Overview of Artificial Intelligence in Dentistry

By **Drs. Mark Jurkovich** and **Gregory Zeller**

We always overestimate the change that will occur in the next two years and underestimate the change that will occur in the next ten. Don't let yourself be lulled into inaction.—Bill Gates, Microsoft Co-Founder[1]

Dentistry may be on the threshold of an explosion in the use of artificial intelligence (AI). We are already familiar with so many AI functions in our daily life—smart homes, robotics, Alexa, and Siri—as well as the remarkable change taking place in our automobiles and truck transportation, ranging from adaptive cruise control to parking assistance, and even to self-driving vehicles. AI, in its many forms, is taking us into an amazing number of new areas in our daily lives.

Health care is also seeing an explosion in AI use. Rather than dampening or slowing down development, the COVID-19 pandemic experience has only accelerated it, as can be seen with the development of so many clinical decision support tools, predictors, and test and vaccine distribution protocols.

Tim Cook, CEO of Apple, the world's richest company,[2] recently stated, "I really believe that if you zoom out to the future and then look back and ask, 'What has Apple's greatest contribution been?' it will be in the health and wellness area." Tens of millions of people now wear an Apple Watch device that monitors key health metrics and allows them to share data anonymously with researchers, which many do. Some 400,000 Apple Watch users participated in one Stanford study. This enables scientists, says Cook, to "democratize research by having much larger constituencies that are able to participate."[3]

Today, one of the first broadly recognized AI tools in health care, IBM's Watson, is not only "old news" but also may be the standard of care for radiologist interpretation of images. Dentistry is now experiencing this push into image evaluation using AI. Several firms are offering tools that can be used today and have promise both for improving clinical workflow and for providing diagnostic and, potentially, treatment planning assistance.

A recent systematic review in the Journal of Dental Sciences, published in January 2021, states, "AI models have been used in detection and diagnosis of dental caries, vertical root fractures, apical lesions, salivary gland diseases, maxillary sinusitis, maxillofacial cysts, cervical lymph nodes metastasis, osteoporosis, cancerous lesions, alveolar bone loss, predicting orthodontic extractions, need for orthodontic treatments, cephalometric analysis, age and gender determination."[4]

The article goes on to explain that accuracy of AI-derived tools for dentistry is impressive so far. "They mimic the precision and accuracy of trained specialists. In some studies, it was found that these systems were even able to outmatch dental specialists in terms of performance and accuracy."[4]

The first robotic dental surgery system was cleared by the Food and Drug Administration (FDA) for dental implant procedures in 2017. At the end of 2017, the world's first autonomous guided dental implant placement system was developed by Zhao and colleagues in China.[5]

It is easy to see that the many forms of AI are already having an impact on our profession. This paper will provide a basic understanding of the various forms of AI; furthermore, it will delve into the currently utilized AI areas as well as those that have been predicted, according to Accenture, to be major influencers in health care, including telehealth, workflow assistance, and even cybersecurity.[8]

In the broad sense, AI systems comprise a science that is designed to mimic human intelligence. There are a number of AI subsets, which include machine learning, deep learning, cognitive computing, computer vision, and natural language processing (NLP). Machine learning involves training computing systems to look for hidden patterns in data to build analytical models. Deep learning utilizes more complex neural networks of computing systems that loosely mimic the human brain to discover and analyze complicated patterns in very large "big data" databases. Cognitive computing refers to the use of computer systems to simulate human thought processes. Computer vision uses deep learning to recognize patterns in images and videos. NLP uses AI to recognize speech and written language and to communicate with system users through more commonly used language.

Although behind medical care in development and adoption, dentistry is experiencing a growing number of AI products and substantially more research and development for potential new products. Many are similar to those developed for our medical colleagues, likely because they can be adapted more quickly than products developed from scratch. Thus, the direction of development of dental products using various aspects of AI trend with those gaining adoption in the medical field.

Forbes stated in 2018 that the most important AI areas for health care would be administrative workflows, image analysis, robotic surgery, virtual assistants, and clinical decision support.[9] A 2018 report in the Harvard Business Review mentioned the same areas and also included connected machines, dosage error reduction, and cybersecurity.[10] A 2019 report from McKinsey and Company states important areas using connected technologies, big data, and AI insights include cognitive devices, electroceuticals, clinical robotics, and robotics for administrative process automation.[11]

There are several current dental AI products and some that are likely imminent.

Image analysis

Using an area of AI machine learning referred to as neural networks, imaging analysis is one field receiving a great deal of attention in dentistry. Basically, the “science” behind imaging analysis is that millions of images may be fed into the computer and the computer begins to identify patterns. The computer is “trained” by dental professionals. There is a reasonable amount of research already that indicates image analysis has the ability to detect caries lesions (possibly even earlier than the human eye), bone loss, radiolucencies, and other less common bone-related problems. Some of the research cited earlier suggests that this image analysis using machine learning performs at or above the level that dental professionals may be able to detect. The more images the machine “sees,” the more likely it is to become more accurate.

Image analysis currently has the capability of assisting dental clinicians in the identification and classification of dental caries lesions that may not yet be detectable by the clinician. This might lead to earlier and possibly nonsurgical interventions that prevent a future need for restoration. Image analysis is also detecting bone levels. Given a series of images over time for the same individual, image analysis can identify the extent and even the speed of change, allowing visualization of these changes with the patient present and possibly providing predictive value for periodontal deterioration and risk assessment. There is already speculation that image analysis may be able to replace the way we populate our periograms, thereby saving time during regular dental preventive visits. Image analysis is already being used by pathologists, radiologists, oral surgeons, and others to assist in identification of tumors, types of tumors, and other types of diseases that have manifestations in the head and neck region. Endodontists are using image analysis for more precise identification of endodontic problems and cracked roots. As costs for image analysis tools come down, it is very likely that implementation will increase.

Robotic surgery

As noted earlier, robotic-assisted surgery for guided implant placement is already taking place. The FDA has approved at least one system. Combined with image analysis, robotic-assisted surgery may allow for highly precise placement and surgical interventions that reduce possible errors and improve potential outcomes for patients.

Light curing composites

Today, dental radiometers exist that can analyze a curing light's ability and match it to the composite material being used.[12] Using machine learning, these radiometers provide clinicians with the ability to fully cure composite restoratives, potentially increasing longevity and improving patient outcomes.

Orthodontics

Digital impressions, cephalometric analysis, appliance design, smile design and visualization, orthognathic surgery evaluation, and treatment planning are becoming increasingly common uses of AI in orthodontics. Neural networks are also used to monitor orthodontic treatment progress as well. Image analysis of traditional radiographs as well as cone-beam computed tomography remains a core feature, which is yet another example of the application of machine learning and neural networks.

Telehealth

This area is exploding among our medical colleagues and has the potential for providing dentistry with greater efficiency. Transfer of images and data from consumer cell phones, videos, telephone conversations, or form-filler software, the common forms of telehealth used in dentistry, are not generally using AI. Medicine is using virtual assistants, remote electronic A1C monitoring, pulse oximeter monitoring for at-home COVID-19 care, and significantly increased patient engagement through standardized questions, whereas AI helps aggregate answers and match to potential needs for tests or in-person visits and can even suggest possible diagnoses. These AI-enabled processes in medicine allow for increased efficiency and improved scheduling, saving everyone time. The potential for dentistry to do the same is being pursued by several firms, so we are likely to see this in the not-too-distant future.

Decision support

Electronic dental records systems offered some of the first decision support tools available in health care. The preventive or "recall" system as well as notifications for patient follow-up for procedures such as follow-up images after endodontic therapy are some of the first examples that do not generally use any form of AI. Newer technologies are using AI. Current systems may assist in the diagnosis of oral cancer and in identifying oral surgical complications, and results are improving as these systems see more cases and use neural networks to enhance learning.

Dental education

Several companies now offer virtual reality clinical simulation systems. These systems rely on AI technologies to train dental students in therapeutic interventions such as cavity preparations. Intraoral optical scanners are also used with AI systems to measure various preparations for proper thickness, depth, and orientation. Such optical scanners, coupled with AI systems, are available for use in daily dental practice systems to determine the adequacy of clinical tooth preparations.

In addition, many dentists are already using various facets of AI for digital impressions, digital scanning, computer-aided design/manufacturing construction of crowns, retainers, splints, and more. Dental laboratories and the equipment they are using might be more advanced than the systems readily available to dental clinics largely because they are aggregating more data and using additional machine learning to enhance quality.

Workflow simplification and administrative efficiencies

NLP, still another form of AI, has been used in dentistry for a decade or more. Additionally, digital assistants with voice recognition are becoming much more common in treatment rooms for documentation by our medical colleagues. In dentistry, we have had tools to do periodontal charting via voice for many years. This entire area may see substantial change, particularly if the continuing development of voice to structured data within an electronic health record can be developed effectively. The potential to dictate notes and have the notes accurately and efficiently documented may be a real time saver and result in change in workflows for both dentists and assistants. Likewise, the capability of a system to convert text into computable, structured data will offer a level of analysis of progress notes and other reports that is currently not available.

For additional administrative and business support, intelligent document processing (IDP) uses AI technologies to extract data from "static" documents, such as email, Word and PDF documents, scanned documents, and clinical progress notes. IDP uses AI technologies such as computer vision, optical character recognition, NLP, and machine/deep learning to automate the capture and processing of the data.[13]

AI is also being used for other administrative duties, including patient communications that can promote business and retain patients. Machine-learning programs are or will be able to interface with dental practice software to track and optimize patient appointments. AI can identify and assist in scheduling unfinished treatment. For scheduling patients of record, the AI system can contact the patient based on their appointment preferences and match the patient with an available appointment.

We are also currently seeing significant decision support being built into the image analysis aspects of some of the tools described above. Further development within this area is likely to offer even more decision support tools moving ahead.

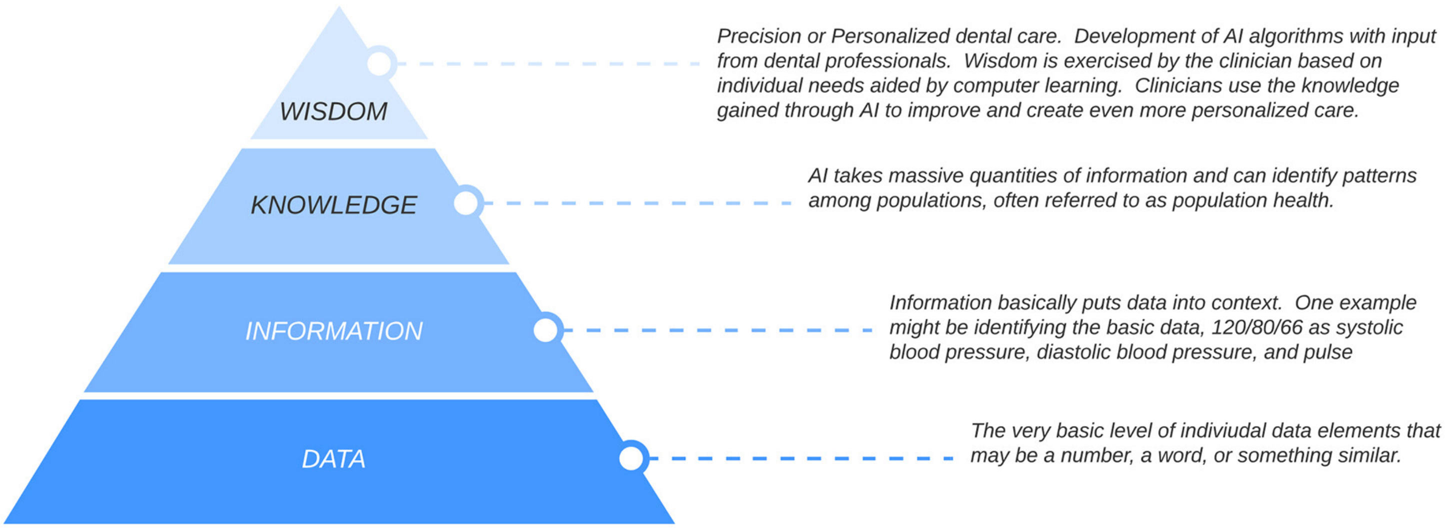
The dental payer community has been using decision support tools fueled by machine learning of huge amounts of claims data to refine benefit plans and identify practice patterns used for everything from recruiting dentists to participate in a network to "rating" systems for dentists, much like we see for physicians and hospitals both from private and government sources. Many dental payers are also in the process of reviewing or implementing imaging AI tools that can assist them in the above functions, identify duplicate claims, and other similar activities as well as developing tools that can improve internal efficiencies and possibly improve predetermination systems and methods.

Although dentistry has seen the increasing development of decision support, dental systems used in many general dental clinics have fallen far behind those used by our medical colleagues, largely because they have less standardized "structured" information available to the system for processing. Dentistry does not regularly record diagnostic codes, various patient observables, structured health history information, risk assessment tools filled out by patients, and a host of other information points that are now common within electronic medical record (EMR) systems.

In the EMR system, when using AI, this structured data is collated and compared across populations to provide medical clinicians with more information and "decision support" to assist them in determining everything from other recommended tests and appropriate prescribing to diagnosis itself. It is critical to note that, although AI systems can provide the clinician with great information on population health patterns, the ability to apply this to the individual patient relies on the clinician.

THE KNOWLEDGE PYRAMID

THE PYRAMID AND AI



AI can help clinicians see patterns, but every patient has individualized needs and patterns. The good news is that as dental systems improve and allow for greater structured documentation, greater computable decision support options will become available to a broader segment of the profession.

The technical aspects of creating computable, structured data in the electronic dental record (EDR) rely on several key points. First, the decision must be made on what type of data to include and whether or not the included data is structured so that it may be used for computations. In addition, such structured data should be based on accepted consensus standards such as the Systemized Nomenclature for Dentistry diagnostic codes or on accepted industry-wide standards such as the Current Dental Terminology procedure codes.

The second consideration for data entry in the EDR is the workflow of the user interface. Entry of structured data is easier than the entry of unstructured free text, which must later be converted to computable data. NLP will greatly ease the burden of data collection through working automatically “behind the scenes” to convert speech into standardized structured data.

Third, the EDR should display the data captured in a useful manner to support clinical care. This includes various ways to sort and view the data to assist with clinical decision support, treatment planning, and billing claims to third- party payers.

The fourth consideration for the EDR should be the capability to aggregate data from all patients in the practice to use AI tools to analyze practice patterns to improve performance. If standardized data is recorded in the EDR, then the practice will be able to share data with other practices or registries using standardized structured data as well as to receive data from other practices to create a larger database for analytics. Such data sharing will allow for the creation of large data warehouses for the application of AI tools, such as retrospective analysis and predictive modeling, to population cohorts for operations and research. This approach using standardized data will also promote interoperability among various EDR and EMR systems.

As AI is incorporated into the EDR, additional considerations such as security, privacy, trust, quality, safety, and data standardization will ultimately determine the reliability and validity of AI tools applied to dentistry.

As one can deduce, AI is already assuming an important role in dentistry. As more data and information become available and as our EDR systems become more sophisticated, further enhancements and assistance for dental clinicians may be inevitable. In addition, consumers will, in the near future, expect access to their EDR data as required in the federal regulations surrounding information blocking that implement the 21st Century Cures Act.[14]

Conclusion

Today, dental providers are aware of the many correlations between oral health and overall health, but we do not yet understand those relationships well. The amount of data being generated on each patient each year is enormous (estimated 5 years ago as over 55 pages/person [not patient]/year). With this quantity of information, there is a critical need to sort through it and identify what is important for a specific patient being treated for a specific condition. Electronic medical and dental health record systems that use machine learning and deep learning constitute an imperative to help us be better clinicians and best support our patients to apply a precision medicine approach most suited to the patients' needs.

The American Dental Association (ADA) is in the midst of developing a data warehouse, the ADA Dental Experience and Research Exchange (ADA DERE), that will ask members to provide their (deidentified) EDR data. This data source will use various AI methods to assist the dental community in identifying accurate and supportable quality measures and practice guidelines to help the dental community move more quickly into the world of precision medicine. This approach is also a critical piece in improving our understanding of the oral/overall health connection that cannot be accomplished with claims data or image analysis alone.

In addition, the ADA, through work leading the development of standards for dental informatics, has published standards and technical reports that can assist our EDR vendors to enhance their systems to meet this dramatically changing information environment. The ADA works both nationally and internationally with other communities to improve methodologies for data capture and interoperable exchange while being acutely aware that this needs to be done efficiently and very cost effectively.

Whether in our everyday lives or in clinical practice, AI is already changing how we do things. We expect these changes to continue to take place and likely accelerate as we understand how to use AI and computing better, as we create better ways to aggregate data and then interpret that data, and as we see the results of what can be accomplished by continuing to move in this direction.

Biographies

Gregory G. Zeller, D.D.S., M.S., is a general dentist who currently serves as Chair of the Clinical Informatics Subcommittee of the American Dental Association Standards Committee on Dental Informatics (ADA SCDI), and he is the Immediate Past Chair of the ADA SCDI. Dr. Zeller is a provider of consulting services for informatics, standards, and organizational development who has been involved in standards development and implementation for over 20 years with organizations such as DICOM, IHE, ISO, and HL7. Dr. Zeller is Professor Emeritus at the University of Kentucky College of Dentistry, where he served as an Associate Dean. Prior to joining the University of Kentucky, he served as Senior Director of Research and Laboratories in the ADA Science Institute in Chicago and as Director of Dental Informatics at the Department of Veterans Affairs Central Office in Washington, DC.

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Advisory Committee and Information Exchange oversight committee. He is chair of the ANSI SNODENT Maintenance Committee and Lead for the SNOMED International Dental CRG.

References

1. Brown D. This perfect Bill Gates quote will frame your next decade of success. Inc. December 4, 2019. Accessed May 24, 2022. https://www.inc.com/damon-brown/this-perfect-bill-gates-quote-will-frame-your-next-decade-of-success.html
2. Hanson D. Here are the 20 richest companies and corporations in the world today. Money Inc. 2019. Accessed May 24, 2022. https://moneyinc.com/richest-companies-in-the-world-in-2019/
3. Roberts M. Tim Cook pivots to fitness. Outside. February 10, 2021. Accessed May 23, 2022. https://www.outsideonline.com/health/wellness/tim-cook-apple-fitness-
4. Perez MV, et al. Large-Scale Assessment of a Smartwatch to Identify Atrial Fibrillation. N Engl J Med. 2019; 381:1909-1917. doi:10.1056/NEJMoa1901183.
5. Standford Medicine News Center. Through Apple Heart Study, Stanford Medicine researchers show wearable technology can help detect atrial fibrillation. Stanford Medicine News. November 13, 2021. Accessed May 23, 2022.
6. Khanagar SB, Al-Ehaideb A, Maganur PC, et al. Developments, application, and performance of artificial intelligence in dentistry - a systematic review. J Dent Sci. 2021;16(1):508-522. doi:10.1016/j.jds.2020.06.019
7. Wu Y, Wang F, Fan S, Kwok-Fai Chow J. Robotics in dental implantology. Oral Maxillofac Surg Clin North Am. 2019;31(3):513-518. doi:10.1016/j.coms.2019.03.013
8. Collier M, Fu R. Artificial intelligence: healthcare's new nervous system. Accenture. July 30, 2020. Accessed May 23, 2022. https://www.accenture.com/au-en/insights/health/artificial-intelligence-healthcare
9. Marr B. How is AI used in healthcare - 5 powerful real-world examples that show the latest advances. Forbes. 2018.
10. Kalis B, Collier M, Fu R. 10 promising AI applications in health care. Harvard Business Review. 2018.
11. Singhal S, Carlton S. The era of exponential improvement in healthcare? McKinsey and Company. 2019.
12. Webb A, Sommers S. Disruptive innovations in dentistry: how AI and machine learning are enhancing resin-based composites. DentistryIQ. January 7, 2021. Accessed July 20, 2021. https://www.dentistryiq.com/dentistry/article/14190000/disruptive-innovations-in-dentistry-how-ai-and-machine-learning-are-enhancing-resinbased-composites

13. Everst Group. Everest Group PEAK MatrixTM for Intelligent Document Processing (IDP) Technology Vendors 2020 | Focus on Parascript. Everest Group Research. April 2020. Accessed May 23, 2022. https://www.parascript.com/go/intelligent-document-processing-assessment.

14. The Office of the National Coordinator for Health Information Technology (ONC). Information blocking. Health IT.gov. Updated May 20, 2022. Accessed May 24, 2022. https://www.healthit.gov/topic/information-blocking