EDITORIAL**Impact of artificial intelligence in healthcare**

Artificial intelligence (AI) is prepared to become a transformational force in healthcare. From chronic diseases and cancer to radiology and risk assessment, there are nearly endless opportunities to influence technology to install more precise, efficient, and impactful interventions at exactly the right moment in a patient's care. AI offers a number of benefits over traditional analytics and clinical decision-making techniques. Learning algorithms can become more specific and accurate as they interact with training data, allowing humans to gain unique insights into diagnostics, care processes, treatment variability, and patient outcomes (1).

Using computers to communicate is not a new idea by any means, but creating direct interfaces between technology and the human mind without the need for keyboards, mice, and monitors is a cutting-edge area of research that has significant applications for some patients. Neurological diseases and trauma to the nervous system can take away some patients' abilities to speak, move, and interact meaningfully with people and their environments. Brain-computer interfaces (BCIs) backed by artificial intelligence could restore those fundamental experiences to those who feared them lost forever. Brain-computer interfaces could drastically improve quality of life for patients with ALS, strokes, or locked-in syndrome, as well as the 500,000 people worldwide who experience spinal cord injuries every year (2).

Radiological images obtained by MRI machines, CT scanners, and x-rays offer non-invasive visibility into the inner workings of the human body. But many diagnostic processes still rely on physical tissue samples obtained through biopsies, which carry risks including the potential for infection. AI will enable the next generation of radiology tools that are accurate and detailed enough to replace the need for tissue samples in some cases, experts predict. Diagnostic imaging team with the surgeon and the pathologist can be brought together which will be a big challenge (3).

Succeeding in the pursuit may allow clinicians to develop a more accurate understanding of how tumours behave as a whole instead of basing treatment decisions on the properties of a small segment of the malignancy. Providers may also be able to better define the aggressiveness of cancers and target treatments more appropriately. Artificial intelligence is helping to enable "virtual biopsies" and advance the innovative field of radiomics, which focuses on harnessing image-based algorithms to characterize the phenotypes and genetic properties of tumours (1).

Shortages of trained healthcare providers, including ultrasound technicians and radiologists can significantly limit access to life-saving care in developing nations around the world. AI could help mitigate the impacts of this severe deficit of qualified clinical staff by taking over some of the diagnostic duties typically allocated to humans (4).

For example, AI imaging tools can screen chest x-rays for signs of tuberculosis, often achieving a level of accuracy comparable to humans. This capability could be deployed through an app available to providers in low-resource areas, reducing the need for a trained diagnostic radiologist on site.

However, algorithm developers must be careful to account for the fact that different ethnic groups or residents of different regions may have unique physiologies and environmental factors that will influence the presentation of disease. The course of a disease and population affected by the disease may look very different in India than in the US. As these algorithms are being developed, it is very important to make sure that the data represents a diversity of disease presentations and populations. we cannot just develop an algorithm based on a single population and expect it to work as well on others (1).

Electronic health records (EHRs) have played an instrumental role in the healthcare industry's journey towards digitalization, but the switch has brought myriad problems associated with cognitive overload, endless documentation, and user burnout. EHR developers are now using AI to create more intuitive interfaces and automate some of the routine processes that consume so much of a user's time. Users spend the majority of their time on three tasks: clinical documentation, order entry, and sorting through the in-basket (5).

Voice recognition and dictation are helping to improve the clinical documentation process, but natural language processing (NLP) tools might not be going far enough. Video recording a clinical encounter would be helpful while using AI and machine learning to index those videos for future information retrieval. And it would be just like in the home, where we are using Siri and Alexa. The future will bring virtual assistants to the bedside for clinicians to use with embedded intelligence for order entry(5). AI may also help to process routine requests from the inbox, like

medication refills and result notifications. It may also help to prioritize tasks that truly require the clinician's attention (5) making it easier for users to work through their to-do lists.

Antibiotic resistance is a growing threat to populations around the world as overuse of these critical drugs fosters the evolution of superbugs that no longer respond to treatments. Multi-drug resistant organisms can wreak havoc in the hospital setting, and claim thousands of lives every year. *C. difficile* alone accounts for approximately \$5 billion in annual costs for the US healthcare system and claims more than 30,000 lives. Electronic health record data can help to identify infection patterns and highlight patients at risk before they begin to show symptoms. Leveraging machine learning and AI tools to drive these analytics can enhance their accuracy and create faster, more accurate alerts for healthcare providers. AI tools can live up to the expectation for infection control and antibiotic resistance (6).

Pathologists provide one of the most significant sources of diagnostic data for providers across the spectrum of care delivery. Seventy percent of all decisions in healthcare are based on a pathology result. Somewhere between 70 and 75 percent of all the data in an EHR are from a pathology result. So the more accurate we get, and the sooner we get to the right diagnosis, the better we're going to be. That's what digital pathology and AI has the opportunity to deliver (7). Analytics that can drill down to the pixel level on extremely large digital images can allow providers to identify nuances that may escape the human eye. Pathologists now getting to the point where they can do a better job of assessing whether a cancer is going to progress rapidly or slowly and how that might change how patients will be treated based on an algorithm rather than clinical staging or the histopathologic grade which is going to be a huge advance. AI can also improve productivity by identifying features of interest in slides before a human clinician reviews the data. AI can screen through slides and direct pathologists to the right thing to look at so that they can assess what's important and what's not. That increases the efficiency of the use of the pathologist and increases the value of the time they spend for each case (7).

In the medical environment, smart devices are critical for monitoring patients in the ICU and elsewhere. Using AI to enhance the ability to identify deterioration, suggest that sepsis is taking hold, or sense the development of complications can significantly improve outcomes and may reduce costs related to hospital-acquired condition penalties. Integrating dissimilar data from across the healthcare system, and generating an alert that would alert an ICU doctor to intervene early on the aggregation of that data is not something that a human can do very well (8). Inserting intelligent algorithms into these devices can reduce cognitive burdens for physicians while ensuring that patients receive care in as timely a manner as possible.

Immunotherapy is one of the most promising avenues for treating cancer. By using the body's own immune system to attack malignancies, patients may be able to beat stubborn tumours. However, only a small number of patients respond to current immunotherapy options, and oncologists still do not have a precise and reliable method for identifying which patients will benefit from this option. Machine learning algorithms and their ability to synthesize highly complex datasets may be able to illuminate new options for targeting therapies to an individual's unique genetic makeup. Recently, the most exciting development has been checkpoint inhibitors, which block some of the proteins made by some types of immune cells. But still all of the disease biology is not understood. This is a very complex problem (9).

EHRs are a goldmine of patient data, but extracting and analysing that wealth of information in an accurate, timely, and reliable manner has been a continual challenge for providers and developers. Data quality and integrity issues plus a mishmash of data formats, structured and unstructured inputs, and incomplete records have made it very difficult to understand exactly how to engage in meaningful risk stratification, predictive analytics, and clinical decision support. Part of the hard work is integrating the data into one place. But another problem is understanding what it is one gets when one is predicting a disease in an EHR (10).

EHR analytics have produced many successful risks scoring and stratification tools, especially when researchers employ deep learning techniques to identify novel connections between seemingly unrelated datasets. But ensuring that those algorithms do not confirm hidden biases in the data is crucial for deploying tools that would truly improve clinical care. The biggest challenge will be making sure exactly what one is predicting even before one starts opening up the black box and looking at how one is predicting it (10).

Almost all consumers now have access to devices with sensors that can collect valuable data about their health. From smartphones with step trackers to wearables that can track a heartbeat around the clock, a growing proportion of health-related data is generated on the go. Collecting and analysing this data and supplementing it with patient-provided information through apps and other home monitoring devices can offer a unique perspective into individual and population health. AI will play a significant role in extracting actionable insights from this large and varied treasure trove of data. But helping patients get comfortable with sharing data from this intimate, continual monitoring may require a little extra work (11). However, patients tend to trust their physicians which may help to ease any discomfort with contributing data to large-scale research initiatives. There is a very good chance that wearable data will have a major impact because our care is very episodic and the data we collect is very coarse. By

collecting granular data in a continuous fashion, there is a greater likelihood that the data will help doctors take better care of patients (11).

Continuing the theme of harnessing the power of portable devices, experts believe that images taken from smartphones and other consumer-grade sources will be an important supplement to clinical quality imaging especially in underserved populations or developing nations. The quality of cell phone cameras is increasing every year, and can produce images that are viable for analysis by artificial intelligence algorithms. Dermatology and ophthalmology are early beneficiaries of this trend.

Researchers in the United Kingdom have even developed a tool that identifies developmental diseases by analysing images of a child's face. The algorithm can detect discrete features, such as a child's jaw line, eye and nose placement, and other attributes that might indicate a craniofacial abnormality. Currently, the tool can match the ordinary images to more than 90 disorders to provide clinical decision support. The majority of the population is equipped with pocket-sized, powerful devices that have a lot of different sensors built in (12). This is a great opportunity for us. Almost every major player in the industry has started to build AI software and hardware into their devices. That's not a coincidence. Every day in our digital world, we generate more than 2.5 million terabytes of data. In cell phones, the manufacturers believe they can use that data with AI to provide much more personalized and faster and smarter services. Using smartphones to collect images of eyes, skin lesions, wounds, infections, medications, or other subjects may be able to help underserved areas cope with a shortage of specialists while reducing the time-to-diagnosis for certain complaints. There is something big happening. We can leverage that opportunity to address some of the important problems which have in disease management at the point of care (12). As the healthcare industry shifts away from fee-for-service, so too is it moving further and further from reactive care. Getting ahead of chronic diseases, costly acute events, and sudden deterioration is the goal of every provider and reimbursement structures are finally allowing them to develop the processes that will enable proactive, predictive interventions. AI will provide much of the bedrock for that evolution by powering predictive analytics and clinical decision support tools that clue providers in to problems long before they might otherwise recognize the need to act. AI can provide earlier warnings for conditions like seizures or sepsis, which often require intensive analysis of highly complex datasets.

Machine learning can also help support decisions around whether or not to continue care for critically ill patients, such as those who have entered a coma after cardiac arrest (13). Typically, providers must visually inspect EEG data from these patients. The process is time-consuming and subjective, and the results may vary with the skill and experience of the individual clinician. In these patients, trends might be slowly evolving. Sometimes when we are looking to see if someone is recovering, we take the data from ten seconds of monitoring at a time. But trying to see if it changed from ten seconds of data taken 24 hours ago is like trying to look if our hair is growing longer. But if we have an AI algorithm and lots and lots of data from many patients, it is easier to match up what we are seeing to long term patterns and maybe detect subtle improvements that would impact our decisions around care (13).

Leveraging AI for clinical decision support, risk scoring, and early alerting is one of the most promising areas of development for this revolutionary approach to data analysis. By powering a new generation of tools and systems that make clinicians more aware of nuances, more efficient when delivering care, and more likely to get ahead of developing problems, AI will usher in a new era of clinical quality and exciting breakthroughs in patient care.

REFERENCES

1. Jennifer Bresnick. Top 12 Ways Artificial Intelligence Will Impact Healthcare. Shared on Twitter. 30th April 2018.
2. Leigh Hochberg. Director of the Center for Neurotechnology and Neurorecovery at MGH.
3. Alexandra Golby. Director of Image-Guided Neurosurgery at Brigham & Women's Hospital (BWH).
4. Jayashree Kalpathy-Cramer. Assistant in Neuroscience at MGH and Associate Professor of Radiology at HMS.
5. Adam Landman. Vice President and CIO at Brigham Health.
6. Erica Shenoy. Associate Chief of the Infection Control Unit at MGH.
7. Jeffrey Golden. Chair of the Department of Pathology at BWH and a professor of pathology at HMS.
8. Mark Michalski. Executive Director of the MGH & BWH Center for Clinical Data Science.
9. Long Le. Director of Computational Pathology and Technology Development at the MGH Center for Integrated Diagnostics.
10. Ziad Obermeyer. Assistant Professor of Emergency Medicine at BWH and Assistant Professor at HMS.
11. Omar Arnaout. Co-director of the Computation Neuroscience Outcomes Center and an attending neurosurgeon at BWH.
12. Hadi Shafiee. Director of the Laboratory of Micro/Nanomedicine and Digital Health at BWH.
13. Brandon Westover. Director of the MGH Clinical Data Animation Center.

Prof. Manjula Shantaram
Editor-in-Chief, Biomedicine