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How technology from other industries can transform dentistry

There is a long history of technology migration between dentistry and other branches of medicine. In this article we review recent technology advances in dentistry and predict the new advances which are set to be driven through technology transfer from other industries.

Competition in the dental market, and the desire to improve patient care, requires dentists to adopt differentiated, patient-centric approaches and to selectively adopt new technology as it emerges. To gain adoption, new technology must pass robust economic tests considered either at the level of the sole practitioner or the dental group. The technology must offer distinct advantages by enabling faster procedural workflow, better outcomes or an improved patient experience.

We predict next-generation dentistry will continue to see new innovations in digital dentistry, the ability to manufacture on site and the ability to image using non-ionizing radiation. The dental office of tomorrow will rely more heavily on connected devices, and patients will use this technology to exert more control over their dental care. Biomaterials science and product design advances will continue to provide incremental innovation, but dental product manufacturers must be prepared to adopt non-core technologies in order to deliver more than incremental innovation. To stay ahead of the competition, we suggest looking to other branches of medicine and other industries for those new technologies.

Digital dentistry and on-site manufacturing

Intraoral scanning is a highly developed and effective method for creating digital impressions, and has gained mainstream adoption in recent years. Images are stitched together to provide a 3D reconstruction of surface profile. Continued improvements in image capture and image processing will enable smaller hand pieces, faster scan times and more accurate data sets. Intraoral cameras have improved the patient experience but the more radical changes in care are still set to come, as the availability of digital data is used more frequently in combination with CAD/CAM in the dental office.

Rob Morgan, VP Medical, Sagentia expands: “In office CAD/CAM has been introduced in recent years and systems such as CEREC allow for the scanning, designing, milling and sintering steps in producing a ceramic restoration to be performed on site, without the need for an outside lab. The capital costs are high, but the logistical advantages and time saving benefits for patients are clear.” He adds: “A crown can now be provided to a patient in one visit, rather than requiring separate visits for the impression and the fitting. Such systems use relatively conventional manufacturing methods, involving milling and grinding, and are limited to certain materials."

3D printing has been adopted widely in commercial manufacturing and in consumer hobbyist applications. 3D printing makes it possible to produce complex objects directly from three-dimensional digital models. Instead of forming a component or prototype by cutting away a solid block of material (such as in subtractive techniques like machining), 3D printing works by stacking two-dimensional cross sections in successive layers to build the final object. This process gives 3D printing its other name – that of additive manufacturing.

Additive manufacturing advances have led to widespread adoption of a variety of technologies allowing manufacture of products at the point of need. Victims of serious facial injuries now benefit from precisely customized, 3D printed titanium implants, used by maxillofacial surgeons. Hearing aids are commonly 3D printed using a scanned impression of the ear as the input for the 3D model. Surgical cutting guides are now routinely printed for knee replacement surgery in order to provide more accurate, patient matched bone cuts.

3D printing machines are now offered for dental applications by more than twenty different manufacturers and applications include models, provisional restorations, implant drill guides and night guards. The technology will continue to advance, allowing a wider range of materials to be used, and so allowing orthodontic and permanent restorative devices to be manufactured on site. Morgan explains "Model costs vary from a few thousand dollars to six figures, but it is the promise of low cost, on site manufacture which makes additive manufacturing methods an exciting advance on the current high cost methods based on machining".

The field of biomaterials has also adopted 3D printing and new 3D printing materials are under development for orthodontics, dental laboratories and surgery. A group at the University of Groningen in the Netherlands is working with recipes that could add tooth decay-fighting chemicals to 3D-printed teeth. A number of research groups are 3D printing cells onto scaffolds and these could hold promise in bone grafting indications such as sinus floor augmentation and alveolar ridge augmentation. Current treatment options are limited to traditional autologous, allogenic or synthetic bone graft materials or the high cost, bone morphogenic protein formulations.

Although dentists will have to factor in additional equipment, maintenance and training costs, the combination of digital dentistry and new manufacturing techniques holds promise as a cost-effective solution to in-office restorations. The ability to produce custom devices chairside within the dental office will reduce iteration times, improve the patient experience and improve throughput for the dentist.

¬ Advanced Imaging for monitoring and diagnosis

Digital 2D X-ray imaging has become well established in modern dentistry. It is providing convenience to dentists in image processing and storage, and it has reduced x-ray radiation exposure levels for patients. 3D X-ray techniques such as Cone Beam Computed Tomography (CBCT) are now available but are priced in the six figure range and so adoption at the individual practice level is limited. 2D and 3D X-ray imaging is used to provide fast, accurate imaging, including bone structure and root positions, and is the gold standard by which all other imaging methods should be judged.

Intraoral cameras, used for inspection and for providing a digital patient record, leverage imaging technology from the consumer electronics industry. Consequently, the costs can be brought down dramatically from initial levels and can introduce new functionality following first introduction in consumer devices. Duel imaging channels and improved dynamic range could both improve functionality. Optical imaging modalities for detecting caries and periodontal disease, discussed further in the section below, could all be integrated with conventional intraoral cameras.

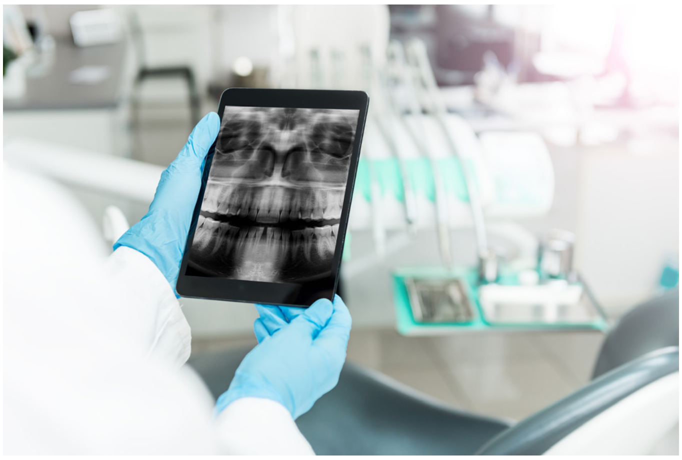
There are a number of alternative imaging modalities which have been introduced into dentistry but which have gained only limited adoption. The most prominent of these are fibre optic trans illumination (FOTI) and fluorescence imaging, and both have been directed towards the detection of caries lesions. Unlike intraoral scanning, which is a surface only optical imaging technique, both methods seek to gain subsurface information. FOTI devices, such as CariVu, provide illumination with a high powered white light source and rely on the greater scattering from caries lesions than surrounding enamel to provide discrimination. Fluorescence imaging devices, such as DIAGNOdent, seek to provide enhanced caries detection, but imaging depth is limited to a few millimeters at most. Fluorescence imaging devices have also been developed to detect intraoral cancer during oral mucosal examinations and include the VELscope. In common with caries detection, the method relies on auto fluorescence and does not seek to make use of the administration of imaging agents combining a fluorescent dye with a tissue specific binding chemistry.

The situation in dentistry can be compared with other branches of medicine in which a raft of powerful imaging modalities are used, sometimes in combination. Morgan comments: "Magnetic Resonance Imaging (MRI), ultrasound, enhanced fluorescence imaging and optical coherence tomography are among many techniques used across a wide range of clinical applications. All offer patient benefits through the avoidance of ionizing radiation. The different care models associated with these techniques must be recognized, with patient care in hospitals allowing the high capital cost of imaging instruments to be accommodated in the care of many conditions." He continues: "In contrast, the care of dental patients in small dental practices limits the adoption of high capital instrumentation. However, new imaging modalities do offer the potential for enhanced diagnosis and monitoring of caries, periodontal disease and other conditions."

MRI allows for high resolution 3D imaging of soft and hard tissue, but systems are currently all designed for whole body imaging. Head only MRI systems are under development and one example is the work published by GE Global Research and the Mayo Clinic on a 3 Tesla head only system designed for neuroimaging. Although such systems would still be cost-prohibitive for individual dental offices, lower-cost MRI could be delivered in dentistry via different, more centralized, care models than employed today. It should also be noted that MRI is seen by many as the gold standard for imaging of temporomandibular (TMJ) disorders, a condition falling within dental clinical practice.

Ultrasound is noninvasive, relatively low cost, and can also be used to image both hard and soft tissue. Clinicians currently use ultrasound for diagnostic imaging purposes and also for providing real time imaging during invasive procedures, such as laparoscopic surgery and percutaneous needle placement. Researchers have reported the evaluation of its utility in dental diagnostics and in TMJ disorders.

Whilst fluorescence imaging has gained limited adoption in dentistry, there is wide spread adoption in other branches of medicine when combined with fluorescence markers. The most widely used marker is indocyanine green (ICG), used to provide contrast between blood vessels and their surrounding tissue. Fluorescence imaging with ICG is used widely in angiography and ophthalmic imaging. In common with ultrasound, fluorescence imaging is used to provide enhanced, real time data during surgery, a trend sometimes called Smart Surgery. The da Vinci robotic surgery system incorporates the Firefly option for fluorescence imaging and a range of new markers are being developed for solid tumor and critical structure visualization during surgery. Can dentistry also benefit from image guided procedures during caries lesion removal or during endodontics?



Biomarkers and in vitro diagnostics

In vitro diagnostics (IVD) tests are routinely used by medical professionals to diagnose and monitor a wide range of conditions. Blood or urine samples are analyzed in central laboratories, and increasingly in point of care (POC) settings, using clinical chemistry, immunochemistry and molecular diagnostic methods. Naturally there has been interest in whether similar methods can be applied to dentistry through the analysis of samples of saliva. The analysis of saliva for diagnosis of periodontal disease has been a focus for research, and has included the assessment of the inflammatory response and the specific bacterial species involved. The analysis of saliva holds promise for the diagnosis of systemic conditions and currently detectable conditions include HIV and oral cancer. The OraQuick Advance test is a CLIA-waived, point of care test which provides HIV results in 20 minutes from an oral swab sample. Saliva tests for oral cancer include the SaliMark OSCC test, which involves the analysis of 6 mRNA markers, and was launched in the US in 2015. A salivary sample is collected from the patient after an oral examination, typically performed by a dental practitioner, and sent for analysis to a CLIA approved laboratory.

Recent advances in salivary diagnostics have been enabled by characterization of salivary biomarkers, including the mapping of the salivary proteome. Further commercially available tests will follow and an immediate target is Sjorgen's syndrome, an autoimmune disease causing dry eyes and dry mouth. Additional salivary diagnostic targets being studied by researchers include the determination of caries risk and detection of salivary gland diseases.

Morgan asserts: "As the evidence from basic research grows, one can imagine dentists routinely wanting to use salivary testing as a means to assess and monitor oral health, introducing new device requirements for dentists." Whilst they might choose to send samples to a central lab for analysis, as many primary care physicians still do with blood and urine samples, POC diagnostics brings convenience and the opportunity for immediate treatment decisions. The commercialization of POC diagnostic devices, used in the dental office, will require the development capabilities seen in the IVD industry, the distribution networks of existing dental equipment providers and the basic science knowledge of dental researchers. Consumers would benefit from home use monitoring devices to assist in the management of their oral health, just as patients now routinely use blood glucose meters to manage their diabetes. The commercialization of home use monitoring kits will similarly require a combination of dental and IVD capabilities, transferring technology into dentistry from other medical markets.

Connectivity and new care models

Connectivity has brought great change to the consumer electronics industry and many medical device manufacturers are now thinking beyond their core device markets to consider digital health. Orthopaedic implant manufacturers are looking beyond the provision of joint replacement implants to connected systems which assist across the entire patient care cycle. Pharmaceutical companies are using digital health to improve patient adherence to chronic disease medication. Chronic cardiac conditions are being managed at home using a combination of remote monitoring and telemedicine.

There is great potential for connectivity to bridge the gap between the daily oral care performed at home and the much less frequent care administered by dentists. Smart toothbrushes are already available for keeping track of our brushing habits and telling us when we've missed a spot. As technology progresses, smart tooth brushes or home use tests could be used to alert consumers of a condition requiring treatment. Alternatively these devices might transfer data to the cloud prior to automated analysis and periodic inspection by our dentist. Device manufacturers are also experimenting with smartphone imaging. Using an app, a patient would record images of their teeth and gums for a dentist to monitor. Dentists would look at the progression of enamel white spots, gum disease and other slow-progressing conditions.

The emergence of IVD methods for dental conditions, combined with connectivity, introduces the possibility for new care models. In the future, health clinics and pharmacies could offer saliva testing. In theory, a patient could pick up a prescription, get a flu shot and submit a saliva sample for a dental checkup. If salivary diagnosis becomes reality, maybe you won't need to go to your dental practitioner for your regular check-up. Maybe you will go to your pharmacy, give a saliva sample, and get the result sent to you on your smartphone two hours later. Based on the result, you're either good for another six months, or you need to make an appointment with your dental practitioner.

Medical device manufacturers are exploring the use of connectivity to achieve operational efficiencies, cutting their sales and distribution costs through remote monitoring of product inventory and reducing capital equipment maintenance costs through remote diagnostics. Remote tracking of product usage and inventory location might allow the dynamics to change in manufacturer/distributer relationships.

¬ Barriers and drivers for adoption

While advances in digital dentistry, additive manufacturing, diagnostic imaging, salivary diagnostics and connectivity have exciting potential, not all dentists will readily adopt new technology, and the economic case for adoption will need to be clear. Practitioners used to upgrading equipment every ten years might have to purchase new equipment much sooner to stay relevant. Digital health has only been adopted strongly by patients and healthcare professionals in life threatening conditions such as Type I diabetes. Salivary diagnostics will need to show the specificity and sensitivity required for adoption as a stand-alone test.

However, dental practices that do adopt new technology will not only have the latest tools to offer the most effective patient care, they will also have the potential to stand apart from the competition.

Dental device manufacturers that recognize and introduce new technology will have the opportunity to be part of exciting and disruptive changes in patient care models.

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