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Artificial Intelligence In Cardiovascular Medicine

Artificial Intelligence for Education, Proctoring, and Credentialing in Cardiovascular Medicine

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Artificial intelligence and machine learning are rapidly gaining popularity in every aspect of cardiovascular medicine. This review discusses the past, present, and future of artificial intelligence in education, remote proctoring, credentialing, research, and publication as they pertain to cardiovascular procedures. This review describes the benefits and limitations of artificial intelligence and machine learning and the exciting potential of integrating advanced simulation, holography, virtual reality, and extended reality into disease diagnosis and patient care, as well as their roles in cardiovascular research and education. Nonetheless, much of the available data resides in electronic medical records or within industry-sponsored proprietary programs that are not compatible or standardized for current clinical application.

Many areas in cardiovascular medicine would benefit from the introduction or increased use of artificial intelligence. Web-based artificial intelligence applications could be used to address unmet needs for education, on-demand procedural proctoring, credentialing, and recredentialing for interventionists and physicians in remote locations. Further progress in artificial intelligence will require further collaboration among computer scientists and researchers in order to identify and correct the most relevant problems and to implement the best data-based approach to achieving this goal. The future success of artificial intelligence in cardiovascular medicine will depend on the degree of collaboration between all pertinent experts in this field. This will undoubtedly be a prolonged, stepwise process. ***(Tex Heart Inst J 2022;49(2):e217572)***

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Artificial intelligence (AI) is rapidly gaining popularity in cardiovascular medicine (CVM).[1] It has been shown that AI tools, such as cognitive computing, deep learning, and machine learning, can be used effectively to integrate information from electronic health records (EHRs) with advanced imaging modalities in order to improve patient care and achieve better outcomes.[1-4] Nonetheless, much of the available CVM data exists in unstructured formats or resides within industry-sponsored proprietary programs that focus primarily on highlighting the benefits of a company's products rather than on expanding knowledge about the complications and challenges encountered during the use of its products.[2] The ability to convert unstructured data, such as information gleaned from EHRs and various imaging modalities, into structured data through use of pattern-recognition algorithms, neural networks, and machine learning[2,3,5] would broaden our problem-solving opportunities and ultimately enable better and safer patient care (Fig. 1).[5,6]

Many areas in CVM—for example, endovascular treatment of structural heart disease, congenital heart disease, peripheral arterial disease, cerebrovascular disease, aortic aneurysmal disease, venous thromboembolic disease, and chronic venous insufficiency—would benefit from the introduction or increased use of AI.[7] In addition, web-based AI applications could be used to address unmet needs for properly structured, up-to-date educational materials for physicians-in-training and for user-friendly, on-demand procedural proctoring, credentialing, and recredentialing in various CVM procedures for interventionists, physicians in remote locations, and others who need it.[3-5,8]

The purpose of this review is to introduce the CVM community to current and future applications of AI in education, proctoring, credentialing, research, and publication. The benefits of simulation, virtual reality, augmented reality, extended reality, and holography are presented as important components of education about various

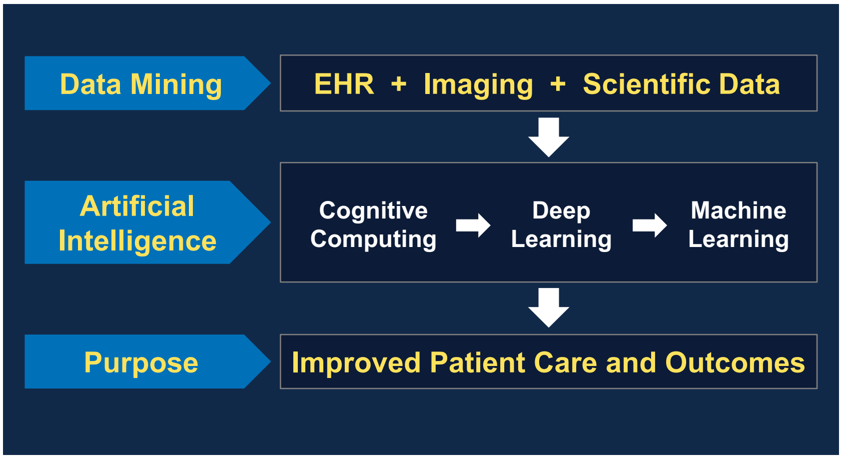

Fig. 1 *Diagram shows steps in essential data collection and artificial intelligence applications to improve patient care and outcomes in cardiovascular medicine.*

EHR = electronic health record

procedures.[8,9] By no means is this a comprehensive description of all AI advances in education and patient care.

Current Issues in CVM Education, Proctoring, and Credentialing

The coronavirus disease 2019 (COVID-19) pandemic has dramatically changed the way we practice and provide CVM education. Many major and minor medical meetings and conferences have transitioned from in-person to entirely web-based programs. This change has shown us that most professional interactions and educational activities can be conducted effectively over the internet. Even after COVID-19 is no longer a major threat, many educational programs will very likely continue to be web-based, to reduce unnecessary costs and time spent.

There is an unmet need for organized educational, proctoring, and credentialing material for physicians-in-training; proctoring for interventionists and for physicians in remote locations; and credentialing or recredentialing for endovascular interventionalists.[3,5,8] Current proctoring for interventional procedures is done observationally, either hands-on or remotely. However, no standardized and universal credentialing protocol exists for interventional procedures. Most institutions require operators to participate in an industry-sponsored educational program that includes both formal classroom education and in-person observation of one or more interventional procedures. This approach is usually sufficient for obtaining a certificate for a particular procedure, which can then be used for institutional credentialing. Many other institutions provide only provisional procedural approval and require additional proctoring by a credentialed local or remote proctor, which can be costly and inconvenient because of the time involved.

What can be done to improve the education, proctoring, and credentialing of physicians who perform endovascular interventions? We propose an AI-based program designed for physicians-in-training and endovascular specialists who seek expertise in certain aspects of endovascular medicine and for physicians in remote locations who will need proctoring during various types of endovascular procedures. The proposed program should be uniform and specialty-agnostic, and it should include all of the tools that AI offers. Some of the technologies are already available, whereas others are still in early stages of development or use. For this reason, and because of the complexities inherent in merging different databases and technologies, integrating AI into education and endovascular intervention will be a lengthy process involving several phases (Figs. 2 and 3).

Proposed Phase I: Integrating Artificial Intelligence Into Education for Endovascular Interventions

Phase I would include the collection and display of up-to-date educational materials necessary for understanding and becoming proficient in the concepts, techniques, and technologies inherent to each specialty within the field of endovascular intervention. This educational component should be designed by a multidisciplinary team that represents each subspecialty. Educational materials can be delivered through a web-based interface and should include publications on each subject, didactic presentations, demonstration videos, and information on commercial products related to the topic.

Phase I is easily achievable by using current information and technology that does not require advanced

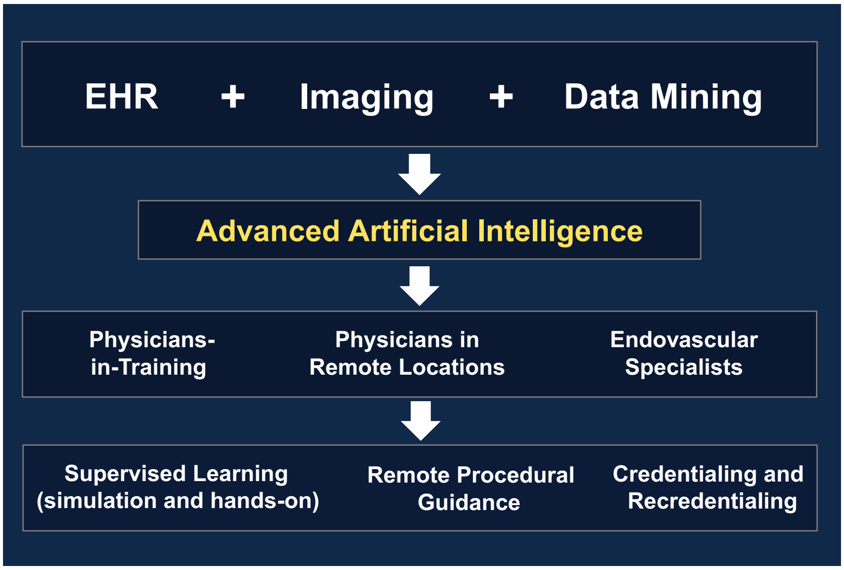

Fig. 2 *Diagram shows various essential components proposed for integrating artificial intelligence into education, proctoring, and credentialing in cardiovascular medicine.*

EHR = electronic health record

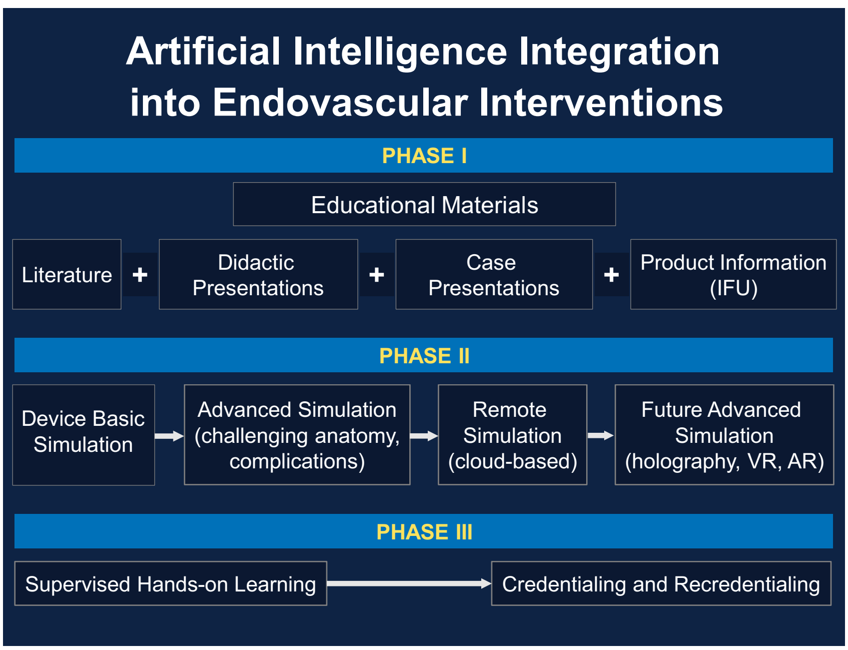

Fig. 3 *Diagram shows proposed phases of integrating artificial intelligence into education for endovascular interventions.*

AR = augmented reality; IFU = indications for use; VR = virtual reality

AI applications. For trainees, successful completion of Phase I should require passing an appropriate test that assesses the examinee's proficiency in the selected topic.

Proposed Phase II: Integrating Simulation Into Education for Endovascular Interventions

Phase II is an advanced component that will integrate currently available basic device simulation into the educational module (Fig. 3). Simulation technology has been used extensively in the aerospace industry for the last 5 decades and has benefited that industry profoundly. For aircraft pilots, it has become an absolute necessity and a first step toward becoming credentialed to operate certain equipment; because flight simulation modules are uniform, pilots can gain the expertise that they need to operate their equipment, regardless of manufacturer. In addition to the standard procedures for equipment readiness, takeoff, in-flight steps, and landing, problem-solving exercises related to equipment malfunction or other expected and unexpected adversities (for example, severe weather conditions) can also be simulated.

Conversely, medical device simulation technology is in the early stages of development and is much less sophisticated than the technology available in the aerospace industry. Educational tools are proprietary to each simulation company and predominantly include software licensed by the company. A recent search of the literature and various websites revealed at least 15 companies offer simulation programs dedicated to CVM and endovascular interventions. These programs are costly and time-consuming to produce. Unfortunately, device-manufacturing companies are unlikely to create and invest in universal simulation modules that include a variety of device simulation programs.

Advanced simulation modules that incorporate cases involving problematic anatomy and typical complications are an essential component of any educational program. Currently, however, most simulation companies do not see the necessity of investing in such programs, partially because it is costly and possibly because visualizing complications that can occur with the use of their products might discourage potential users of their technology. As an alternative, unbiased educational entities, such as professional societies, might do a better job of providing comprehensive educational material. For this reason, the societies should engage in this.

In the near future, advanced imaging—virtual reality, augmented reality, mixed reality, extended reality, simulation, and holographic imaging—will offer substantial benefits in educating, proctoring, and credentialing endovascular specialists.[9] Understanding the concepts underlying each of these applications is important to understanding their future roles in endovascular education.

Virtual Reality, Augmented Reality, and Mixed Reality

In simple terms, virtual reality is a complete immersion experience that shuts out the physical world. By using virtual reality devices such as Oculus Rift or Google Cardboard, CVM users are transported into real-world and imagined environments, such as a cardiac catheterization laboratory or an interventional endovascular suite.[9] Augmented reality adds digital components to a live view, often through use of a camera. Mixed reality combines elements of both augmented and virtual reality, such that real-world and digital objects interact.[9] Extended reality, a broad term that encompasses all of the various technologies that enhance our senses, can provide additional information about the actual world or create completely simulated worlds to experience.

Virtual reality in interventional medicine is a computer-generated, 3-dimensional (3D) simulation with which the physician can interact through use of special electronic equipment, such as a helmet with a screen and gloves with sensors. After donning a headset connected to the virtual reality viewer, a trainee can clearly see every step of an interventional procedure, and an instructor who appears electronically as an avatar can guide the trainee in the 3D space. Virtual reality systems are already helping physicians-in-training to plan upcoming procedures and are educating patients about various treatments.

Mixed reality technology is just now being applied in interventional medicine, given that holographic imaging and virtual reality have already proved highly useful during diagnostic and endovascular procedures.[8] For instance, in the last few years, Microsoft has joined with Philips Healthcare to deploy the HoloLens 2, one of the most advanced mixed-reality technologies available today, on Philips's Azurion radiologic imaging platform.[10] This integrated technology affords the operator easy virtual access to radiographic equipment controls, various devices, and the patient's anatomy (Figs. 4 and 5).[8,10-13]

All of these reality tools will become more important with time and integral to simulation in CVM.[9]

Holographic Imaging in Education

Holography is a process for creating 3D images (holograms) by using laser beams, the properties of interference and diffraction, light-intensity recording, and illumination of the recording. The process was first described in 1948 by Dennis Gabor, who discovered it while performing research to improve the electron microscope.[14] Holography uses the light field that results from a light source being scattered off objects, which can be recorded and reconstructed when the original light field and original objects are no longer present.[15]

Any dataset derived from use of a 3D medical imaging modality, such as computed tomography, echocardiography, chest radiography, angiography, or magnetic resonance imaging, can be converted into a digital hologram.[7-9,15,16] Digital holography is a 2-step process involving use of computer modeling software with specific proprietary algorithms. The first step consists of recording the radiographic image, which is then transformed into a photographic record. The second step

Fig. 4 *Photograph shows a physician viewing a holographic image of the aorta with use of the HoloLens 2 during an interventional procedure.*

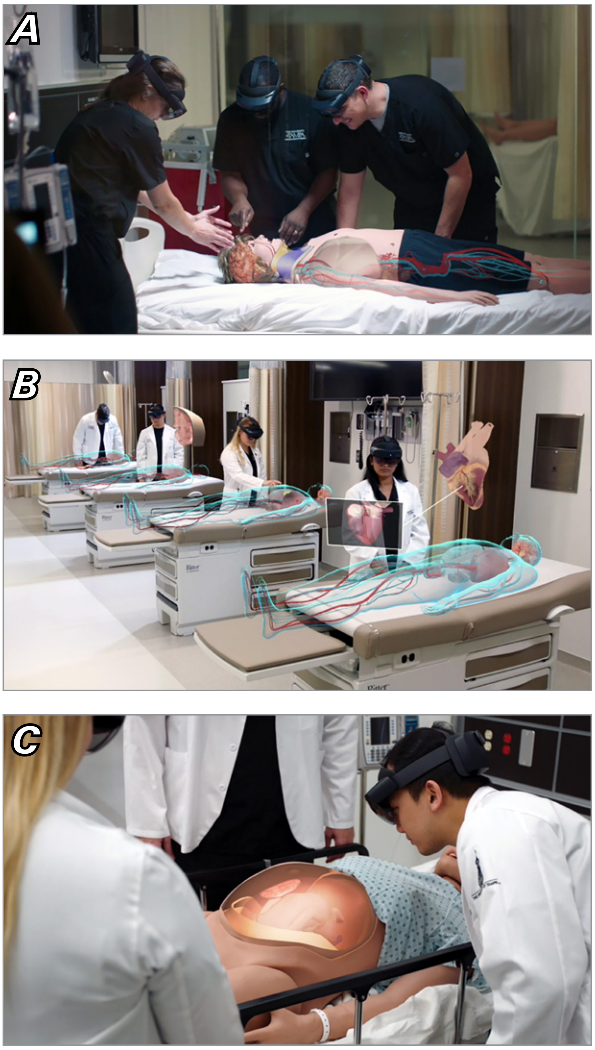

Fig. 5 *Photographs illustrate how the HoloLens 2 can be used to teach human anatomy by showing **A**) internal organs (for example, the brain); **B**) the circulatory system; and **C**) gestation.*

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consists of image reconstruction, in which the hologram is transformed into a virtual image. This process relies on the interference between 2 holograms. The resulting 3D images can change according to the position of the viewer (Fig. 4).[10]

There are 2 types of holography: conventional and dynamic. Conventional holography produces a static image of the 3D object. Dynamic holography captures and displays the motion of a 2-dimensional or 3D object. Current holograms are also autostereoscopic, which allows objects to be visualized in 3D without use of 3D glasses.[16]

Holography can be used effectively for educational and proctoring purposes in CVM. It offers physicians-in-training and proctored students an opportunity to visualize all of a procedure's components from various angles and to appreciate imaging details that might not be visible from the viewer's position (Fig. 4).[10] Holography is already benefiting echocardiographers and is being used as an investigational tool to guide physicians during interventional procedures. During procedures such as endovascular abdominal aortic aneurysm repair (EVAR), thoracic endovascular aortic aneurysm repair (TEVAR), and transaortic aortic valve repair (TAVR), this technology gives an operator easy access to the controls, images, and equipment. This enables the operator to perform these procedures more efficiently, which may in turn make many complex endovascular procedures safer.

Holography can also be used to teach anatomy to trainees and to supplement the information available to physicians and their patients. This technology presents a unique approach to teaching anatomy more effectively than hands-on cadaver anatomy lessons can. The application of holography in this manner offers the viewer on-demand access to different tissue layers from many different viewing angles.[12] Holography can also make teaching anatomy more appealing and intuitive, enabling educators to better explain a patient's anatomy and various procedures (Fig. 5).

Future Holographic Imaging in Radiology and Cardiovascular Intervention

The use of holography in radiology and CVM is evolving. This imaging technique is expected to be particularly useful to interventionists and surgeons during preprocedural planning and for guidance during open surgery or endovascular intervention. However, holographic imaging technology currently lacks the spatial resolution needed for radiologic imaging.

Holographic storage and retrieval systems are likely to become the storage medium of choice in the future. Storing holographic data as a volumetric density in 3D, in contrast to storing standard data on optical disks or DVDs, requires smaller physical storage space—typically, 1,000 times less. Holographic systems can read data exponentially faster than currently available technologies can.[9,15]

Proposed Phase III: Proctoring, Credentialing, and Recredentialing

Procedural Telemedicine for Education and Remote Proctoring

In light of the challenges that providers have faced during the COVID-19 pandemic, procedural telemedicine offers healthcare providers an easier way to proctor, credential, and educate colleagues remotely and to collaborate with peers and industry experts anytime, anywhere, without the risks and costs associated with travel. Unlike patient telemedicine, procedural telemedicine uses technology to connect physicians with collaborators during remote procedures. Remote users can control displays from multiple high-definition pan-tilt-zoom cameras and external imaging sources, to see multiple images at the same time. Both operators and remote users have an option to use annotation over the live or paused video. More than 10 years ago, we used technology from InTouch Health (Santa Barbara, Calif) for remote proctoring during EVAR and TEVAR (Fig. 6).

The primary benefit of remote proctoring is to accelerate education about the new technology and to foster quicker adoption of new technologies in a didactic, professional, informative way. Secondary benefits include lower infection risk in less crowded procedure rooms; access to real-time, on-demand industry support; less physician travel, thereby reducing costs and time spent related to proctoring procedures; and more scheduling flexibility and lower expenditures overall.

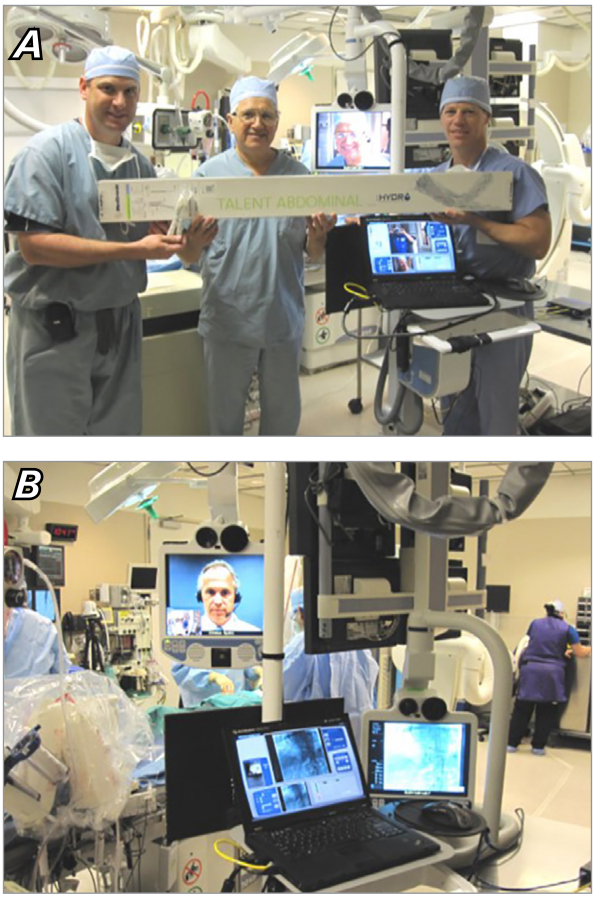

Fig. 6 *Photographs show a Texas Heart Institute endovascular suite during an interventional procedure in which imaging equipment, multiple cameras, and imaging screens are being used for remote proctoring with real-time support from industry partner InTouch Health.*

To realize these benefits, hospitals, ambulatory surgery centers, office-based facilities, and laboratories will need to offer virtual proctoring. This technology should encompass various procedures, be portable, and be vendor-neutral, given that several procedural telemedicine companies exist. The best known are InTouch Health and Avail (Palo Alto, Calif). Avail's technology is among the most advanced and most widely used today (Table I).

Procedural Telemedicine for Credentialing and Recredentialing

Phase III will enable physicians to participate in hands-on learning that can lead to credentialing for those who meet the requirements (Fig. 3). Proctoring will include online observation of procedures and the activities of interventionists in remote locations. Reverse proctoring will enable physicians in remote locations to observe all components and steps of the procedure and to be trained by an expert. This proctoring method is rarely used at present, even though all necessary technologies are readily available. The same approach and tools can be used in the future for credentialing and recredentialing.

Proposed Phase IV: Future Mentoring During Interventional Procedures

It is conceivable that guidance during diagnostic and interventional procedures will soon be monitored by an AI mentor or avatar that has a vast repository of information about any planned procedure. This avatar could then obtain in advance all pertinent information from EHRs, images, and other sources and guide the physician throughout the procedure by selecting the most optimal access sites and equipment. The avatar could also alert an interventionist when mistakes are made and suggest the most appropriate corrective action.

TABLE I. Potential Benefits of Procedural Telemedicine

Remote Proctoring	Clinical Education	Industry Support
Accelerate adoption of new technology to differentiate practice, program, or both	Accelerate adoption of new technology to differentiate and promote practice, program, or both	Provide on-demand access to real-time support from industry partners
Minimize physician travel and improve physician quality of life	Enhance training and education for staff	Control access to procedure room to minimize crowding and infection risk
Improve scheduling flexibility and minimize impact of case cancellations	Digitize medical education programs and expand the reach of the institution	Improve flexibility of procedure support and minimize scheduling burden

The Future of Simulation

Currently, companies that own simulation equipment and proprietary software offer medical simulation only on request. Given advances in computer software, remote cloud-based simulation that can be achieved at lower cost and on demand will probably be available soon. The future of simulation for endovascular interventions will involve web-based applications of virtual and augmented reality that will be integrated with holographic technology.

Artificial Intelligence in Research and Publishing

Artificial intelligence is rapidly gaining popularity in the age of "big data" for research and publication. Scientists are now able to use complex algorithms and large volumes of data to produce statistical models that rival or exceed human capabilities.

Data mining is a fast-growing area in the field of research and publishing.[17-19] Data mining, part of a process called knowledge discovery in databases, includes data selection, cleaning, preprocessing, and transformation. In essence, computer algorithms are used to discover hidden patterns and unsuspected relationships among elements of large data volumes.

An example of big data mining is a large study that we undertook several years ago to analyze the benefits of percutaneous EVAR, TEVAR, and TAVR with use of deidentified patient-level data from a national registry called the IBM Explorys Therapeutic Dataset.[20] This registry houses data from approximately 55 million patients (approximately 15% of the United States [US] population), aggregated from 23 large healthcare systems comprising approximately 360 hospitals and 330,000 providers.[20] The data, which are collected from EHRs, outgoing billing records, and adjudicated claims from commercial and public payers, provide a longitudinal view of a patient's medical history across the care continuum. These data are available from IBM Watson Health; however, restrictions apply to the availability of the data, which were used under license for this study.[20]

All study data were fully deidentified and were accessed through protocols compliant with patient confidentiality requirements in the US, including Health Insurance Portability and Accountability Act of 1996 (HIPAA) regulations; this study was therefore exempted from institutional review board approval. This study and data analysis would not have been possible without the use of big-data computers and algorithms.

Knowledge acquisition, knowledge representation, and inference (including search and control) are 3 fundamental AI techniques used in data mining. Because data mining seeks to identify interesting patterns in various forms, such as association rules, classification rules, and decision trees, knowledge representation is of particular interest.[18,19,21-23] Multiple factors influence the reliability of the AI algorithms used for data mining and the study results (Table II).

The medical community has been slower than others to adopt AI for research and publication because of health data–sharing limitations related to HIPAA. Nonetheless, in the last few years, substantial progress

TABLE II. Factors Influencing the Reliability of Artificial Intelligence Algorithms Used for Data Mining and Study Results

Pertinent Questions	Purpose
What is the quality of the data?	Ensure that the model uses reliable data
What was the collection method?	Identify problems in the data that could limit their usefulness
Is the data source similar to the target goal and population?	Understand the feasibility of replicating the study
Are the findings robust?	Understand the sensitivity, specificity, and positive and negative predictive values of the model
Have subgroup analysis and subgroup validation been done?	Reduce the risk for suboptimal performance of the model in subgroups
Can the selected model be tested against standard methods?	Understand the potential application to populations with different diseases
Could there be unintended consequences?	Understand potential negative and unintended consequences that may affect patients or the healthcare system
Are the findings consistent with clinical practice using other methods?	Understand the benefits, if any, from the model performance
Will this model substitute for other methods or improve the performance of existing technology?	Develop realistic expectations for potential applications and improvement of current technology

related to data sharing in healthcare has been made. Artificial intelligence is now being used to process large volumes of claims data that are much harder, and potentially impossible, to deidentify[17,18] and that are void of the richness contained in patient medical records. This situation prompts the question: What barriers are preventing the sharing of the rich data contained in EHRs across the world?

The issues surrounding sharing healthcare-related data vary across the globe and are rapidly evolving. From a policy perspective, HIPAA directives in the US and the general data-protection regulations in the European Union provide some framework and support for engaging the patient or consumer in the release of the information; many other countries have similar restrictions on sharing of healthcare-related data. Certain medical and academic journals have adopted policies requiring open sharing of deidentified data; some of these data-sharing policies may be in conflict with regulations.

Beyond the regulatory and ethical aspects of sharing healthcare data, there is also the question of the healthcare data's value and ownership. Healthcare organizations may have invested substantial sums of money in acquiring the technical personnel and equipment needed to annotate datasets for AI research. This intellectual contribution may be used in parallel with data resulting from direct patient contribution, which may further cloud ownership of healthcare data. Within the US, state-to-state variations in declarations of the ownership of medical record data range from the hospital or physician owning the data, to the patient owning the data, to the absence of any legal perspective. Public sharing of the data may result in the loss of intellectual property.[19,22] Nonetheless, we must continue to accelerate our efforts to advance health care through collaboration and data accessibility.

Conclusion

Nearly all areas of CVM have benefited from major achievements in recent years. However, the application of AI and machine learning in education, proctoring, and credentialing has lagged behind. It is evident that optimizing AI will require close collaboration among computer scientists, researchers, educators, and endovascular specialists, to identify the most relevant problems to be solved and the best approaches for using data sources to achieve this goal. The future of AI in CVM will be as bright as the degree of collaboration between all pertinent experts in this field.

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