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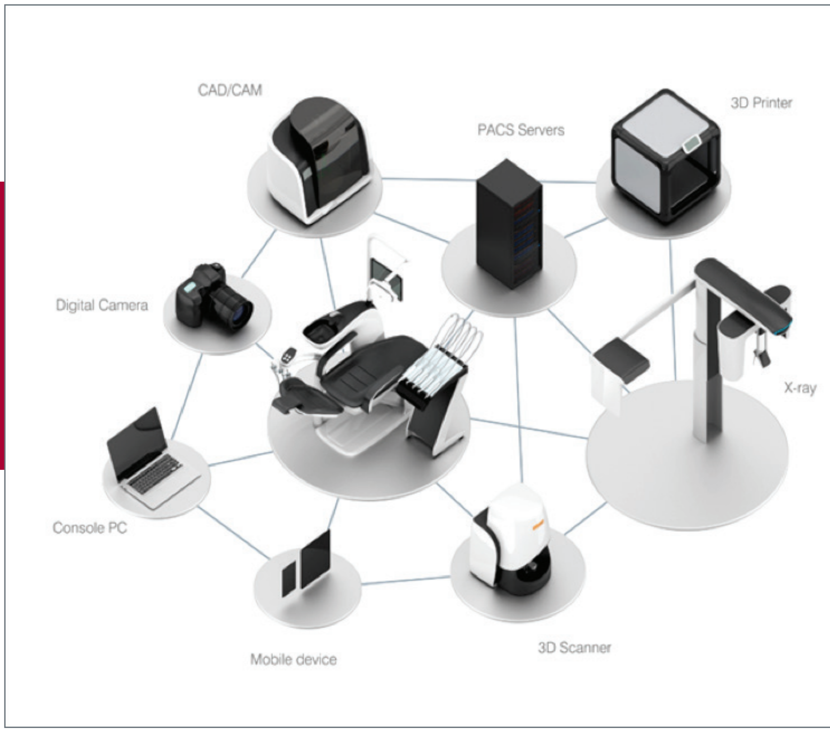
The Current Impact of Digital Technology in Prosthodontics

The profession of dentistry continuously demonstrates innovation and improvement on many fronts. Historical advances in public health by the introduction of water fluoridation and targeting oral health awareness to address a mid-century caries epidemic, an expanded understanding of the pathophysiology of periodontitis, the improvement in dental materials, equipment, and the advancement of clinical therapies and outcomes throughout the second half of the 20th century underscore a strong professional commitment to oral health care and wellness. There exist ongoing challenges of access to oral health care, the impact of aging on oral health care, understanding the relationship of oral and systemic health, and providing long-lasting restorations that improve health and the business of dentistry. The more recent advances in dentistry have involved the adoption of digital technologies in all forms to improve the quality of care, and patient experiences.

Digital dentistry includes the broad array of technologies that bring the communication, documentation, manufacture and delivery of dental therapy under the umbrella of computer-based algorithms. It begins with patient-based records that include charting of clinical data, visual images and integrated radiologic images gathered into business, documentation, and planning software. Three-dimensional imaging based on radiographic, surface scanning, and photographic/videographic data sets enables the capture of diagnostic information and the design of prostheses that can be manufactured by computer numeric control (CNC) systems that automate both additive and subtractive production schemes. Additionally, optical and non-ionizing radiation methods of diagnosis and treatment such as lasers are included under this umbrella of computer-based control of clinical dental activities. Ongoing efforts are directed toward integrating these technologies synergistically to create improved therapeutic environments.

Broad dissemination of digital technologies in dentistry began in the early 1990s with the introduction of digital radiography and the earliest versions of intraoral scanning and computer-assisted design and computer-assisted manufacturing (CAD/CAM) crowns. The development of cone beam computed tomography (CBCT) heralded a second wave of excitement as three-dimensional images of the craniofacial region offered new advantages in diagnostics and therapy. When iterative improvements in hardware, software, and materials merged in the early 2000's, new accomplishments in clinical dentistry were realized. Same-day, chairside restorations of remarkable dimensional and esthetic fidelity were obtainable. Guided implant surgeries provided enhanced therapeutic workflow and safety. As the techniques and advantages mounted, the most recent decade of activity by early adopters fueled innovation. Digital technology is driving remarkable change in the practice of Prosthodontics.

This multilevel quality improvement afforded through digital technology is recognized in workflow and efficiency, record keeping, data fidelity and therapeutics.



THE BENEFITS OF DIGITAL TECHNOLOGY

The many benefits of digital dental technologies can be summarized under four broad categories. The first is improved communication. Clarity in communication is enhanced by electronic patient records that offer platforms for clear exchange between dentists, patients, dental laboratory technicians, and third party stakeholders. The digital record can accelerate, elevate the accuracy of and enable digital commerce (billing, drug prescriptions, laboratory prescriptions). Photographic representations of intraoral conditions and digital radiographs elevate the transfer of information to patients and among health care providers. Three-dimensional imaging technology using radiographic or surface scans enhances diagnosis, planning and communication between dentists and other health care professionals, dental laboratory technicians, patients, as well as third party providers. Error free, real time communication underscores the efficiency of integrated electronic patient records.

The second is improved quality. Beyond the digitized, pixel/voxel quality of data, the digitization of data supports quality control measures. This multilevel quality improvement enhances workflow and efficiency, record keeping, data fidelity, and therapeutics.[1] Software can assure data entries and improve and protect decision-making. The intraoral scanning of tooth preparations that are viewed in high contrast, magnified fields on a computer screen and often in direct sight of the patient permit real-time modification for iterative clinical improvement. Regarding the productivity, efficiency, and accuracy of digital impression systems and related milled crowns, Fasbinder (2013) reported that the digital impression technique is faster according to some reports, and that a crown fabricated using a digital impression possesses equal or greater marginal accuracy than conventional crowns.[2] A recent systematic review and meta-analysis, Chochlidakis (2016), concluded that digital impression techniques provided better marginal and internal fit of fixed restorations than conventional techniques did. The perceived and measured enhanced quality of care derived through digital technology is a main clinical advantage of digital technologies in dentistry. The quality of crown margins produced by digital technology[3] is equivalent or enhanced compared to conventional techniques.

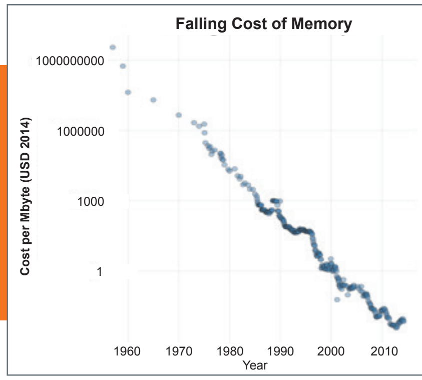
"No significant difference was observed regarding the marginal gap of single-unit ceramic restorations fabricated after digital or conventional impressions."

- Tsirogiannis et al, 2016

Digital technologies also allow for the merger of diverse digital datasets (DICOM, STL), resulting in new applications and purposing. For example, dental implant placement using surgical guides[4] can be improved. The generation of patient-specific instrumentation as surgical guides has enabled new workflows in oral and maxillofacial surgery and dental implant therapy. Here, accuracy, efficiency, and communication converge to enhance the clinical outcome and the experience for the dentist, the technician, and the patient alike. Importantly, digital workflows also provide the operator improved control of the design and production of definitive prostheses.

Diagnostic improvements through digital technology provide important benefits. Quantitative and documented information can be derived and included in patient records. The advantages of digital radiology, representing the first widely adopted digital technology in the operatory, are widely recognized. They include lower exposure doses, reduced working time and simplified manipulation, enhanced workplace management (no wet processing), absence of processing artifacts, image enhancement (e.g, contrast and density), and digital diagnostic enhancement.[5] Improved dental caries diagnosis further requires alternative or adjunctive detection methods with sensitivity sufficient for initial lesions and various laser-based digital methods are advancing.[6] Advancements in 3-D radiographic imaging have led to widespread acquisition of CBCT hardware and related diagnostic and treatment planning software. A recent review of 43 such devices recognizes several advantages[7] including excellent imaging quality at reduced radiation doses and at lower costs than conventional, multislice CT imaging. Key variables include field of view (FOV), detector methodology (e.g. flat-panel), voxel size and tube potential and current. The ability to reduce radiation dose, enhance image quality, and provide representative 3-D images of the region of interest continues to improve with developing technology.

Additional tools in diagnosis include the effective digitization of photographs and diagnostic casts. Regarding intraoral scanning for the purposes of diagnosis and planning, a recent study demonstrated that there was no difference between plaster cast dimensions and those from intraoral scans, except for the mandibular intermolar width.[8] When considering desk top scanning of plaster casts, the generated digital models were proven reliable and clinically acceptable for measuring tooth and inter tooth dimensions.[9] Digital photography quickly replaced film and digital cameras are now fully integrated in smartphones. The advantages of digital photographs include the relatively low cost of storage, the archived nature of the document, and the relative accuracy of photographs versus clinician's memory of previous conditions. As part of the electronic health record, it is imperative that consent be acquired and the document storage and use be consistent with Health Insurance Portability and Accountability Act (HIPAA) regulations. Aside from documentation, digital photography enhances communication between the dentist, patient, staff, dental laboratory technician, and other stakeholders. The cost of digital photography is no longer a barrier to use, however, its routine inclusion in the diagnostic steps meet barriers in practice.



The third benefit is archiving individual patient data. Storing of virtual diagnostic casts is possible due to the high fidelity of the scanned image. Advantages of archived diagnostic casts in 3-D include a) producing durable images without loss or damage of original casts, b) interfacing with other images for analysis by innovative analytic and design software, c) eliminating human error and d) reducing the cost of storage.[10] As the cost of memory has continued to drop, digital records are readily and inexpensively archived. The decreasing cost of memory has made storing large numbers of large data sets (DICOM, STL, Patient records) possible, enabling the storage of comprehensive patient datasets that can be recovered for year-to-year comparisons, for planning and communication, and for manufacture of one or another device. Together, these three general advantages of digital dentistry lead to practical and economic advantages for the entire therapeutic team and patient.

A forth and critically important benefit of digital technology in Prosthodontics is its positive impact on the patient experience. The improvement in diagnostic data serves to inform enhanced treatment plans. The digital platform elevates the discussion of planning and informed consent to three dimensions where clarity is provided. The reality of a single visit indirect restoration is not easily attained without digital technology and is now widely available. There is greater comfort for many patients who experience intraoral scanning compared with conventional elastomeric impressions.[11] There is reduced radiation dose for digital radiographic images compared with those obtained using conventional radiography.[12] All of this data can be conveniently collated, shared, and maintained in a HIPAA compliant environment for communication and archiving for each patients' ownership. Without comprehensively surveying the corpus of dental laboratory technology, it is sufficient to state that digital technology enhances planning and execution by rapid prototyping, enhances production by automation and high fidelity of the CNC process, distributing manufacture to the clinical site where appropriate, and archiving the prostheses for repair/retreatment.[13] Many of these advantages are not possible in an analog environment.

BARRIERS TO THE ADOPTION OF DIGITAL TECHNOLOGY

Innovative information and digital technology platforms are now firmly embedded within everyday dental practice, having emerged from a minority, early adaptor acceptance to more broad-based utilization (early majority adopters) in dental laboratories and, in many instances, operatories. Experts indicate that the main motivations for accepting or rejecting a new technology include the relative advantages they offer compared to analog methods they replace and these can be subdivided into time advantages, financial advantages, and clinical advantages. As indicated by others, the rapid adoption of dental technology was well represented over a half century ago when water/air turbines replaced belt driven handpieces; advantages of time, simplicity and comfort were immediately obvious and desired by both patients and dentists. In contrast, there has been a relatively slow adoption of chair-side CAD/CAM restorations that introduced a foreign skill set (computers), raised questions of relative quality (now erased by new materials and increased quality of scans and milled restorations), and has changed financial decision-making from relatively small, commodity based decisions to larger, capital equipment based financial decisions. There are realistic financial advantage questions that must be addressed in adopting digital technologies in dentistry. In addition to the relative costs, apprehension may be elevated in response to concerns over advancement-fueled and obsolescence-related deflation of recently purchased technology. Enhanced accuracy through technology may be a double-edge sword; many embrace elevated quality of their care while others worry that its innate documentation presents a standard not readily attained. Better technology may require better office systems (fortunately linked through electronic patient records), and better, if not more diligent, dentists.

The adoption of electronic health records by physicians informs us of issues regarding adoption of technology. A comprehensive review highlighted several recognizable barriers including a) time, b) cost of IT support, c) absence of basic computer skills, d) workflow disruption, e) concern about security and privacy, f) interprofessional and intersystem communications, and g) technical and expert support.[14] In a similar manner, a study of barriers to innovation in the construction industry included, a) understanding of risk and liability, b) financial disincentives, c) high equipment costs, d) lack of basic research support, e) regulatory concerns, and f) poor leadership.[15] Digital dental technologies are also viewed as providing new opportunities or imposing potentially new risks. Initial costs, potential financial risks, time, and unanswered questions regarding the integrity of the digital solution (suspicion) appear common barriers among different professionals' adoption of technologies. While these opportunities and risks can be measured, it was recently suggested that the main barriers to dentists' adoption of new technology are awareness and emotion.

Barriers and incentives to adoption of digital technology					
	Pragmatic	Education	User	Clinical Environment	Social Environment
Barrier	• Cost • Learning curve • Complexity • Related Capital investment (space, IT support)	• Access to new information • Pragmatic barriers imposed at dental schools • No CODA standards driving option	• Lack of basic computer skills • Lack of access to new information • Retrenchment • Fear	• Lack of peer support • Absence of IT knowledge or support • Absence of dental laboratory support	• Absence of reinforcing education in community • Lack of support from local laboratories • Little industry support
Incentive	• Cost savings • Space savings • Quality • Predictability and standardization communication • Archived storage	• Pragmatic advantages provided to dental schools • Industry supports education • For profit educational opportunities	• Advantage in marketplace • Workplace enforced • Laboratory encouragement • Recognition of pragmatic incentives and barriers	• IT support • Digital environment in place • Multi-doctor workplace • Educational support in house (peers) • Frequent need and use	• Support of local dental organizations • Local key opinion leader influence • Local laboratory support

Other factors do influence the adoption of new technologies in dentistry. The changing landscape of dental practice certainly has broad implications. Adoption of digital technology in dentistry is higher in multi-dentist and large, corporate practices where the cost of equipment is shared broadly among users and deployed at a greater rate throughout the day. The associated IT costs of managing large datasets should not be lost in the consideration of these technologies, especially the aspirational, fully integrated digital record and manufacturing systems of the near future. The training of staff and dentist to manage the equipment is another issue that must be addressed.[16]

Education also influences dental practice and dental schools are reconfiguring current curricula to lead an evidence-based program of education utilizing digital technology in dentistry. A 2015 survey of faculty members by the American College of Prosthodontists revealed that dental educators currently report 92% use 3-D radiography, 69% use intraoral scanners, and 50% use in office mills and this contrasts to 56%, 32%, and 17% of private practice prosthodontists, respectively. The familiarity of prosthodontist faculty with digital technology is a key feature that may positively influence the adoption of digital technology in the broader community of interest. The traditional of barriers within dental schools are rapidly eroding.

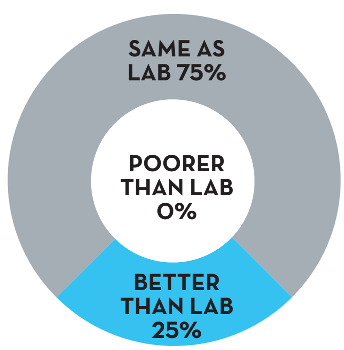
THE IMPACT OF DIGITAL TECHNOLOGY IN DENTAL EDUCATION

At the clinical level, the three most widely adopted digital technologies were digital radiography (91%) and cone beam CT (85%), CAD/CAM indirect restorations (58%), and virtual surgical guides and implant placement (30%).[17] Focusing only on the prosthodontic discipline, educators are engaging in emerging digital technologies. A recent survey of US dental school deans conducted by Brownstein et al (2015) reported that greater penetration of digital technology occurred in preclinical didactic courses and the lowest was in preclinical laboratories. CAD/CAM has reached the clinical environment as well. One important observation regarding digital dentistry in the academic environment is that technology adoption in US dental schools is keeping pace with or exceeding the early adoption in private practices (Brownstein et al (2015); American College of Prosthodontists Survey (2015)).

Digital technology will improve dental education. This is particularly interesting for teaching of restorative techniques. Technology permits improved self-assessment and can even provide for a virtual learning environment. Dental students gain instant, objective, and visual feedback that permits enhanced self-assessment.[18] Haptic learning tools may offer students 24/7, independent, and individual feedback for dexterity training that is perceived as easy to use and a fun learning experience.[19] Software based evaluations may improve education by offering an objective grading system and by calibration of faculty.[20] A new curriculum with enhanced learning objectives and defined outcome measures is needed to fully embrace and leverage the opportunities offered by digital technology in dentistry to its education.

Creating and maintaining the academic environment for digital dentistry is not, however, without current and future challenges. A recent survey of Deans identified new clinical technologies and technology costs among the main factors that challenge fiscal strategies of dental schools.[21] Digital technology, broadly represented, does present financial challenges for dental education. While not documented, the superimposition of digital restorative technologies upon conventional restorative techniques confounds academic, pragmatic, and financial decision making in academic programs.

Digital technology is present in dental education. The use of CAD/CAM for restorative dentistry literally crept into dental school curricula via the laboratory industry servicing the clinical activities. A majority of single unit crowns are currently produced using a digital workflow. Multiple dental schools have firmly established a direct, chairside milling approach to digital manufacture of crowns. In fact, there may be a preferential swing toward digitally produced restorations as faculty perceptions appear to favor even a CAD/CAM chairside crown. When students were surveyed, 90% of students reported that they "enjoyed designing a full contour crown using CAD" compared with 13% who enjoyed using the wax-added technique (Douglas et al, 2014).[22]



Faculty determined CAD/CAM chairside crowns were equal or better quality than laboratory fabricated PFM or metal crowns.[23]

Reifeis et al, 2014

Regarding digital denture technology, a recent survey[24] (Fernandez et al 2016) revealed that approximately 50% of post-graduate prosthodontic programs included aspects of this technology in their programs while only 12% of undergraduate programs included this technology in their curriculum. Fewer dentures were processed using this technique. However, most educators plan to include digital denture fabrication in their curricula by 2020.[22] Digital denture technology will emerge in dental schools as the many advantages in education are superimposed on pragmatic advantages that reduce clinical timeframes and eliminate the laboratories required for teaching through the use of stone casts and articulators, waxing and processing of dentures in the preclinical environment.

Removable partial denture technology has lagged in the transfer to digital environments. Recently, it has become possible to produce removable partial denture frameworks using CAD/CAM design and manufacture. Given the complex nature of the RPD framework and its individual design components, the digital environment is well suited to teaching and exploring all aspects of RPD design. Scanning of soft tissues and the complexity of manufacture have slowed technology transfer, but many of these challenges have been addressed with some success. The possibility and some advantages of partial removable prosthesis fabrication by digital scanning, design, and manufacture has been reported at the clinical level. Dental educators must adopt quickly to digital technology in this clinical arena as the educational advantages are remarkable.

In a 2015 survey of the members of the American College of Prosthodontists, after 'increase public awareness", "lead the advancement of digital dentistry" was the second most cited response to "Please identify ways that the College and Foundation can better serve you and the interests of the specialty." Digital dentistry was the most cited topic in response to the question "On which of the following topics do you believe the ACP should conduct research?" 65% of prosthodontists utilize digital dentistry in their practice. While not all clinicians utilize digital software for regular treatment planning, nearly 50% of ACP members have adopted this.

OUR FUTURE AND DIGITAL DENTISTRY

Prosthodontics has much to offer and plenty to gain from the current emergence of Digital Technology into all facets of dentistry. In the coming few years, the more complete integration of data from all sources into an integrated electronic patient record will place digital technologies centrally within diagnostic and planning activities. The ability to create a complete virtual record of the patient – one that can be updated over time – can provide a four dimensional record of our patients. The impact of time and environment on our patients' oral conditions and our restorations will be viewed in realistic three-dimensions with micron-scale accuracy. These technologies are currently all available, but not fully integrated. Over the longer term, digital diagnostics using non-ionizing radiation and molecular genetics linked to our patients' overall systemic health will infiltrate our clinical domain and the digital patient record. The value of a comprehensive record linked to a comprehensive treatment plan may serve multiple stakeholders from the dental laboratory, to the consulting physician, to the third-party payment organization. Thus, digital technology-supplemented EHRs will be reinforced as a communication tool in primary health care that includes dentistry.

Prosthodontics as a specialty will continue to lead the broader discipline in adopting new therapies and improving clinical outcomes. Current digital dental technology is based on decades old ideas and industrial techniques that have been adopted to dentistry. The advances in ceramics have expanded the use of milling technology and these continue to be refined through our research and clinical efforts. Dental laboratories have demonstrated the remarkable value in digital work flow and clinicians are adapting rapidly. We are presently realizing the gains in efficiency, productivity, and accuracy from digital technology. The next years will see innovations in imaging and manufacture. Improved surface scanning hardware and advances in imaging software will enhance our design capabilities, while developments in manufacturing technology, especially additive technologies for metals and polymers (in the future biologics), will enable rapid manufacture of prostheses and components to address the complexity of emerging therapies (e.g., lingual orthodontics, full mouth rehabilitation using partial coverage ceramics, oral and maxillofacial grafting procedures). The digital dental operatory and digital dental laboratory will become more seamless and better adapted to the challenges of improved clinical therapy.

Dental education's complete adoption of digital dentistry will require the aspirational spirit of early adopters of ever-changing technologies who possess foundational knowledge and the integrity to apply an evidence based approach to change. Continued change will present itself in to the realm of restorative dental therapy and positive, assured steps in the right direction will be needed. A strong curriculum that embraces fundamentals of technology and biology can serve as a foundation supporting ongoing change. Integration of a comprehensive digital curriculum in our schools that embraces the knowledge and application of emerging technologies is an important transformational point in the broader adoption of digital dentistry.

SUMMARY

Digital technology brings many advantages to dentistry. While these advantages are often remarkable and clearly distinguish digital from conventional techniques, adoption has been slow. In all digital dental applications from electronic patient records to selective laser sintering of complex prosthetic frameworks, the common advantages of improved communication, increased control, greater quality and data archiving, and improved patient experiences simply cannot be matched using exiting conventional methods. Despite the general and other specific advantages available through digital dentistry, significant barriers to adoption remain. Several factors influencing the adoption of technology, including familiarity of knowledge and education, are frequently overlooked as central drivers of adoption. The lack of information and skill necessary to integrate and utilize technology efficiently – and the apprehension concerning acquiring this information and skill – are underappreciated factors that limit adoption. Other factors frequently mentioned include cost, accuracy or utility, and outcomes. The factors that drive adoption of technology are as important as the factors that drive innovation.

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