Artificial intelligence in pediatric cardiology and cardiac surgery: Irrational hype or paradigm shift?

"Healthcare is an information industry that continues to think that it is a biological industry."

– Laurence McMahon at the AAHC Thought Leadership Institute meeting, August, 2016.

With the current imbroglio of health care and burden of work, some of us have been bereft of the pure joys of being a physician or caretaker in pediatric cardiology. Now imagine your future experience as a practitioner for children with heart disease in the year 2040:

You are in the serene cardiac intensive care pod where real-time analytics are displayed (rather than the de rigueur vital signs) and deep learning (in the form of recurrent neural network) are now routinely used for personalized intensive care unit decision support and to mitigate the stress of families and physicians/nurses. There is no longer formal lengthy AM rounds as communication among team members is now continuous. The old electronic record and computers are all no longer omnipresent, and patient information is displayed on the video wall only upon activation or automatically in the case of sudden changes. The conversations are recorded with a tiny microphone on your shirt and analyzed with natural language processing (NLP) in order to capture key information onto the electronic record. You receive notifications about recent advances in diagnostics and therapy that pertain to your patients, and you read these new notifications and answer questions to gain points for individualized continuing medical education (as board examinations have been eliminated finally).

You then go to the outpatient area. Several of your patients are triaged to be seen remotely with telepresence. A new child with heart failure is seen after the admission process is completed automatically with robotic process automation, and the echocardiogram is preliminarily read, aided by computer vision (by the use of convoluted neural network [CNN]). A precision medicine protocol is promoted by individualized therapy options, and pharmacotherapy is accompanied by the pharmacogenomic profile. A cognitive architecture based on heart failure experts from numerous centers, published reports in this disease condition, as well as the accumulated data from the entire pediatric heart failure patient cohort is utilized for best clinical decision for this child. You use augmented reality to explain the heart condition to the parents including illustration of a micro-axial device for ventricular support (as orthotropic transplantation has been supplanted by advances in miniaturized support devices and nanomedicine). The patient is then set up for wearable technology with embedded artificial intelligence (AI) to monitor her blood pressure and heart rate while she is on new medical regimen at home.

For a subspecialty that is particularly rich with imaging and clinical data already, and with more sources of data to come in the very near future (especially with electrocardiogram [EKG or ECG] apps, implantable monitors, and biosensors), pediatric cardiology remains relatively dormant in this burgeoning domain of AI.[1] A comprehensive review by Johnson *et al.* discusses the many dimensions how AI can affect cardiology: from research to clinical practice and even population health.[2] This review also well delineated the basics of machine learning (supervised/unsupervised learning and even the abstruse concept of reinforcement learning). Another excellent and concise review by Shameer *et al.* focuses on the aspects of cardiovascular medicine in the context of machine learning.[3] Finally, there is an excellent review that showed how effective AI can be in the context of precision cardiovascular medicine, an aspect of cardiology that will be the cornerstone of pediatric cardiology in the near future.[4]

First, there is relatively increased use of AI and data science in the domain of cardiac imaging ranging from ECG to echocardiography for both diagnosis and prognosis. The major contribution to medical image interpretation has been CNN [Figure 1]. For signal modalities, an arrhythmia detection end-to-end deep-learning strategy (accomplished with a 34-layer CNN) with a single-lead ECG (with >90,000 single-lead ECGs from over 50,000 patients with 12 rhythm disturbance categories such as atrial fibrillation and ventricular tachycardia) accomplished interpretation at a cardiologist level.[5] While a prior study described work on automated quantification in echocardiography (chamber quantification for left ventricular [LV] function and assessment of valvular disease),[6] more recent works delineated how CNN was used for automated real-time standard view classification and image segmentation to improve workflow.[7,8] In addition, machine learning

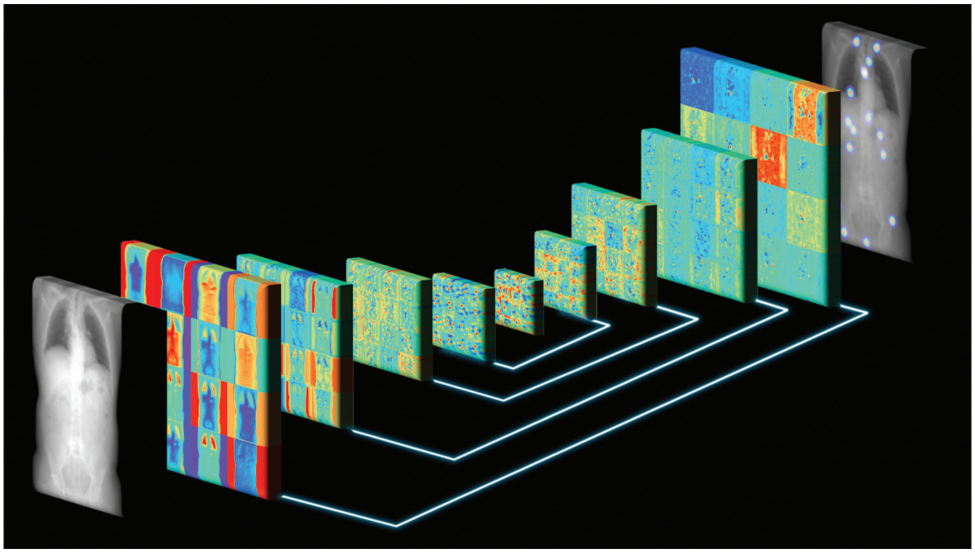

Figure 1: Convolutional neural network, a type of deep learning, and its many layers for medical image interpretation (courtesy of Tobias Heimann of Siemens engineering)

has been applied to the ever so challenging (1) heart failure patients with preserved ejection fraction and helped to set up a new phenotypic risk assessment system for heart failure[9] and also (2) patients with either hypertrophic cardiomyopathy or athletes LV hypertrophy based on expert-annotated, speckle-tracking of echocardiograms.[10] One study even described using NLP for large-scale, automated, and accurate extraction of structured, semi-structured, and unstructured data from echocardiography reports.[11] Deep-learning algorithms have also been applied to cardiac magnetic resonance imaging (MRI) as a prognosis prediction tool in patients with pulmonary hypertension and shown to be superior to clinicians' assessment.[12] In short, while ECGs and static images such as cardiac MRI are relatively straightforward for machine and deep learning, more complicated cardiac imaging such as echocardiograms as well as three-dimensional and four-dimensional images are also being studied with machine and deep learning. There is even a future role for hybrid imaging: combination of several modalities of imaging to maximize the advantages of each modality.[13]

There are also published reports of using AI for clinical decision support in various settings in both adult and pediatric cardiology. Decision-making in cardiology is often complex and is particularly vulnerable to many heuristics and biases.[14] A deep-learning algorithm (called deep learning-based early warning system [DEWS]) that used only four vital signs had a high sensitivity and a low false-positive rate for the detection of patients with cardiac arrest in a multicenter study.[15] A machine learning in the form of support vector machine devised an effective risk calculator that was shown to be superior (less-recommended drug therapy with less adverse events) to the existing accepted American College of Cardiology (ACC)/ American Heart Association (AHA) cardiovascular disease risk calculator.[16]

Overall, there are relatively few reports of AI-focused publications in children and adults with congenital heart disease. An AI-assisted auscultation algorithm that performed well in a virtual clinical trial may be difficult to become a routine approach given readily available echocardiographic assessments; in short, an AI strategy for an older technology (the stethoscope) may or may not be adopted by clinicians.[17] Machine learning algorithms were deployed to train a large dataset of adults with congenital heart disease to prognosticate and to facilitate management.[18,19] A similar study to the aforementioned DEWS study revealed that predictive models created by AI can lead to earlier detection of patients at risk for clinical deterioration and thereby improve care for pediatric patients in the pediatric cardiac intensive care setting.[20] In addition, four AI-based algorithms were employed to facilitate a clinical decision support system for estimating risk in congenital heart surgery.[21] One innovative report described using machine learning and system modeling to facilitate a multicentric collaborative learning project for rapid structured fact-finding and dissemination of expertise; this forward-thinking approach can provide a complement (and perhaps render less necessary to) the traditional multi-center, randomized clinical trials that are sometimes challenging to execute.[22]

As cardiology is both a perceptual or image-intensive field and a cognitive or decision-making subspecialty, AI is a particularly valuable technology for cardiology with potentially very rich dividends that are vastly underexplored at present but has great promise. Given the complexity of operative and interventional procedures in pediatric cardiology, perhaps it will be decades before a robot will be performing a cardiac procedure in its entirety. Nevertheless, AI is a much-needed resource as the cardiovascular disease burden remains singularly the largest and continues to climb in an aging population worldwide.

Overall, the cardiologist can be liberated from the long list of relatively mundane tasks to higher level of medical decision-making with full deployment of the various AI tools available. In the complex decision-making area, deep reinforcement learning and cognitive architecture can be particularly useful for the ever-increasingly complex nature of diagnostic and therapeutic precision cardiovascular medicine in both the intensive care ("precision intensive care") or hospital setting and the outpatient arena. This type of individualized medicine will need the many layers of data and information, all integrated into an AI-enabled strategy for the delivery of key information for knowledge and treatment. With more research and development, more sophisticated robotic procedures in the interventional catheterization laboratory, as well as in the operating room, will reach clinical use. The administrative aspects of a heart program can be better managed with some of the robotic process automation tools that are already available. Overall, all of these AI efforts promulgate a new paradigm in cardiovascular medicine of machine intelligence-derived phenotype profiling using multiple sources of data to eventually derive new clinical insights.

It is more than 100 years since the Flexner report that shaped our present medical school education strategy. With the advent of the aforementioned emerging technologies, it is now more important than ever before to reassess our relatively banal educational and training strategy in pediatric cardiology and cardiac surgery. The advent of AI (and other emerging technologies) is a precious gift from our technological colleagues and is the naissance of a special epoch in medicine. While AI is not necessarily going to replace clinicians, it should be part of every medical student's educational curriculum as well as every physician's clinical portfolio from this point forward.

So is AI in pediatric cardiology and cardiac surgery an irrational hype or a paradigm shift? I have had the privilege of discussing the possibility of AI in pediatric cardiology and cardiac surgery for the past three decades (even named a specialized cardiology supercomputer "Leo" after Leonardo da Vinci, who first described a congenital heart defect as well as a coronary artery lesion in the 1500s). The more than a dozen technologies described in the aforementioned scenario are all now available; pediatric cardiology is the singularly best subspecialty to benefit the most from the portfolio of AI methodologies and emerging technologies.[23] My long-awaited arrival of AI for our field has finally arrived; we cannot passively wait for the future, but we will need to create this future paradigm shift for our younger colleagues and our beloved children and adults with heart disease.

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