the preparation and the opposing model (from the bite registration images).

Digitizer scanner (IOD [D4D Technologies]) was used to capture occlusal scans of the bite registration over the preparation and the occlusal surfaces of the neighboring teeth.

Next, scans from the occlusal, lingual, and buccal aspects were taken of each preparation with the IOD scanner to build the virtual model to completion. Multiple scans are taken per preparation, capturing the full contours and undercuts of the neighboring teeth and preparations, in order to achieve proper proximal contacts and overall anatomical contours. Once the images of the preparation, neighbors, and bite registration are captured, the computer then has all the information it needs to prepare the working model—the preparation and the opposing model (from the bite registration images).

The real 3-D virtual model is then presented on screen. It can be rotated and viewed from any perspective (Figure 9). The operator can choose to view the model in animation (stone view) or in a real ICEverything View (ICE), which represents a wrapping of the actual images over the digital mesh. ICE provides a realistic view of the clinical conditions, allowing the operator to distinguish discolorations, buildups, soft tissue, and even enamel and dentin in many areas.

The first step in designing the restoration is to virtually define the parameters and borders of the final restoration. These are defined using the bite registration information, the adjacent teeth, the contact areas, and finally, the gingival margins of the preparation. The computer, with the aid of the Autogenesis (morphing) software, will place the restorations automatically in a preferred and appropriate position (based on all input and neighboring anatomical detail), but now the operator's experience, training, and knowledge of form and function is needed to reposition and contour the restoration manually to the clinically ideal location, if needed.

With a few simple mouse clicks, the position and rotation of the crown can be altered as desired. The software's automatic occlusion application will automatically readjust each individual cusp tip and triangular ridge. It will also automatically adjust the restoration's contours, contacts, and marginal ridges, based on the preferences and bite registration information, according to the newly desired position and rotation. The virtual restoration responds and adapts to all parameters immediately as they relate to the new position. The position and intensity of each contact point is graphically demonstrated and color-mapped immediately on the screen. These can be adjusted easily pending operator and clinical preference.

Customized aspects and artistic creativity are also possible through an array of virtual carving and waxing tools. These can be used to manipulate occlusal anatomy, contours, and occlusal preferences, basically mimicking the actual laboratory methods and armamentarium. Each step is immediately updated on screen so that the operator can see the effect of any changes (Figure 10). In addition, visual representations of material thickness; X, Y, or Z slicing; or a number of other variables can be checked, confirmed, or changed as needed—all within the DentaLogic software.

When the final virtual restoration has been completely designed, it is simply a matter of loading the milling chamber with the predetermined shade and size of ceramic (or

Figure 11. Milled restorations with sprue.

Figure 12. Stain and glaze.

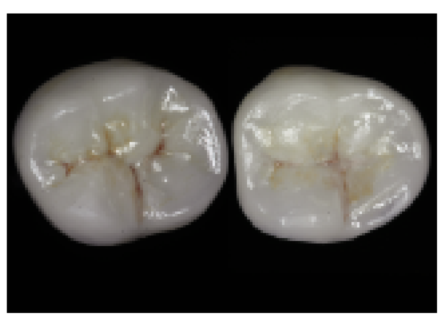

Figure 13. Completed restorations after stain and glaze.

Figure 14. Final restorations after bonding.

composite block), and pressing an on-screen button. In a short time, an exact replica of the design is reproduced in ceramic (Figure 11).

THE IN-OFFICE LABORATORY PROCESS

The ceramic restorations are then removed from the milling chamber and prepared for final aesthetic enhancements. First, the milling sprue must be removed. Then, if desired, surface texture and occlusal anatomy are defined using diamond and carbide burs (Brasseler USA, Premier Dental, or AXIS). Care should be taken not to alter the occlusal or interproximal contacts, since these areas were perfected in the E4D software and accurately reproduced during the milling process. After aesthetic contouring, restorations are rinsed with water to remove surface ceramic debris and dried. Since the patient is still anesthetized and in the chair, try-in for proximal and marginal fit can be completed chairside with assurance. Once the restorations are verified and adjusted, conventional ceramic stain and glaze techniques can be used, if needed. If desired, with minimal training required, the restorations can be aesthetically enhanced by the addition of subtle colors (stains) and glaze application using an appropriate glazing oven in the dental office (Figure 12). The ceramic chosen for this case was Empress CAD Multi-blocks. These ceramic milling blocks were designed to offer optimal aesthetics by offering varying degrees of color and translucency designed into the block. This was created to mimic the appearance of dentin and enamel as well as the polychromatic nature of natural dentition (Figure 13).

RESTORATION PLACEMENT

Next, the internal surfaces of the stained and glazed ceramic restorations were etched with 5% hydrofluoric acid (IPS Ceramic Etching Gel [Ivoclar Vivadent]) for one minute, rinsed thoroughly, and dried. A silane-coupling agent (Monobond-S [Ivoclar Vivadent]) was then placed for one minute onto the internal surfaces and then lightly air-dried. A self-curing (chemical-curing), resin-based luting cement (Multilink Automix [Ivoclar Vivadent]) was selected for final cementation. A&B primer was mixed vigorously and scrubbed onto all preparation surfaces. The restorations were loaded with the appropriate shade of cement and were seated to place; excess was removed. The occlusal contacts were checked and harmonized in static occlusion, and excursive pathway freedom was verified. Minimal adjustments were needed due to the correct capture and alignment of the bite registration data.

The finished restorations, which were designed and created by the team effort of the author and coauthors without the aid of an impression, were found to be in functional and aesthetic harmony (Figure 14). They were completed in one appointment.

CONCLUSION

The dental profession currently regards CAD/CAM technology as just a machine that fabricates full-contour ceramic restorations or frameworks. Digital dentistry and the digital dental team represent a totally new way to diagnose, treatment plan, and create functional aesthetic restorations for our patients in a more productive and efficient manner. CAD/CAM dentistry will only further enhance the dentist-technician-assistant relationship as we move together into this new era of patient care.

Automation has been slow in coming to dentistry, and although new equipment has been introduced to make our jobs easier, we still create complex dental prosthetics using old techniques. And, even though the "lost wax" technique is still a reliable method of fabrication, there will come a day in the near future when all frameworks and full anatomical crowns will be designed on a computer. Only then will we truly realize the wonder and awe of dental CAD/CAM technology that was introduced to the profession so long ago.✦

References

1. Otto T, Schneider D. Long-term clinical results of chairside Cerec CAD/CAM inlays and onlays: a case series. *Int J. Prosthodont.* Jan-Feb 2008; 21 (1): 53-59.

Dr. McLaren graduated Phi Beta Kappa and magna cum laude from the University of Redlands. He received his dental degree from the University of the Pacific School of Dentistry, where he graduated Omicron Kappa Upsilon, and received his specialty certificate in prosthodontics from UCLA School of Dentistry. He maintains a private practice limited to prosthodontics and aesthetic dentistry in which he does all of his own ceramics. He is the director of the UCLA Center for Esthetic Dentistry and is the founder and director of the UCLA Master Dental Ceramist program. He is an associate professor in the biomaterials and advanced prosthodontic department. He is also an adjunct assistant professor at the University of Oregon Dental School. He can be reached at emclaren@dentistry.ucla.edu.

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