

The Advent of Artificial Intelligence in Cardiology: The Current Applications and Future Prospects

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ABSTRACT

The technology of artificial intelligence is emerging as a promising entity in cardiovascular medicine, with the potential to improve diagnosis and patient care. In this article we review the literature on artificial intelligence and its utility in cardiology. We provide a detailed description of concepts of artificial intelligence tools like machine learning, deep learning and cognitive computing. This review discusses the current evidence, applications, future prospects and limitations of artificial intelligence in cardiology.

Keywords: Artificial intelligence, Machine learning, AI, Cardiovascular, Robotic

INTRODUCTION

Cardiovascular diseases (CVDs) are the major cause of morbidity and mortality in the world. According to the World Health Organization (WHO) an estimated 17.9 million people die each year from CVDs, accounting for 31% of all the deaths across the globe (WHO 2020). It is imperative that mitigating strategies are devised to provide optimal and cost effective care for the CVDs.

There has been an exponential increase in the generation of health care data over the past decade. According to some sources the growth of new data is almost 48% each year, overwhelming the physician and changing the dynamics of health care services (Stanford Medicine. 2017). It is therefore essential that this large volume of data is harnessed for research, formulating preventive measures and to provide efficient patient care (Stanford Medicine. 2017). This availability of unlimited data makes it difficult for the health care professional to assimilate it and take a prompt errorless decision (Dilsizian et al., 2014). Computer systems have the inherent capabilities to store big data, process this information intelligently and arrive at quick conclusions (Future Advocacy. 2018). Artificial intelligence (AI) and its tools like machine learning have the potential to aid the field of cardiology in reducing the physician's burden, and dispense precise, rapid and personalized care to the patients (Boeldt et al., 2015, Steinhubl et al.). Machine learning can analyze large complex data and provide a solution that can be used by the clinician for making accurate prognostication (Perez 2018).

The AI tools are making their impact in the rapidly evolving field of cardiology. It's important that cardiovascular medicine services appreciate the capabilities of this technology to make efficient use of it in the coming years. With the increased usage of AI for solving complex tasks and quantification of data, it is predicted to usher into improved outcomes for the patients, cardiologists, health services, insurance providers and the executive

powers across the world (Rajkomar et al. 2019). AI has a huge potential to aid the physician in the field of medical diagnosis, disease treatment, drug discovery and risk prediction (Gulshan et al. 2016).

We present a literature review of the role of AI in cardiology, focusing on the basic concept of AI tools and current application in cardiovascular sciences. Lastly, we discuss future directions and challenges in AI adoption.

ARTIFICIAL INTELLIGENCE

Concepts of Artificial Intelligence

Simply put, artificial intelligence is a science which enables human-like intellect into machines (Krittanawong et al., 2017). It comprises machine learning, deep learning and cognitive computing methods to equip machines with intelligence (Yan et al. 2019). The intelligence here is synthesized to mimic the natural human decision making process and take action, as a human would do.

For a machine to clone human intelligence and behaviour, it needs:

1. Contextual knowledge
2. Variety of situational solutions
3. Ability to make right decisions based on the situation posed.

Machine learning

Machine learning (ML) is the crux of AI. This technology solves complex tasks of big data by recognizing variables and providing a model, based on which future accurate predictable data can be created (Ghahramani 2015). Machine learning is categorized into supervised, unsupervised and reinforcement types. In supervised learning the machine algorithms utilize data labeled by humans to predict and achieve the desired outcome (YAN et al. 2019, Johnson et al. 2018). Supervised learning is also vital in the operation of many biological and artificial neural networks (Raymond 2018).

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In unsupervised learning the machine finds the patterns from the hidden data without any human input. These learning algorithms have been applied in the cardiovascular disease prediction, diagnosis and care, and also in cardiovascular image interpretation (Krittanawong et al., 2017). The drawbacks of unsupervised learning are that the primary cluster pattern needs to be unbiased and validated with other cohorts (Perez 2018).

Reinforcement learning is a combination of supervised and unsupervised learning. In this type of learning the aim is to empirically augment the precision of algorithms (Krittanawong et al., 2017).

Deep learning

Deep learning is a powerful upgrade of machine learning technology (Hosny et al. 2018, Camacho et al. 2018). This utilizes artificial neuronal networks and mimics the operations of the human brain to generate automated predictions from the inserted data (Perez 2018, Rajkomar 2018). This technology has enhanced the advancement in speech and visual object recognition, object detection, and drug invention and genomics. Deep learning has made significant breakthroughs in the processing of image, video, voice and audio data (LeCun et al., 2015).

Cognitive computing

In cognitive computing using the machine or deep learning algorithms, a system or a device creates automated computerized problem solving models mimicking the human thought process (Krittanawong et al., 2017).

The Pillars of AI Ecosystem

The AI tools, i.e. machine learning, deep learning and cognitive computing form the pillars of the AI ecosystem (Perez 2018, Johnson 2018, Kelly et al. 2019) (Figure 1). The various outcomes by the integration of these methods in AI are enumerated as follows:

1. Data: For the machine to make an accurate decision, a plethora of data sets are required to be able to make the predictions better.
 - a. Volume- comprise of data from electronic health record (EHR) i.e. historical clinical data, patient data, demographic data, images, audios, videos of the scan, doctor prescriptions, pharmaceutical reference & drug data.
 - b. Velocity- this requires real-time feeds from individuals, real-time feeds on the geographical conditions, news on epidemics and regular updates from clinical references.

- c. Variety- the variable formats of the data sets based on the provider, source of data and the stream.
 - d. Veracity- While there is a flood of data flowing around, it is important to ascertain that the data being used is of high-quality catering to the dimensions of accuracy, completeness, latency and sufficiency parameters.
2. Training the data set: The crux of AI, i.e. machine learning lies in the training of models which analyses this multi-stream data and classifies and prepares it for the models to consume. The technologies of image processing, natural language processing, text mining are used to arrive at a meaningful synopsis of the data sets. Many methods of classification/supervised and clustering/unsupervised techniques are tested for its accuracy before arriving at the right model which is applicable for use.
 3. Engine: The heart of AI is the engine which based on the situational data, utilizes the knowledge gained, and applies algorithms to arrive at the best possible outcome. After every prediction, it should be able to personalize the results to the patient and the doctor before concluding on the outcome.
 4. Action: For precision action, the AI system communicates to the humans by using of alerts (sounding off threshold attainment) and provides a prescriptive analysis (situation based options available for the doctor to choose). This results in analytical guidance on the case for the physician to make an informed decision.

The technological advancement available today enables all these functions of AI to work in tandem:

- Big data technologies & memory-based processing helps in managing the data sets efficiently.
- Technologies of image recognition (IR), natural language processing (NLP) and text mining help in data preparation.
- Off the shelf models in a multitude of languages assist in quick availability in the market.
- Communication methods such as message-based alerting, chat-bots, live assistance and links to multiple health apps can be utilized to make a direct connection to the hospital. It can also be used for auto-dialing of ambulance services in case of a medical emergency.

Lastly, building an efficient AI ecosystem needs an integrated expertise of the doctor, technologist and data scientist.

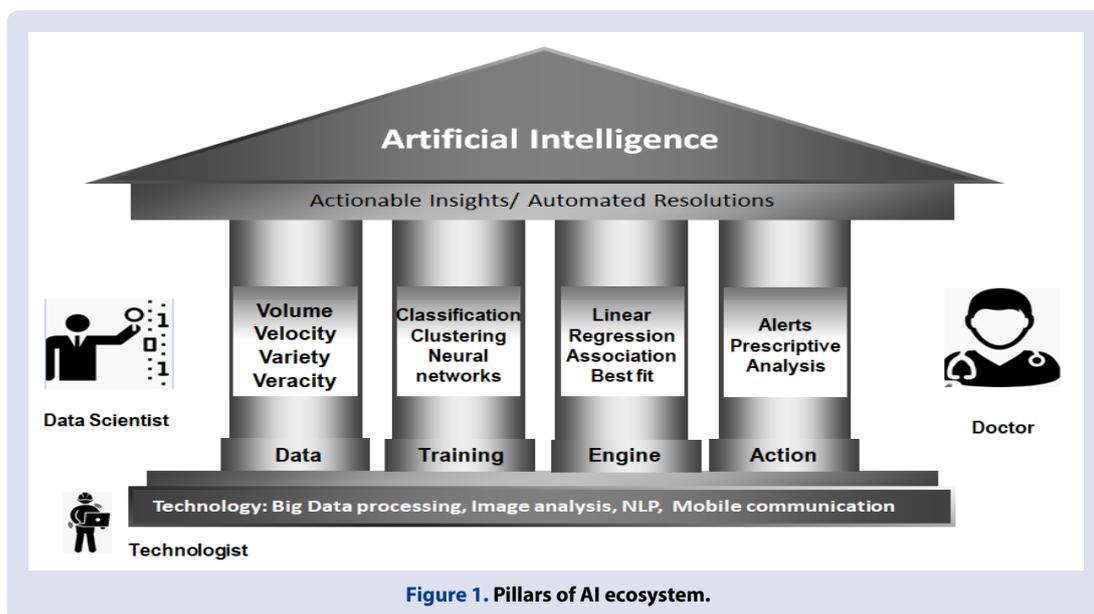


Figure 1. Pillars of AI ecosystem.

AI IN CARDIOLOGY

Cardiology is the field where precision, accuracy and quick response times are critical for the survival of the patient. Apart from being a lifesaver, the responsibility of the physician is to understand his patient aptly and guide him for his overall well-being. All these can be achieved with a well-rounded solution of artificial intelligence which assists the cardiologist to be adept, nimble and empathetic to the larger social community.

The key applications of AI in the field of cardiology are (Perez 2018, Yan Y et al. 2019) (Figure 2):

PREDICTION OF FATALITY

Based on the streaming data of the individuals from health apps, wearable devices and patient scan images, the AI is used to rightly predict the event of a fatality. This is possible by applying algorithms to machine learning and big data analytics.

Researchers from Cedars-Sinai Medical Center in the US conducted a 15 year prospective ESINER trial in 1912 asymptomatic subjects and used machine learning to assess the risk of myocardial infarction and cardiac death (Commandeur et al., 2019). In this study the ML integration of clinical parameters with coronary artery calcium and automated epicardial adipose tissue quantification was done, and 76 subjects presented an event of myocardial infarction or cardiac death during the follow-up period of 15 years. The researchers concluded that compared to standard risk assessment, machine learning integration of clinical risk factors and imaging measures can accurately predict the patient's risk of suffering an adverse event such as heart attack or cardiac death (Commandeur et al., 2019).

Personalized prescription and precision medicine

AI can be utilized to provide prescriptive analytics to the physician, based on the patient's unstructured EHR dataset, i.e. age, gender, ethnicity, family history, demographic location, lifestyle, past treatment history and health vitals etc. This could be utilized by the cardiologist for diagnosis of the disease and implement an accurate, personalized medical plan for each patient. Thus, AI can reduce the burden of the physician and help him to provide more precise care to the patient (Johnson et al., 2018). Health care professionals should get familiarized and trained in AI technology, as they can apply AI to analyze big data

and leverage this to improve cardiovascular disease diagnosis and treatment. Soon precision medicine will utilize more of AI to provide tailor-made health solutions for each patient (Yan et al. 2019).

A Personal Assistant to the Physician

AI can provide guidance and alerts to the doctor about the patient, such as knowledge about possible drug interactions and allergies. This can be used by the physician for planning rapid pre-emptive interventions on the patient. AI has the potential to reduce undue variation in clinical practice, improve deliverance and prevent avoidable medical errors that will affect most patients during their lifetime (McGlynn et al., 2015). Many AI concept validation studies have aimed to improve the clinical workflow, including automatic extraction of logical information from transcripts (Kanan et al., 2018), predicting failure of the patient to attend hospital appointments (Nelson et al., 2019), summarizing patient's doctor consultations (Rajkomar et al., 2019) and even recognizing speech in doctor-patient interactions (Chiu et al. 2020).

Police Individual Health

AI can be used for real-time monitoring of individual's data and correlate it clinically with possible outcomes. Personalized message to the patient's wearable sensors and devices can be sent with guidance on medications, preventive measures, and also recommend specialized treatment facilities in the geographical vicinity of the individual in case of a health emergency. This technology can be useful in detecting arrhythmias in susceptible individuals (Attia et al., 2019, Hannun et al., 2019). Advances in consumer technology can be leveraged to plan studies; an example is the ongoing prospective study to detect atrial fibrillation in 419,093 individuals owning a commercially available smartwatch (Turakhia et al., 2019).

Cardiovascular Imaging

Cardiac imaging is one area in which machine learning and deep learning methods have been extensively harnessed and demonstrated promising outcomes (Dey et al., 2019) AI technology has been used for automated image quality control, acquisition and reconstruction of an image more efficiently, and image segmentation. These algorithms are also used for myocardial motion and coronary arteries blood flow analysis, and computer-aided diagnosis (De Marvao et al., 2020, Shadmi et al., 2018). Deep learning technology has been used for analyzing coronary calcium scoring from computer tomography scans (Zarins et al., 2013). In the recently published CONFIRM registry, an analysis

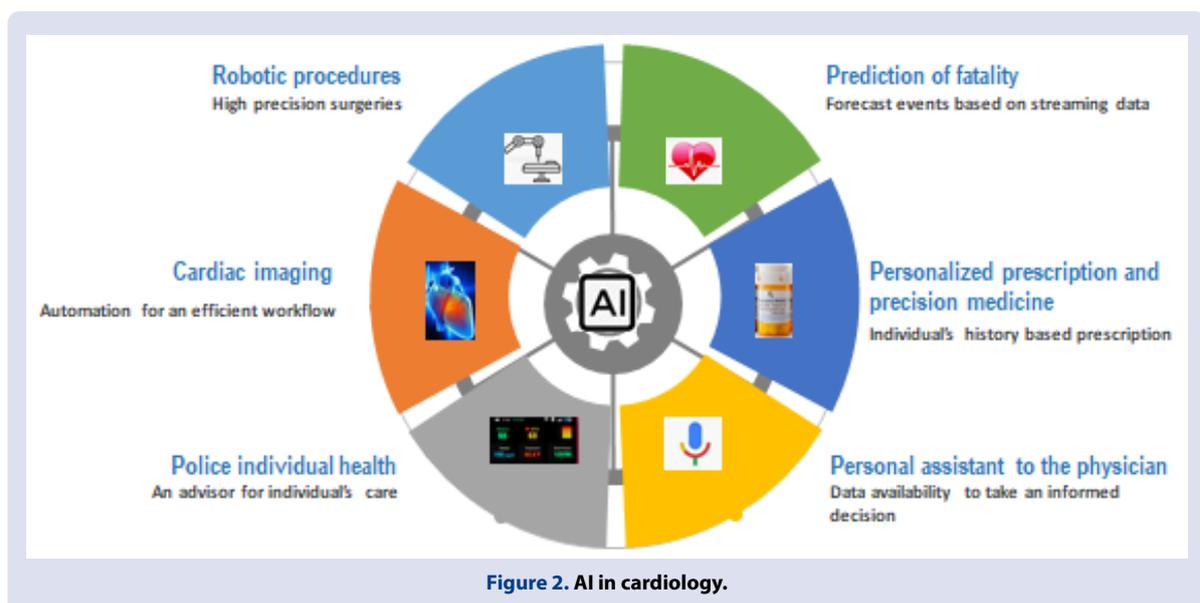


Figure 2. AI in cardiology.

of 13 054 participants using an ML algorithm incorporating clinical variables in addition to coronary artery calcium score (CACs) derived from coronary computed tomography angiography (CCTA), could accurately estimate the pre-test probability of obstructive coronary artery disease (CAD) on CCTA (AlAref et al., 2020). ML technology has shown to accurately detect obstructive CAD on CCTA better than the clinician's visual assessment of significant CAD on the reconstructed CCTA images (Marwan et al., 2019, Oikonomou et al. 2020). Radiomic based ML algorithms can be used for phenotyping of coronary lesions on CCTA [34]. High risk coronary atheromatous plaque features, and coronary micro-calcification and inflammation on CCTA can be more accurately identified by radiomic based ML platforms than visual interpretation by the clinician (Puchner et al., 2014, Fleg et al., 2012, Maurovich-Horvat et al., 2014, Liu et al., 2018, Kolossváry et al., 2017, Kolossváry et al., 2019, Kolossváry et al., 2019).

Hemodynamic assessment of a coronary lesion is done by the invasive fractional flow reserve (FFR) on cardiac catheterization or non-invasively by estimating myocardial flow reserve on ¹³N-Ammonia positron emission tomography (PET) (Oikonomou et al., 2020, Dey et al., 2015, Dey et al., 2018). ML derived algorithms accurately detect hemodynamically significant obstructive coronary lesion when compared to FFR and PET (Oikonomou et al., 2020, Dey et al., 2018, Dey et al. 2018), and were comparable with that of complex computation fluid dynamic modeling method to detect obstructive lesion (Coenen et al., 2018, Tesche et al., 2018).

AI enabled CT scan can be used to accurately detect myocardial scarring due to myocarditis and myocardial infarction, and left ventricular dilation and systolic function in patients of ventricular tachycardia (Antunes et al., 2016, Mannil et al., 2018, Esposito, et al., 2018, Hinzpeter et al., 2017).

Deep learning algorithms have been used to enable cardiac magnetic resonance imaging (CMR) for automated image segregation and evaluate myocardial motion analysis for human survival prediction (Bello et al., 2019).

Deep learning technology is adept at image recognition and is being used in cardiovascular imaging modalities like two- and three-dimensional echocardiography (2D and 3D) especially in speckle-tracking echocardiography and strain imaging data (Perez et al., 2018). Commercially available major imaging companies are equipping the ultrasound system with AI to help analyze echocardiogram images for better output and quality. One of the vendors has used ML 3D echo dataset acquisition algorithms to automatically analyze the variation in the acquired cardiac anatomy image slices, optimize them and choose the best standard views for presentation. It would take many years for an echocardiographer to gather similar information (Perez et al., 2018).

Robotic Procedures

AI has a huge potential in cardiac procedures like percutaneous coronary intervention (PCI) and electrophysiology (EP) for catheter ablation of cardiac arrhythmias. AI models can be used to perform high precision interventions by auto maneuvering, improving patient safety and reducing radiation exposure to health care professionals (Yan et al., 2019).

In December 2018, the world's first in-human telerobotic PCI was performed in India utilizing vascular robotic technology, and this intervention was conducted from a remote location outside of the catheterization laboratory (Corindus CorPath Used in World's First-in-Human Telerobotic Coronary Intervention. December 6, 2018). This technology has a huge potential to deliver precision cardiac interventional procedures to patient populations with poor access to cardiovascular services (Corindus CorPath Used in World's First-in-Human Telerobotic Coronary Intervention. December 6, 2018). Other

commercially available cardiovascular robotic systems are creating a clinical database of successfully performed robotic PCI interventions across Africa and Europe. This registry is for subsequent generation of devices to provide safer and precision vascular interventional procedure (Robocath Successfully Completes First Robotic Coronary Angioplasties in Africa, 2020).

Robotic electrophysiology uses Stereotaxis technology that employs magnetic catheter tip and imaging, for precise and safer navigation during EP ablation interventions for ventricular arrhythmias and atrial fibrillation (Weiss 2019). Soon fully automated robotic process in electrophysiology would be available for catheter ablation procedures (Weiss et al., 2016).

FUTURE PROSPECTS

AI potentially is the next revolution in cardiovascular sciences (Bauernefeind et al., 2011). The constraints with present tools and methods utilized in clinical medicine will act as a catalyst to spur the increased usage of AI tools in patient care. This technology is bound to grow in the near future, as many large corporates are investing in AI health care start-ups, and it is estimated to be USD 25 billion business in 2020 (The return of the machinery question. Economist. 25 June. 2016). AI is part of the digital transformation occurring across all sections of the economy. The availability of increased digital data sourced from EHR and rapid progress in computer technology and the internet have all created a fertile ground for the growth of AI (Kohli et al., 2020). One such example of harnessing AI is the usage of a commercially available smartwatch sensor to monitor atrial fibrillation in the population, and the findings were comparable to the traditional insertable cardiac monitor arm in the study (Wasserlauf et al., 2019). Another example of technological advancement of AI is the remote navigation of robotic EP system for catheter ablation of cardiac arrhythmias. This allows the physician to control the catheter navigation from a comfortable location protected from radiation and reduces operator fatigue (Weiss 2019).

Soon the major areas of cardiovascular care in which AI is going to play a substantial role are cardiac imaging, prediction of risk scores and outcomes, daily decision making such as diagnosis and treatment, and developing algorithms from large databases mapped with known guidelines (Perez 2018, Kohli et al., 2020).

The novel approaches of AI in cardiology would help to provide rapid, precise and less erroneous patient care, with important clinical and economic implications. The physicians should embrace AI for improving workflow dynamics without the undue fear of being replaced by AI technology (Artificial intelligence assists cardiologists with workflow, diagnoses, 2020).

CURRENT CHALLENGES WITH AI ADOPTION

Application of AI in health care has certain challenges to overcome (Souza Filho et al., 2019).

1. AI is still evolving: The solutions in the market place have not reached a maturity where the predictions and the outcomes can be relied on with no manual intervention by the physician. This has a bearing on the widespread adoption of AI with confidence. The maturity of the technology, iterating cycle of machine learning and quality of data sets are some of the contributing factors (Souza Filho et al., 2019).
2. Substantial investment: Building an AI solution requires large infrastructure, a variety of data sets and related technologies. These require a substantial capital investment which could be challenging for the institution to substantiate the investment. The continuous improvement and enrichment of the AI ecosystem also demands operational expenditure. In many countries, the expenditure to

enable AI systems in the hospital could be exponentially more than the expense incurred for the patient's disease treatment.

3. Accuracy of the prediction and analysis: For example, in one study, images of benign moles were misdiagnosed as malignant ones, by adding adversarial noise or just rotation (Kelly et al. 2019). Any wrong prediction is going to have a substantial bearing on the physician and patient care.
4. Organizational readiness: The large quality data to incorporate into AI algorithms may not be readily available. In addition to that, investments in technology, medical and technical experts need to be available at disposal to run a program of such a scale.
5. Privacy concerns: There are ethical concerns that application of AI technologies in research might infringe on an individual's privacy and guidelines should be formulated to protect human rights (Ramesh 2017).

CONCLUSION

AI has a tremendous potential to redefine cardiology practice in the near future. This technology is already showing its impact in the field of cardiovascular imaging and electrophysiology. Cardiologists need to embrace AI to improve workflow efficiency and deliver precision care to the patients. At the same time physicians should be aware of the challenges of AI implementation into clinical practice and research. AI algorithms should undergo vigorous prospective clinical trials before implementing them into cardiology practice. Foremost consideration should be given to the patient's right to privacy and ethical policies should be drafted before AI adoption.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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