Integrating images in dental manufacturing technology: the prosthetic value chain

Tomorrow’s practice of dentistry will likely include interventions, such as biological scaffolding and tissue regeneration, but for today and the immediate future reconstructive dentistry will continue to be based on the surgical removal of diseased and malpositioned teeth, and the prosthetic replacement and restoration of damaged or missing teeth into form and function. Successful treatment of these conditions will always involve physical intervention; however, many elements within the diagnostic, planning, and treatment phases of patient care can now be accomplished within the virtual environment—digitally. Currently there are many digital domains or, as Daniel Wismeijer more aptly describes, dental “digital islands,” which may still appear to be unrelated: photography, cone-beam computed tomography (CBCT), optical impressions, and computer-assisted design (CAD)/computer-assisted manufacture (CAM). With the increasing use and convergence of these technologies, it is not difficult to predict that the dental profession will one day operate within a totally digital environment. What is more difficult to judge though is when this will happen and what business model, implementation strategies, and associated enabling technologies will be present in successful practices. At this stage, some hesitancy and uncertainty exist in implementation, as no practitioner wants to be using technology in clinical practice that becomes the dental equivalent of “Betamax.”

The dental industry is certainly not the first to have growing pains from the implementation of digital technology. The computer industry changed dramatically and permanently when software took over in the 1980s. Today, software is profoundly changing the mobile phone industry, with the rise of open operating systems, such as Winmobile, Symbian, and Android. The introduction and increasing market share growth of competitive alternate software also affects other areas of enterprise, including the automotive and health care industries, as well as many others. The implications of such innovations transcend just engineering implementation issues. According to business management concepts introduced by Porter, they can have profound effects on any or all of the activities within an industrial production sequence—from inbound logistics, operations (production), outbound logistics, marketing and sales (demand), and services (maintenance). This interlinked chain of activities for a business operating in a specific industry is referred to as a value chain, implying that each process in series adds value to the final product. One of the main lessons that the mobile phone and automotive industries have learned, in some cases painfully, is that the amount of software development required to maintain innovation does not allow it to keep building closed, end-to-end systems that use proprietary software and manufacturing devices. To reduce the software development costs per user, both industries have been using standards for many years to provide a consistent user experience.

This lesson certainly applies to the digitization of the dental industry and, in particular, the manufacturing processes involved in the production of dental prosthetic replacements—the prosthetic value chain. Key activities in this value chain include clinical assessment, diagnostic imaging diagnosis, treatment planning, surgical site preparation (which may include preparation of teeth or placement of implants), temporization, impressions, prosthetic design (CAD), restoration fabrication either at chairside or in the dental laboratory, and prosthesis insertion. A number of elements within this chain are already “digital” in nature. The era for implant- and tooth-supported prosthetics based on CAD/CAM has reached maturity over the past 2 decades, in large part because of market-driven development of various generations of visible light impressions systems. Before this, clinicians relied on physico-chemical impressions and stone models on which to fabricate indirect restorations. Chairside CAD/CAM restoration fabrication, although now mainstream, is still used by...
the minority of clinicians. Most certainly, CAD/CAM will grow rapidly in the future at the bedside or in the centralized milling laboratory. Similarly, digital data transfer of optical impressions directly from the mouth and virtual modeling are increasingly being used for planning. Although the spatial resolution of CBCT systems is currently insufficient for CAD/CAM restoration of teeth, image-guidance applications of this technology are expanding and, in some areas, already exceed purely diagnostic radiology implementation. CBCT is a valuable adjunct to planning dental-implant placement, providing sufficient resolution for making virtual or real study models, and facilitating construction of surgical templates and, in some systems, the implant-borne prosthesis itself. The immediate future of dentistry will undoubtedly see great strides toward the fusion of data obtained from 2 or more portions of the electromagnetic spectrum to create a hybrid dataset. Transmission-based imaging (i.e., CBCT) will most likely provide the digital virtual framework with supplemental details being provided by reflective-based imaging (e.g., optical scanners). As this concept develops, fusion of images from systems with higher textural (e.g., surface scans) or spatial (e.g., intraoral scans) resolution will become more commonplace. Integration of these digital elements requires a consensus standard for image data interchange. This would overcome present limitations of proprietary design that are problematic given the mix and match of different players along the prosthetic chain.

There is but one basic set of standards for image file format: the international DICOM (Digital Imaging and Communications in Medicine) standard. This is the International Organization for Standardization (ISO)-referenced standard for image format and communications. It covers all images, including visible light, as well as radiographic procedures, including simple transmission images, CT, CBCT, magnetic resonance imaging (MRI), ultrasound, and so forth. The DICOM Standards Committee has 27 active working groups, including WG 22 (Dentistry) and WG 24 (Surgery). Such working groups often work together to advance the DICOM standard. The dental diagnostic imaging value chain has benefited from the DICOM standard for many years. For example, third-party preoperative planning software works with data from any CBCT scanner, so long as that scanner generates DICOM-compatible results. In addition, new supplements for intraosseous implants, including those used for dental implantology, have been developed by collaboration among working groups. This is very different from the current prosthetics value chain comprising scanning, design, and manufacturing elements. Currently there are no standard transfer interfaces defined between scanning and design phases, or between design and manufacturing. As a result, dental professionals who wish to avail themselves to totally digital prosthetic workflow currently face being “locked in” to a proprietary “end-to-end” or closed system or can choose between various components from a variety of manufacturers without the full assurance of connectivity, quality, and comprehensive support services facilitated by compliance to a standard. Although this approach directs practitioners toward specific vendors for various digital solutions, it ignores the lessons already learned in other industries with regard to the efficiencies realized by adoption of standards across a value chain. There are great advantages to the patient, dentist, and manufacturer in digitizing the prosthetic value chain. Procedures will become more comfortable and performed more quickly, reducing the number of visits for the patient, and minimizing costs. Many procedures would become reversible, and free from imprecision, resulting from the physical instability of materials over time, such as impression dimensional change or errors related to study model preparation and laboratory fabrication. For practitioners, digital flow provides a communication platform referring dentists, patients, insurance companies, suppliers, and milling centers. Efficiencies will also be realized with elimination of redundant material and time associated with intermediate processes involved in impressions and study model fabrication. For vendors, adoption of a digital prosthetic chain reduces inventory and allows concentration of resources to manufacturing activity and expanding markets rather than software development, reducing user cost.

As dental workflow from imaging to impressions to fabrication and manufacture of prostheses becomes ever-more digital, expansion of the DICOM standard has become necessary to include all aspects of the digital dental production cycle. To restrain costs for manufacturers and to achieve interoperability for dental practitioners and their patients, universal standards are greatly needed. With the recent announcement by a prominent manufacturer within the prosthetic value chain to provide open systems, it is apparent that the benefits of a universal standard are acknowledged commercially and that this situation will soon change.

This challenge will likely be led by interactive project groups of DICOM WG 22 and WG 24. Two workitem proposals are in process with leading manufacturers involved. The first proposal is directed toward developing an interface standard between scanning and design, whereas a second deals with design and manufacturing. These activities will ensure integration of scan technologies with design software and allow conversion of virtual simulations into dental elements via
multiple manufacturing technologies, including milling and 3-dimensional printing. More simply stated, construction of bridges between “digital islands” within the shrinking analog world is well under way.

Thanks are extended to Dr. Allan G. Farman, American Dental Association (ADA) representative to the DICOM Standard Committee, cochair to the ADA Standards Committee on Dental Informatics WG 12.1 (Interoperability) and to DICOM WG 22 (Dentistry), and Dr. Michiel van Genuchen, head of Dental Software Solutions, Straumann Digital Solutions, who were my coauthors in a recent publication on which this editorial is based.19

William C. Scarfe, BDS, FRACDS, MS
Section Editor, Oral and Maxillofacial Radiology

do:10.1016/j.tripleo.2011.05.045

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