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The Impact of Artificial Intelligence on Dental Care Delivery: A Comprehensive Review

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The Emergence of Artificial Intelligence in Dental Care Delivery

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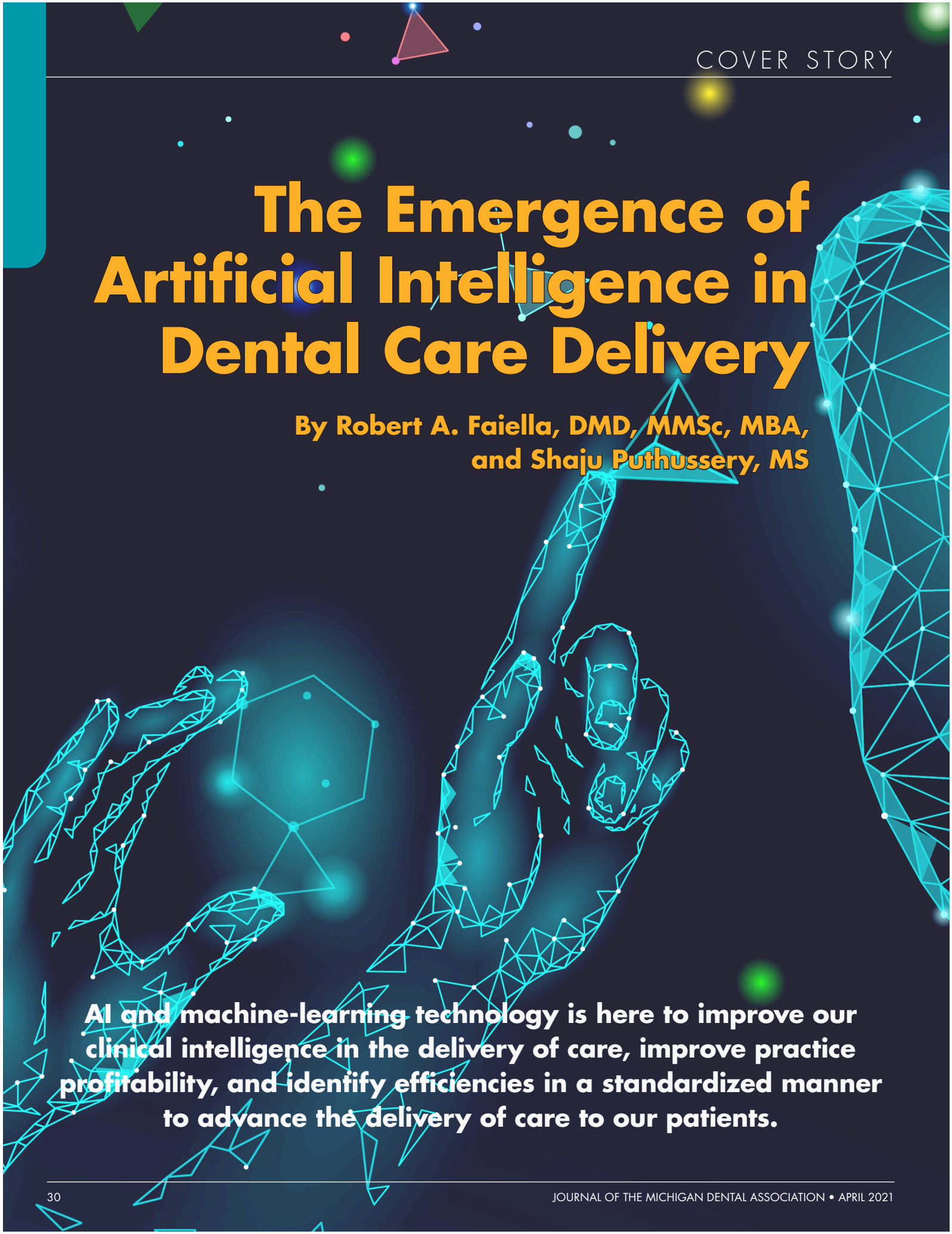

AI and machine-learning technology is here to improve our clinical intelligence in the delivery of care, improve practice profitability, and identify efficiencies in a standardized manner to advance the delivery of care to our patients.

As oral health specialists, our role as dentists is to use scientific principles, clinical acumen, and technical expertise to prevent, diagnose, and care for patients with oral disease or injury, and to help maintain and improve their oral health throughout their lifetime.[1] Dentistry's understanding of the etiology of oral diseases, as well as the techniques and interventions available for their management, continues to evolve. Simultaneously, the expansion of information related to collection of patient metrics, advanced treatment protocols, and the influence of oral-systemic disease relationships has implications for both patients and providers, particularly in the complexity of treatment options and the difficulty patients face in accepting treatment.

Artificial intelligence (AI) approaches are currently at the frontier for health care in medical imaging, therapeutic intervention, and drug design and manufacturing. The global health care market for AI is increasing at a rate of 44.9% and is expected to reach $45.2 billion by 2026,[2] with growing adoption of AI health care imaging, diagnostics, and operational support projected at the highest growth rate. Can AI offer a breakthrough in advancing prevention through risk assessment, predicting diagnoses through radiographic visualiza-

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tion of diseases to enhance treatment planning and case acceptance, and demonstrably improve the delivery and outcomes of dental care?

In this review, the ambition of AI and computer visualization in transforming dentistry will be described, and current applications of models in the management of both clinical treatment and dental practice will be discussed.

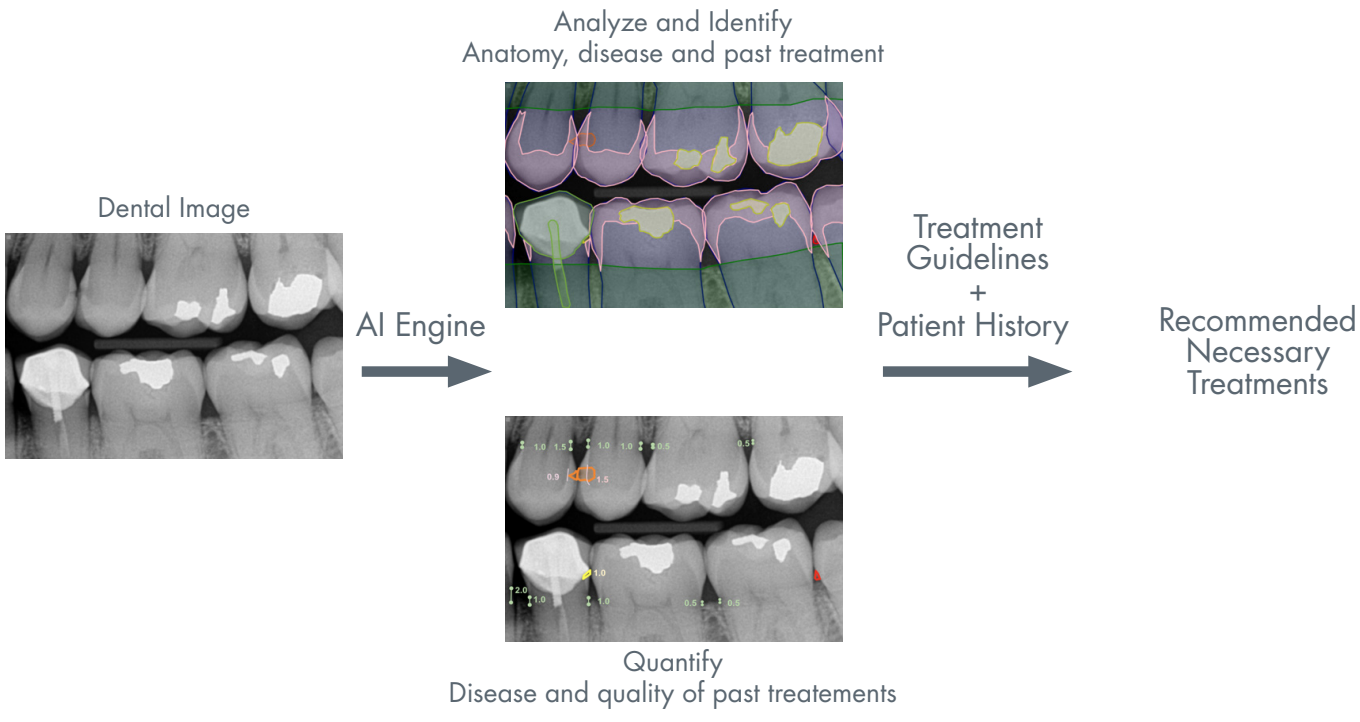
Implications of AI on health information management

Health care, as an industry, is based upon a knowledge-driven economy, and clinicians are acutely aware of the challenges in assimilating new information to improve their understanding and patient care. In 1950, the time to double medical knowledge was considered to be 50 years; in 1980, seven years; and in 2010, three-and-a-half years. Today it is projected to take just 73 days.[3]

The dental profession is certainly no exception to the challenges of health information management.[4] Successful prevention strategies depend upon knowledge of disease causation, progression dynamics, and early detection and treatment, all challenged by access to data and inherent constraints (missing, unstructured, or non-standardized patient information).[5,7] The adoption and expansion of electronic health records has dramatically increased the quantity of clinical data available for our clinical treatment decisions. In addition, the implementation of data analytics to gain insights beyond human capabilities across large data sets has created unique opportunities to predict disease occurrence, reduce inefficiencies, and advance patient care.[6] Predictive analytics linking data from dental and medical records, claims, and patient-reported sources will define the data elements to allow recognition of patterns within the disease process, leading to opportunities for earlier identification of known risk indicators, and timing of treatment.

Consider for a moment the knowledge and clinical expertise required to manage each patient individually. Providers and staff must acquire information from the medical and dental history, interpret the possible influence of medical conditions and current medications, record quantitative dental examination metrics and radiographic imaging, and abide by protocols to store and share the information securely.[4,7] Once done, dental professionals must render a diagnosis and offer recommendations for treatment in a manner to allow informed consent by the patient. As an additional challenge, the medical information, test results, and medications may change during the

Figure 1 — AI machine learning prediction pathway to determine the necessity of treatment with high-level accuracy.



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course of treatment. Consultations with medical colleagues may be necessary, as patients become more acutely aware of the connection between oral health and their overall health. Over the course of a year, millions of data points are collected from thousands of patients seen by multiple providers, and in many cases, over multiple locations. The data collected is primarily used at the point of service for the patient, but it is rarely reviewed independently when the patient is not present for care.

An important element in the implementation of analytics at scale is to make it actionable.[6] Systems that identify patients in need, while also making predictions available with minimal disruption to the existing workflows in the office, increase the ability for providers to take action in treatment decisions at the point of care. The system must both inform the provider and educate the patient regarding the recommendation for treatment with objective reason. By allowing this level of access to information, AI technology can empower providers to identify needs for confirmation and discussion with each patient we serve.[8]

Expanding digital dentistry to include predictive diagnostic support

Dentistry is currently experiencing significant changes in the management and delivery of treatment due to the extensive introduction and expansion of digital capabilities. Most dentists are currently embracing digital workflows at some level, from submission of insurance claims with digital attachments, to treatment delivery through digital impressions connecting CT imaging, to CAD/CAM prosthesis fabrication by digital printing.[9] The expanded computational speed and storage capacity required for these workflows would also allow AI algorithms to analyze radiographic images and unstructured patient data (such as digital images including intra-oral photos and digital impression files and electronic record notes and claim narratives) in order to aggregate all practice data to improve our clinical cognition at scale.

Currently available AI models are expected to support providers with diagnostic accuracy for confirmation and interpretation to the patient in the delivery of care,[8,10] and can accurately identify dental anatomy (tooth numbers, bone levels, enamel surfaces), oral diseases (caries, periodontitis, lesions, and endodontic obturations) and quality of restorations (open margins, marginal over-extensions) from dental radiographs (both digital and scanned). In addition, incorporation of additional digital data, seamlessly

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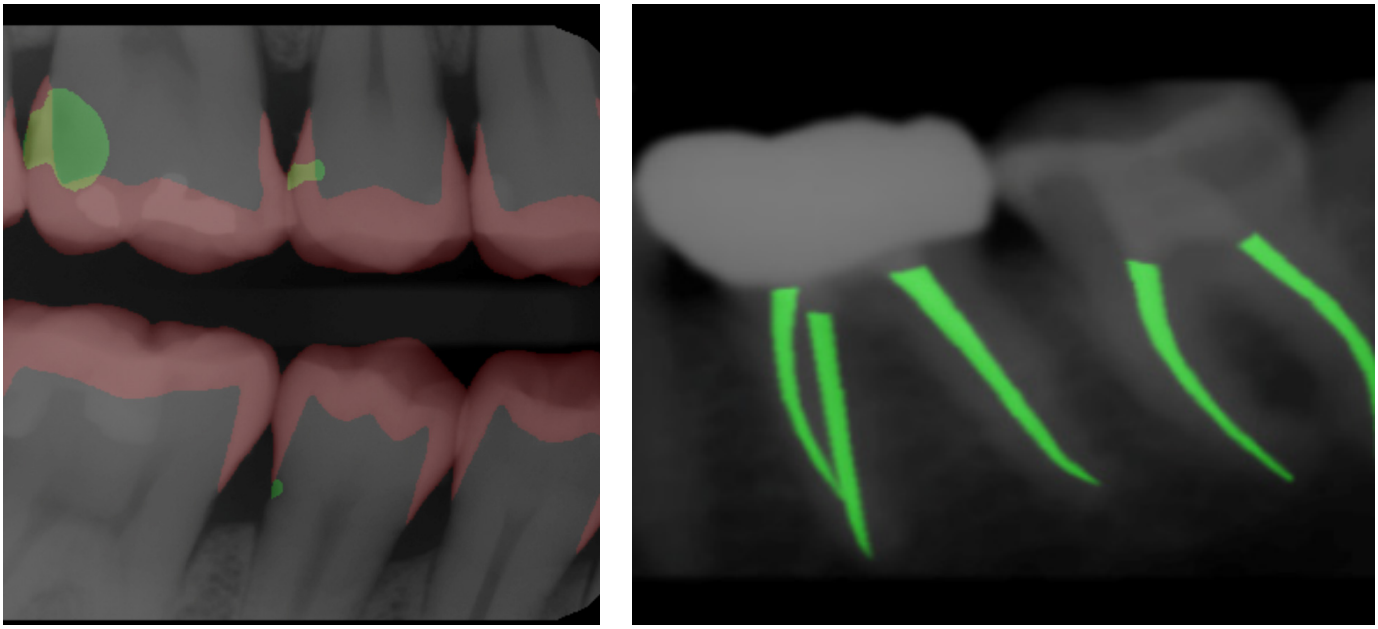
Figure 2 — The left panel demonstrates prediction of enamel and caries extent beyond the DEJ, and the right panel exhibits machine learning identification of endodontic obturation in the development of modules for clinical use.



extracted from practice management software, can then be combined with known dental procedure code parameters and guidelines to identify clinically appropriate treatments, and presented to the clinician at the point-of-care. This digitally enhanced process would allow for improved efficiencies in diagnosis, treatment decisions, workflow, and ultimately better treatment outcomes.[11]

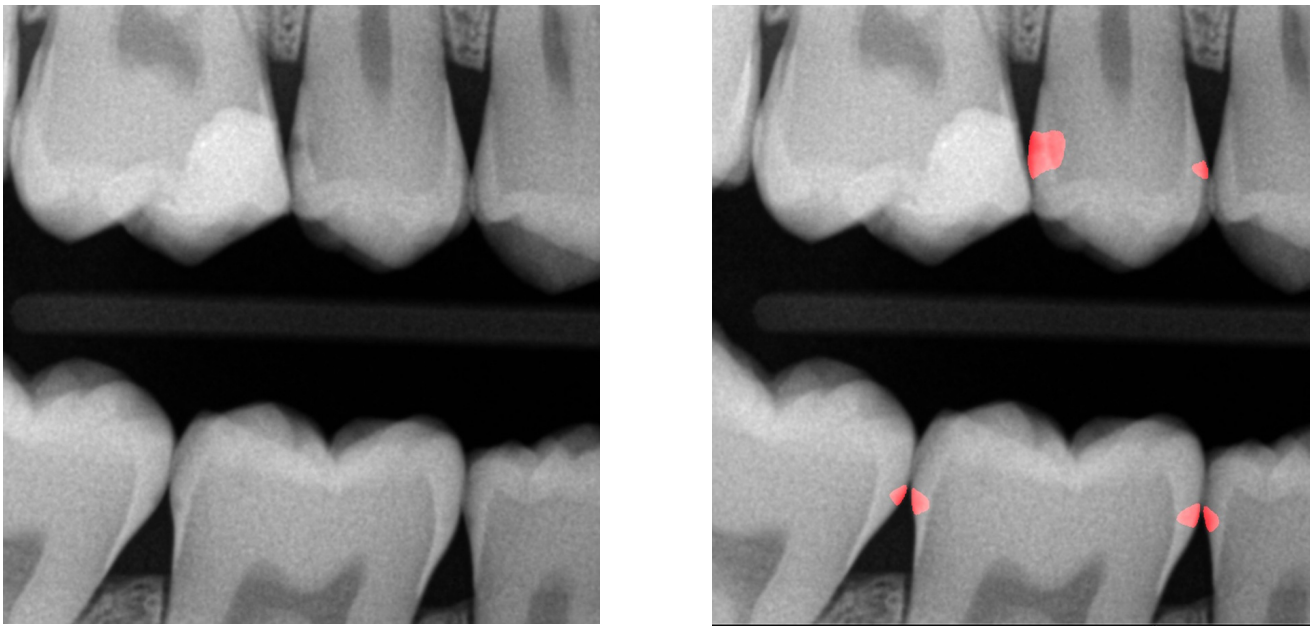
For example, findings of bone loss for specific teeth greater than 2.0 mm[12,13,14] and probing depth greater than 4 mm, as well as the presence of root surface calculus, can be presented on annotated images relevant to the site in question. A dashboard will also present a timeline over the past 18 to 24 months, noting all dental procedures for each visit for the patient to determine if there has been a periodontal charting or comprehensive examination within that time frame. In addition, annotated radiographic images identifying the teeth exceeding criteria for bone loss, carious lesions, overextended restorative margins, and indications for crowns (such as a missing cusp, the size and condition of an existing restoration, and the percentage of the clinical crown that is decayed, missing or filled) are presented. The indication for appropriate treatment can be reviewed and presented to the patient during the appointment, allowing the provider to toggle the annotations on and off to demonstrate the objective findings to the patient and inform them of the need for treatment.

Case acceptance has traditionally been based upon the trust between the patient and provider.[15] The use of technology to provide objective findings at scale across the entire database of the practice shifts the treatment acceptance from "trust" to "trust with verification" by demonstration of need, while educating the patient with reason.[16] This allows use of the AI model to determine indication for treatment, such as all the patients in the practice who have indications for SRP due to bone loss of 3 mm with four or more teeth in a quadrant, or the presence of caries. The ability for patients to visualize, recognize, and understand objective indications for treatment, with interpretation by the clinician, gives them more control in making the right decision for their condition.

A treatment planning process based upon stratified risk

Health care systems have generally used simple decision trees or logistic regression models to determine risk levels. This is in part due to time constraints at the point of care.[17] Identified risk has included those patients with

Figure 3 — As compared to the original image (left), highly accurate unassisted prediction of caries by AI is presented on the right.



co-morbidities such as smoking, diabetes, atherosclerotic cardio-vascular-disease, and other systemic diseases known to have shared risk factors with oral diseases. Health care organizations that currently use analytic systems have focused on identifying the algorithm that can best stratify data in near-real time, allowing actionable use for patient care.[18]

The use of current AI systems in dentistry to identify dental disease can enable the clinician to determine treatment needs, but stratification of risk requires segmentation of patients by defined co-morbidities that may influence the prevalence and severity of disease progression, as well as response to treatment protocols. Self-reported patient indicators identified by natural language processing models from the electronic health record within the practice can identify risk factors such as diabetes, smoking, frequency of maintenance appointments, and current medications.[19,20] The ability to identify such predefined criteria can allow the clinician to stratify patients with a specific diagnosis into high-, intermediate-, and low-risk groups for dental disease development or progression, and can be a powerful predictor of treatment success. This approach for patient cohort stratification to guide prevention of highly prevalent chronic diseases is meant to improve outcomes and increase the cost-effective use of health care resources.[21]

Improving payer-provider alignment through better code identification and submission

Many health care insurers are currently placing AI into action.[22] Using AI in claim life-cycle management between provider and payer systems improves payment accuracy, thereby reducing claim denials and cost through reduction of administrative overhead. One of the key initiatives from the payer community is in intelligent claims automation, which distinguishes between processing speed for pre-authorization and post-treatment claims for automatic

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Figure 4 — A clinical intelligence dashboard demonstrating real-time caries, bone loss measurements, and calculus, with findings listed on the right that may be toggled on or off for clinical review or patient demonstration.

adjudication. A pre-authorization process provides a confirmation that the patient is a covered enrollee and the payer agrees with the provider's recommended treatment before the treatment is performed. This process of automation eliminates delays in approval and improves speed of treatment and payments to providers. Patient eligibility verification through AI-automated workflow also improves efficiency and increases the provider-payer interaction experience with speed and convenience.[23]

Improving quality of care through standardization of treatment protocols is a priority for every dental office. AI-assisted diagnostic support will analyze, identify, and recommend treatment options, to increase the accuracy of disease detection, and improve patient outcomes. Artificial intelligence can also analyze insurance claim rejection reasons, collection performance, and dental treatment coding profiles in dental office operations, as well as encode and verify insurance processing guidelines prior to claim submission. This process will reduce errors in claim submission and increase adjudication decision-making based on real-time insights from dental office data with sustained information accuracy. For example, AI-assisted agents in the dental office can verify requirements for document attachments to insurance submissions proactively.

Considering the sea of information within our control, the challenge we face today is to establish interoperability across electronic medical records (EMR) systems to create a cohesive, holistic view of the patient health history.[24] Social determinants of health (SDOH) are the conditions within the environments where people are born, live, learn, work, play, worship, and age that affect a wide range of health, quality of life, risks, and outcomes. Incorporating SDOH indicators (such as economic stability and education) into overall health care delivery will produce potentially better outcomes.[25] Artificial intelligence and machine-learning solutions can identify and analyze the SDOH factors that impact a patient's health by mining these data from dental and medical EHR notes, and facilitate stratification of risk.[26]

The ability to monitor treatment effectiveness and outcomes

The process of assessing risk for dental diseases, such as periodontal disease and caries, has been less quantitative and more qualitative in current provider-payer systems. The advent of AI to analyze and quantify patient risk factors from dental imaging, along with qualitative SDOH factors from patient behavioral questions, will make this process more quantitative and real-time. Incorporating stratified risk levels proactively in the management of patient care will enable dentists and hygienists to intervene in real time, implement early preventive measures, and improve treatment outcomes over time. For example, if the patient has diabetes and is a smoker, and has evidence of bone loss and/or radiographic root calculus, the provider may modify treatment options, which could include increased maintenance intervals, periodontal intervention, or smoking cessation methods.

It is common for dentists to defer specific treatments at the patient's request and observe progression over time, but without objective metrics combined with stratified risk the timing of appropriate treatment may pass. AI-powered metrics offer the ability to identify disease progression over time.[27] The appropriate documentation of treatment deferred or refused by the patient allows the clinician to escalate the urgency for care and provides for an appropriate record of lagging patient compliance.

The use of AI technology also allows improved data-based oversight in the administrative management of

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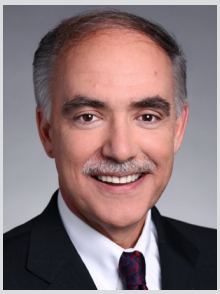
Faiella

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Puthussery

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the practice.[28] Current dashboard configurations available can provide real-time key performance indicator (KPI) metrics,[19] such as production YTD, collection ratio, active patients, and new patients MTD. In addition, the software can aggregate data to track the number of patients within the practice with indications for a certain procedure identified objectively by the software.

Dentists must also assume responsibility for the management of the practice as well as measures of quality control among the providers. Maintaining the standard of care, and mandated regulatory compliance, demands careful oversight. The implementation of chart audits, the time required for review, and the scope of the work is beyond the capability of most practice administrators to assure identification of missed treatment needs (such as indications for SRP or early carious lesions), documentation (appropriate radiograph and charting intervals), and disrupted treatment workflows, as well as compliance with office protocols that may be overlooked in the context of a busy practice. How can we improve the process for the benefit of our patients and improve treatment efficiencies?

Challenges and perspectives for the future

The adoption and implementation of artificial intelligence within the dental profession is poised to be a transformative technology in dental care delivery. That said, it will not be without the perspectives and challenges that come with innovation, and will require our focused attention as applications for use continue to evolve. Technical challenges will arise as data attributes, formats, and transfer speeds evolve. The ethics revolving around data privacy, the evolving assurance of data security in transit and at rest, and the exclusion of bias in the data used in the development of the algorithms will demand the attention of the health care informatics community as we broadly embrace artificial intelligence.[29] In addition, the introduction of clinical AI-based solutions by the dental education community will be critical to foster the required digital literacy needed in the future dental workforce.[8,30]

The American Dental Association is an approved Standards Developing Organization, with authority to propose standards for the profession. The Standards Committee

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on Dental Informatics develops standards and technical reports for electronic health records, interoperability across technology platforms, secure storage and transmission of patient data and digital images, and dental education and research systems. The Standards Committee on Dental Products addresses dental materials, digital devices, equipment, and oral hygiene products.[31] The skill sets, techniques, and best practices to help our profession comply with the legal, ethical and regulatory oversight of AI-based information are currently being addressed by the ADA and will continue to evolve as AI applications continue throughout the dental industry.

The case for a continuously learning health care system in dentistry

The aggregation of practice data allows for efficiencies in practice management, scheduling staff, reviewing practice goals, and streamlining patient treatment. By using the insights gained, the ability to perform a needs assessment to maintain a standard with performance benchmarks for quality metrics of care encourages the development of a continuously learning environment within the practice.

In 2001, the Institute of Medicine defined the six aims for high-quality care: safety, effectiveness, efficiency, equity, timeliness, and patient-centeredness. Simply expecting providers to keep pace with the expansion of the knowledge base alone will not improve the quality of care. A learning health care system is one in which "science, informatics, incentives, and culture are aligned for continuous improvement and innovation, with best-practices seamlessly embedded in the care process . . ." and developed through the adoption of process improvements over time.[32]

AI and machine-learning technology is here to improve our clinical intelligence in the delivery of care, improve practice profitability, and identify efficiencies in a standardized manner to advance the delivery of care to our patients. It is likely that AI will transform all major verticals of the estimated $130 billion dental industry, including dental practices, payers, manufacturers, distributors, and laboratories.

The enhancement of our capacity to analyze patient needs objectively for continuous quality improvement will only expand in the coming years, and will provide digital frameworks in the transformation of dental care delivery. Most importantly, the ability to enhance the patient experience by providing timely treatment, engaging their understanding of treatment recommendations with reason, and improving their outcomes over time with objective metrics provides a patient-centric environment to advance patient health status and enhance the trust that is central to the delivery of care.

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