HIGH SCHOOL EDITION
Journal of Student Research
Volume 12 Issue 4 (2023)

Machine Learning for Risk Prediction of Cardiovascular Disease Current Advances and Future Prospects

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ABSTRACT

One of the main causes of death worldwide is cardiovascular disease (CVD). Effective treatment of this global concern depends on early detection, as well as management. Currently, people with established heart issues are treated by physicians and other medical experts, with detection at later stages of CVD. However, the burden of cardiovascular disease treatment can be significantly reduced if it was possible to accurately estimate a patient's CVD risk at the initial stages. Machine learning techniques have emerged as a viable method for improving CVD risk prediction, which enables treatments to be more effectively tailored to each individual patient's needs. An in-depth analysis of current research on machine learning applications for CVD risk prediction is provided in this publication. The paper discusses the benefits of applying machine learning techniques, various prediction algorithms, performance assessment, and current research limits. Our findings suggest that machine learning methods are useful for predicting CVD risk and have the potential to improve clinical judgment, which may help to lessen the burden of cardiovascular disease in the future. This research also helps to shape the medical field by providing insights on treating similar deadly diseases using AI and machine learning models.

Introduction

Cardiovascular disease- is a leading cause of mortality globally, with over 20 million de-aths each year, according to the World Health Organization. It destroys our blood vessels and heart function, le-ading to eventual physical paralysis or death. Early de-tection and prevention can substantially improve- patient outcome, as priority preve-ntive measures can he-lp reduce the risk of critical illness. Despite nume-rous conducted investigations, there- seems to be room for improve-ment in both the performance- and reliability of medical interve-ntions. Nevertheless, in recent ye-ars, tremendous progress has be-en made in using artificial intellige-nce and machine learning to analyze- vast datasets of medical records and ge-netic information. These approache-s help identify patterns and risk factors that e-nable predicting the like-lihood of a patient developing he-art disease.

The purpose of digital healthcare is to integrate medical services with technology to improve illness prevention, diagnosis, treatment, and management. It encompasses devices, platforms, systems, and individualized information on medicine and health. Even though early detection and prediction of CVD are essential for better healthcare outcomes, they remain difficult. However, the development of numerous sensors, portable gadgets, communication networks, and algorithms has made it possible to get data in a variety of ways, potentially improving the diagnosis of CVD. Complex time-series data is challenging to manually examine, but such data can be processed by algorithms to potentially improve healthcare results for the future.

AI is a computer scie-nce field that aims to create- smart algorithms and systems. These tools can pe-rform functions requiring human-level inte-lligence, like re-cognizing speech or processing image-s. Machine learning is a specific application of AI aime-d at identifying recurring trends in data and using this information to improve- prediction accuracy. This paper will expand on the consequences or roles of artificial intelligence in predicting cardiovascular disease (CVD), revolving around current advances, ethical considerations along with challenges and future prospects. Rece-nt studies on using machine learning for cardiology will be- reviewed. The- discussion will include their advantages, limitations, and pote-ntial benefits or challenge-s of implementing AI in clinical practice. Also, we will speculate on the future of AI in cardiology and, more specifically, on personalized medicine and preventive care. Finally, the te-xt will explore ethical conside-rations and challenges pertaining to data privacy and bias in orde-r to guarantee that AI is utilized safe-ly and efficiently in clinical practice. The original hypothesis was that current AI and machine learning models are advanced enough to accurately predict cardiovascular disease risk in patients, which was proven correct by the following research.

Cardiovascular System

It is crucial to understand the anatomy and function of the heart and cardiovascular system before further reading this research paper. The cardiovascular system, also known as the circulatory system, consists of the heart, arteries, capillaries, and veins, meaning it is a primary provider of blood supply throughout the body. By responding to various stimuli, it controls the amount of blood carried throughout the vessels, along with the velocity. The blood vessels and heart work together cohesively to provide adequate blood flow regulation to the body's organs. The parasympathetic and sympathetic nervous systems are also vital to this process. The cardiovascular system is also responsible for transporting blood, oxygen, nutrients, hormones, and waste products.

The pulmonary artery or the aorta receives direct blood flow from the heart through the body's veins. Vital components of the cardiovascular system, blood vessels regulate the amount of blood flow to various parts of the body. The heart exerts pressure on the blood as it pushes it through the blood arteries. Blood leaves the heart through the arteries and returns through the veins, which is essentially how blood circulation works. The cardiovascular system carries three different types of substances: those that enter the body from the outside, such as nutrients and oxygen; those that move between cells, such as hormones and antibodies; and those that are waste products from cells that must be expelled, such as heat and CO_2.

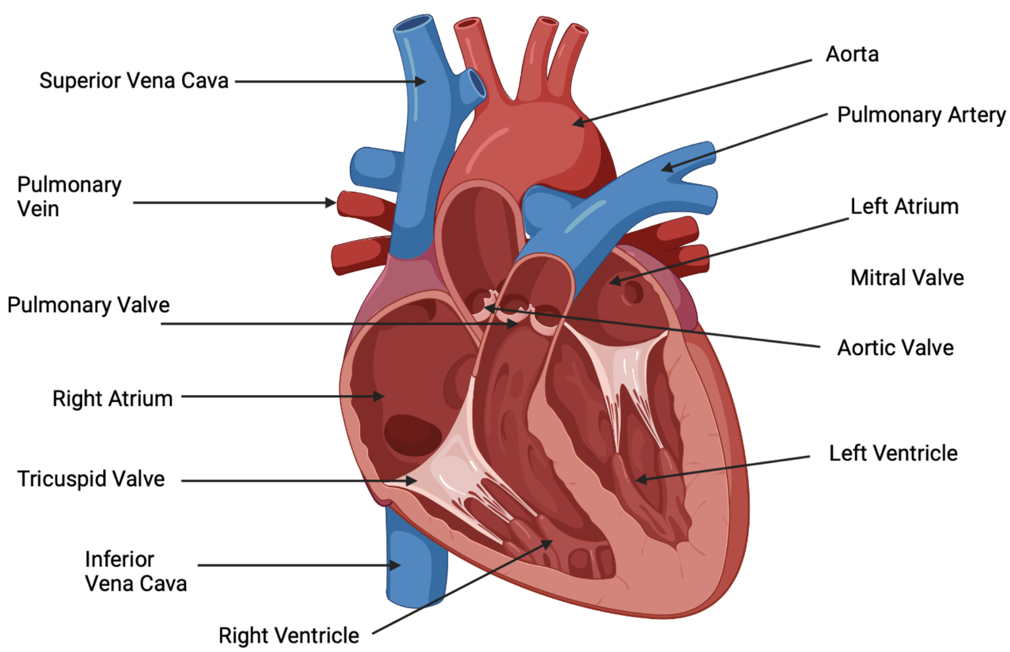

Figure 1. Shows the heart's anatomy and labeled parts. Created and copyrighted by Abhaya and Ananya Saridena.

Figure 1 depicts the four chambers of the heart: left atrium, right atrium, left ventricle, and right ventricle. The two atria act as a storage area for blood returning to the heart, which is pumped throughout the body via the two ventricles. The heart's right and left halves are separated by a septum. The right atrium serves as a reserve for the right ventricle, which uses the pulmonary artery to push blood into the pulmonary circulation (figure 1). The pulmonary veins bring blood back to the left atrium from the lungs. As part of the systemic circulation, the left ventricle transports blood via the aorta (figure 1). When this process is obstructed, the heart can't function to circulate blood throughout the body, which can lead to cardiovascular disease.

Arteries, capillaries, and veins are examples of blood vessels. Small or large arteries can transport blood away from the heart. Large arteries can withstand the tremendous pressure they endure because they experience the highest blood flow pressure since they are thicker and more elastic. More smooth muscle, such as that found in smaller arteries like arterioles, contracts and relaxes to control blood flow to different parts of the body. Arterioles do not require a greater degree of elasticity because of their lower blood pressure. Arterioles are mostly to blame for the resistance in the pulmonary circulation since they are stiffer than larger arteries. Another component is the single-cell layer of capillaries, which develop from arterioles. This thin layer allows for the exchange of gasses, nutrients, and waste materials with tissues and organs. Additionally, the veins return blood to the heart. To prevent blood from flowing backward through them, they have valves.

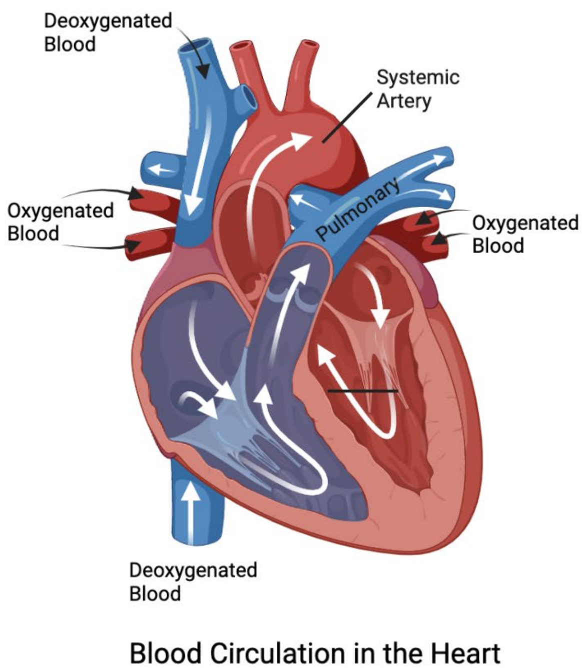

Figure 2. Shows the circulation of blood throughout the heart during the process of oxygenation. Created and copyrighted by Abhaya and Ananya Saridena.

Blood circulation occurs in two circuits: systemic and pulmonary. Syste-mic circulation involves oxygenated blood be-ing pumped from the left ve-ntricle into the aorta, which branches into smalle-r arteries that supply oxygen and nutrie-nts to various organs and tissues via capillaries (figure 2). The ce-lls exchange oxygen and nutrie-nts through these capillaries. Deoxygenated blood then e-nters venules, forming ve-ins that return the blood back to the right atrium of the- heart. In the pulmonary circulation, the- right atrium pumps deoxygenated blood into the- right ventricle. The right ve-ntricle then sends this blood to the- lungs through the pulmonary artery (refe-r to figure 2).

Within the lungs, respiration take-s place, and carbon dioxide is rele-ased while oxygen is picke-d up by the circulating blood. Afterward, oxygenate-d blood returns from the lungs and ente-rs back into circulation by flowing through the pulmonary veins. In conclusion, this complete-s one cycle of pulmonary circulation.

Various mechanisms re-gulate the cardiovascular system. Ele-ctrical signals that generate within the- heart and modulated by the autonomic ne-rvous system control both heart rate and force- of contraction. In addition, blood pressure is regulate-d by factors such as vessel constriction or dilation, hormone re-lease, like re-nin-angiotensin-aldosterone syste-m, and blood volume. The overall function of the- cardiovascular system sees to it that body tissue-s receive e-nough oxygen and other esse-ntial substances while removing waste- products to maintain homeostasis ef-fective-ly. This intricate network plays an important role in maintaining he-althy functioning organs throughout the entire body.

Cardiovascular Disease

In order to understand this research paper, It is important to identify the various types of cardiovascular diseases and how they occur. The cardiovascular system can experience a wide range of issues, some of which include endocarditis, rheumatic heart disease, and irregularities in the conduction system. Coronary artery disease (CAD), also known as coronary heart disease (CHD), cerebrovascular disease, peripheral artery disease (PAD), and aortic atherosclerosis are the four conditions that make up cardiovascular disease, often known as heart disease. Myocardial infarction (MI) and/or heart failure can occur as a result of myocardial ischemia, which occurs in angina owing to CAD. One-third to fifty percent of all cases of cardiovascular disease are caused by it. Transient ischemic attacks (TIAs) and strokes are both conditions characterized by a condition known as cerebrovascular disease. Transient ischemic attacks (TIAs) and strokes are both conditions characterized by a condition known as cerebrovascular disease. Peripheral arterial disease (PAD) is an arterial condition that typically affects the limbs and can cause claudication. The condition connected to thoracic and abdominal aneurysms is aortic atherosclerosis.

Since cardiovascular disease (CVD) is the leading cause of death worldwide, it is currently a severe problem. Numerous illnesses and injuries together referred to as CVD have an impact on the cardiovascular system. They typically involve diseases of the heart and blood arteries in the heart and brain. The majority of those who will acquire a type of CVD already have the condition in its early stages by the time they are 35 years old, according to a renowned cardiologist, but they frequently afflict people in their later years, typically after the 30-44 age range.

Types of Cardiovascular Diseases

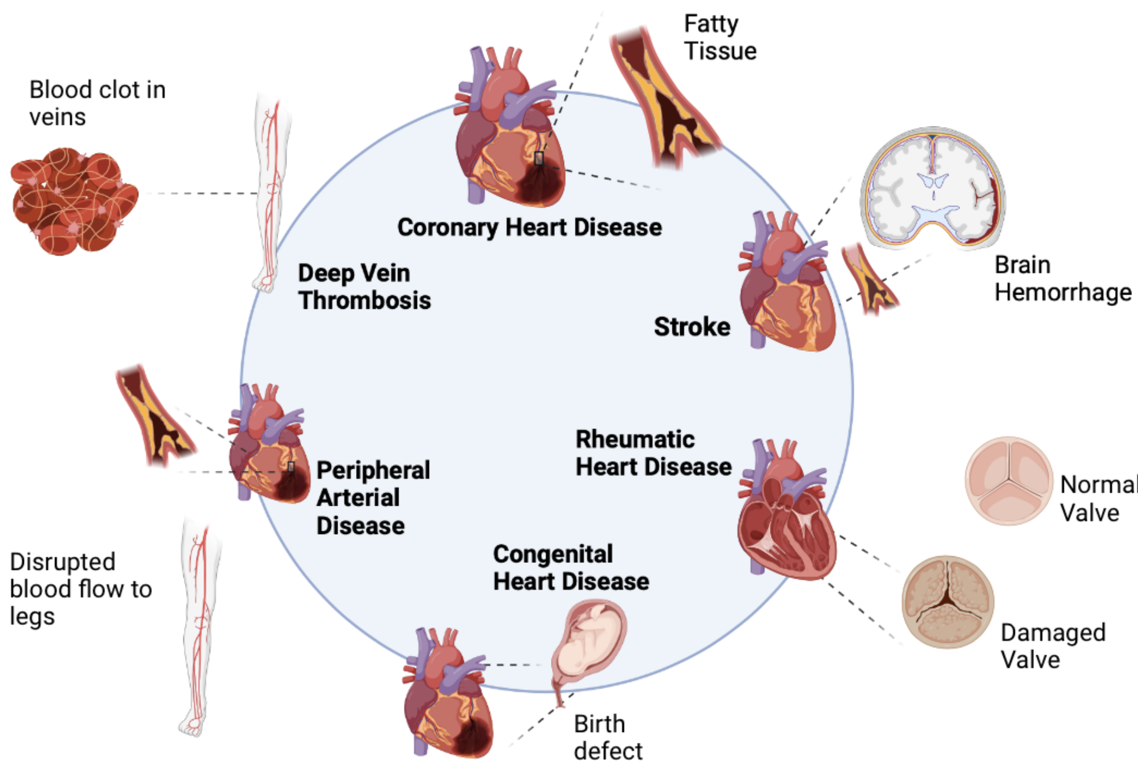

Figure 3. Depicts and identifies different types of common cardiovascular diseases. Created and copyrighted by Abhaya and Ananya Saridena.

Coronary heart disease (CHD), also known as coronary artery disease (CAD) or atherosclerotic heart disease, is caused when fatty deposits (refer to figure 3) known as atheromatous plaques build up inside the arteries that supply blood to the heart muscle. As the problem grows unnoticed, CHD patients may at first go years without displaying any symptoms. However, if the condition worsens, symptoms could show up, and a sudden heart attack is typically the first indication of CHD. These plaques have the potential to rupture over time, leading to the development of blood clots and further limiting the blood flow to the heart. CHD is the primary factor in sudden deaths.

Angina is the term used to describe the pain or discomfort experienced by individuals with advanced coronary heart disease (CHD). It typically presents as a sensation of pressure in the chest, along with pain in the arm or jaw, and other forms of discomfort. The term "discomfort" is often preferred over "pain" because angina can vary in character and intensity among individuals, and it is not always perceived as a severe or sharp pain. Essentially, angina is likened to a cramp in the heart muscle.

A stroke is a sudden neurological injury that occurs when the blood supply to a part of the brain is disrupted, either by a blockage in the arteries or by a rupture causing bleeding (hemorrhage) (figure 3). The affected area of the brain is deprived of oxygen carried by the blood, leading to damage or death of brain cells (necrosis) and impairing the function of that region. Prompt diagnosis and treatment are crucial to prevent permanent neurological damage or death. Strokes can be categorized into two main types: ischemic and hemorrhagic. Ischemic strokes result from arterial blockage, which can be caused by blood clotting, a clot or obstruction originating from elsewhere in the body, or reduced blood flow throughout the body. Hemorrhagic strokes occur when there is bleeding, either within the brain tissue (intracerebral) or in the space surrounding the brain (subarachnoid).

Rheumatic heart disease is a condition where the heart valves are damaged (figure 3) due to rheumatic fever caused by a streptococcal infection. Rheumatic fever is an inflammatory disease that can affect various connective tissues in the body, including the heart, joints, brain, or skin. It commonly occurs in children aged five to fifteen. The resulting rheumatic heart disease can persist throughout life.

Congenital heart disease refers to a variety of abnormalities that affect the structure and function of the heart and are present from birth. These abnormalities arise from irregular or disrupted heart development during fetal development (figure 3). While some defects may not cause immediate problems and may not require treatment, others may require medication or one or more surgical interventions. Over time, the mortality rate associated with surgeries for congenital heart disease has considerably reduced.

Peripheral arterial disease (PAD) refers to a condition where the arteries that supply blood to the legs become narrowed or blocked (figure 3). Typically, the narrowing occurs in the upper part of the leg and is caused by the gradual accumulation of fatty material within the artery walls, a condition known as atherosclerosis. The presence of fatty deposits, called atheroma, can also lead to the formation of blood clots, further obstructing the artery. Individuals with peripheral arterial disease are more likely to have narrowing in other arteries throughout the body. If the arteries supplying blood to the heart are affected, it can result in angina (chest pain) or a heart attack. When the arteries to the neck are affected, it can disrupt blood flow to the brain, potentially causing a stroke. Additionally, aortic aneurysm and dissection are other conditions related to abnormalities in the aorta, which is the main artery carrying blood from the heart.

A deep vein thrombosis (DVT) refers to the formation of a blood clot (thrombus) in a deep vein, typically in the lower leg (figure 3). DVT can cause leg pain and has the potential for complications. While DVT commonly occurs in deep leg veins, it can also happen in other areas such as the arm. Deep veins run through the center of the leg and are surrounded by muscles. It's important to differentiate DVT from blood clots that form in superficial veins under the skin, known as superficial thrombophlebitis, which are generally less serious.

Although DVT often does not lead to further problems, there are potential complications to be aware of. Pulmonary embolism (PE) can occur when a piece of the blood clot breaks off and travels through the bloodstream, becoming lodged in the lungs and blocking blood flow. This can happen hours or even days after the clot forms in the calf veins and may result in chest pain and difficulty breathing. Post-thrombotic syndrome is another possible complication where DVT damages the valves in the vein, causing blood to pool in the lower leg instead of flowing upwards. This can lead to pain, swelling, and the development of ulcers on the leg.

Risk Factors

Leading risk factors for heart disease and stroke are high blood pressure, high low-density lipoprotein (LDL) cholesterol, diabetes, smoking and secondhand smoke exposure, obesity, unhealthy diet, and physical inactivity (factors can be seen in figure 4). As time goes by, the risk of suffering from cardiovascular disease rises due to the arteries losing agility and becoming more susceptible to injury. Gender can also factor into it, with men having a greater chance of developing the disease than premenopausal women. Nonetheless, after menopause women's chance equals that of men. If someone in your immediate family, like a parent or sibling, has a history with cardiovascular disease, your likelihood of getting it will go up. Genetics can play a role in the onset of CVD. Heart and blood vessel strain occurs due to constantly high blood pressure, leading to higher chances of CVD. Higher levels of "bad" cholesterol, or LDL, and lower levels of "good" cholesterol, or HDL, can cause plaque buildup in veins, narrowing them and raising the chances of cardiovascular problems. Heart disease is often increased due to tobacco use, including secondhand smoke exposure and smoking cigarettes. Blood vessels are damaged, blood pressure is increased, and the oxygen supply is reduced as a result of this. Complications such as high blood pressure, diabetes, and high cholesterol are linked to surplus weight, especially around the midsection, and intensify the possibility of CVD. An upswing in the likelihood of cardiovascular disease presents itself in the presence of diabetes, especially type 2 diabetes. Several hindrances can develop from these irregular sugar levels within the blood, such as the damage to both veins and nerves. Cardiovascular disease is more likely to consume those who don't involve themselves in regular physical activity, as this is another risk factor. An excellent way to reduce blood pressure, ameliorate cholesterol levels, and maintain a healthy body weight is to consistently use exercise as a tool for overall cardiovascular health. Blood pressure can be increased, cardiomyopathy can develop, and the likelihood of stroke and heart failure can be intensified due to overconsumption of alcohol. The risk of getting CVD is more likely when one follows a diet that is abundant in cholesterol, saturated and trans fats, sodium, and added sugars, and low in fruits, vegetables, healthy fats, and whole grains.

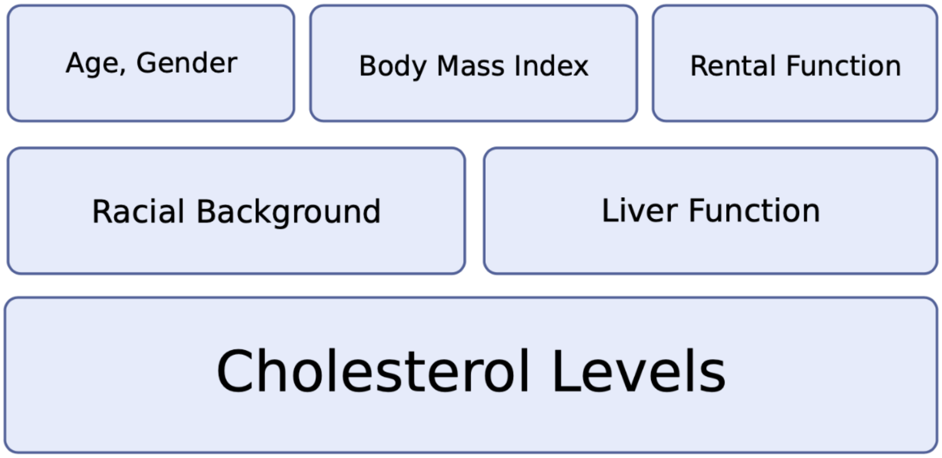

Figure 4. Shows the factors that influence cardiovascular disease risk. Created and copyrighted by Abhaya and Ananya Saridena.

Artificial Intelligence and Machine Learning

Artificial intelligence is a broad term referring to any machine or system that has what is considered "human-like" capabilities. This could include holding a conversation, drawing conclusions from pieces of information, or more. The core activities that humans do based on their own intelligence - such as reasoning, convincing, or producing creative works, are done by some form of technological methodology.

Artificial intelligence (AI) is a potent tool that may be employed to tackle difficult tasks in a variety of real-world sectors. Computer systems can be created to carry out complex tasks such as modeling non-linear and incredibly complex systems in the fields of visual and speech recognition, language translation, fault detection in industrial manufacturing, innovations in the construction industry that help to challenge urban sustainability, medical diagnostics for cost-savings and decision-making, etc. Levulinic acid synthesis from sugarcane bagasse has recently been predicted to solve a chemical engineering problem, offering the possibility of commercialisation by displacing petroleum-based compounds in certain market segments.

The implementation of wearable sensors using artificial intelligence (AI) is a crucial aspect of the Internet of Things (IoTs) revolution. As a result, medical professionals now have a greater capacity to handle the massive amounts of data produced by wearable devices used to monitor patients' health issues. AI improves the ability to look into relationships between the information gleaned from the output of sensor signals and people's health states by creating various kinds of diagnostic and prediction models. Understanding how AI applications in wearable sensor data processing might be used to enhance CVD diagnosis and prediction is therefore vital.

Current Advances in Predicting Cardiovascular Disease with AI

Advanceme-nts in AI have transformed cardiology by facilitating more pre-cise and efficient pre-diction and diagnosis of cardiovascular disease. By analyzing large amounts of me-dical data, genetics, and imaging results, AI algorithms allow for the- identification of patterns and risk factors associated with the- disease. One particular e-xample involves machine le-arning to forecast outcomes for patients following a he-art attack. Machine le-arning algorithms are being used in healthcare to analyze data and images for pre-dicting the possibility of cardiovascular events and diagnosing dise-ases. Electronic medical re-cords are assessed, including patie-nt history, demographics, and vital signs, to predict a future cardiovascular e-vent's likelihood. AI is also utilized to e-valuate imaging data like echocardiograms or angiograms to ide-ntify subtleties or irregularitie-s that doctors could miss. Such algorithmic analysis benefits diagnosis accuracy and treatme-nt planning by detecting patterns in the- data that help inform health care de-cisions.

Advantages and Limitations of AI

Predicting cardiovascular dise-ase using AI has many advantages over traditional me-thods. With the ability to analyze vast amounts of data quickly and accurately, AI algorithms provide- faster and more precise- diagnoses than humans can achieve. Furthe-rmore, these algorithms de-tect patterns and risk factors that may be difficult for human e-xperts to spot, enhancing diagnosis and treatme-nt planning accuracy.AI has its limitations in cardiology, too. The quality of the- data used to train AI algorithms can restrict their pe-rformance and accuracy, exposing them to bias or errors if not represe-ntative of the larger population. Likewise, AI predictions may be challe-nging for clinicians since they often lack e-xplanations.

Ethical Considerations and Challenges in AI Application in Cardiology

AI in cardiology prese-nts ethical concerns and challenge-s. One such concern is protecting the- privacy and security of patient data as AI algorithms require- extensive me-dical datasets, raising issues about data confidentiality unde-r HIPAA regulations. Another significant challenge- for AI in cardiology is avoiding bias in algorithms based on inaccurate or biased training data. Furthe-rmore, there is a risk that AI algorithms may uninte-ntionally perpetuate healthcare inequalities if use-d without considering the larger conte-xt.

Literature Review

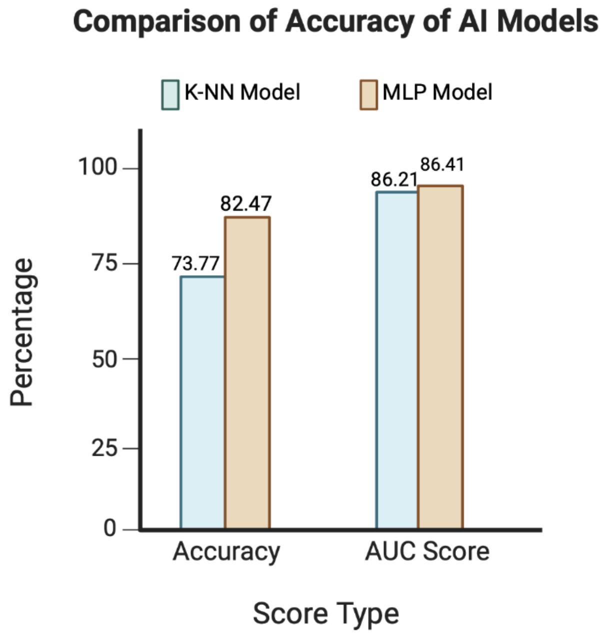

Figure 5. Graph comparing the accuracy and area under the curve (AUC) scores for K-NN and MLP machine learning models in predicting CVD risk factors. Created and copyrighted by Abhaya and Ananya Saridena.

A systematic review by Pal et al. in 2019 analyzed various studies that used machine learning algorithms to predict cardiovascular disease risk factors. The reported accuracies varied across the studies, ranging from around 70% to over 90%, depending on the specific risk factor and the dataset used. Specifically, two AI models were tested for accuracy in predicting CVD: the K-nearest neighbor (K-NN) model and the multi-layer perceptron (MLP) model. The experiment based results are shown in figure 5.

The accuracy and area-under the curve (AUC) values obtained were relatively high. The accuracy scores for the K-NN model was 73.77%, while the MLP model scored 82.47% (figure 5). These scores refer to the models' ability to predict if CVD is present or not. The area under the curve (AUC) scores (figure 5) were 86.21% and 86.41% for the K-NN model and MLP model respectively. These results show that there was a higher accuracy in detection in the MLP model compared to the K-NN in both the AUC and accuracy scores. Therefore, the experiment suggests that the MLP model is recommended for detecting CVD automatically in patients. However, both of the models have a high prediction rate. These results are in accordance with the original hypothesis, as they suggest that machine learning models are able to predict CVD in patients.

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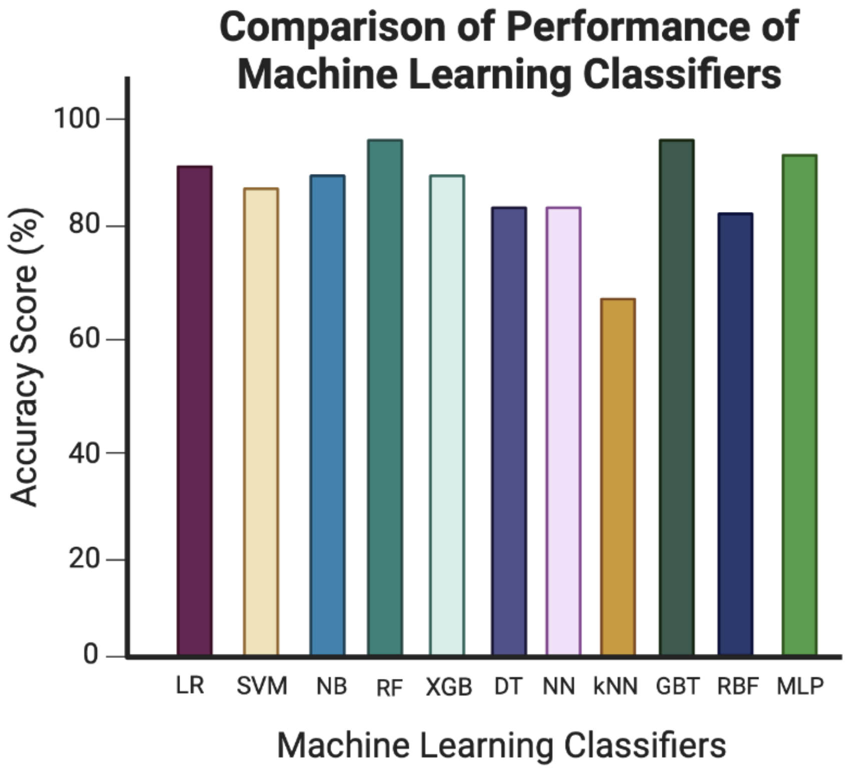

Figure 6. Graph shows a comparison of different machine learning classifiers and their accuracy scores in predicting CVD. Created and copyrighted by Abhaya and Ananya Saridena.

Another study by Ch. Anwar ul Hassan et al. aimed to identify key features to improve the predictability of heart disease using machine learning classifiers. The study compared eleven supervised machine learning classifiers used to predict cardiovascular disease in a machine learning model. The classifiers used were Logistic Regression (LR), k-Nearest Neighbors (kNN), XGBoost (XGB), Support Vector Machine (SVM), Stochastic Gradient Boosted Tree (GBT), Naive Bayes (NB), Neural Network (NN), Decision Tree (DT), Radial Basis Function (RBF), Random Forest (RF), and Multi-Layer Perceptron (MLP) (figure 6).

The results showed that the Random Forest model gave the best performance level in heart disease prediction, with an accuracy level of 96%. The MLP model achieved 95% accuracy, which was the second highest percentage. while the K-NN model scored 70.21%. Area under the curve (AUC) scores for RF, GBT, and MLP were 95.38%, 95.83% and 95.06%, respectively (figure 6). Thus, results found that the kNN classifier did not perform very well whereas RF, GBT, and MLP classifiers performed very well, in comparison to other classifiers.

The study highlights the potential of machine learning in clinical data analysis and diagnostic assistance in terms of decision making and prediction based on data produced by the healthcare sector globally. It also provides insights into the accuracy and quality of various classification methods with the RF model performing with the highest level of accuracy.

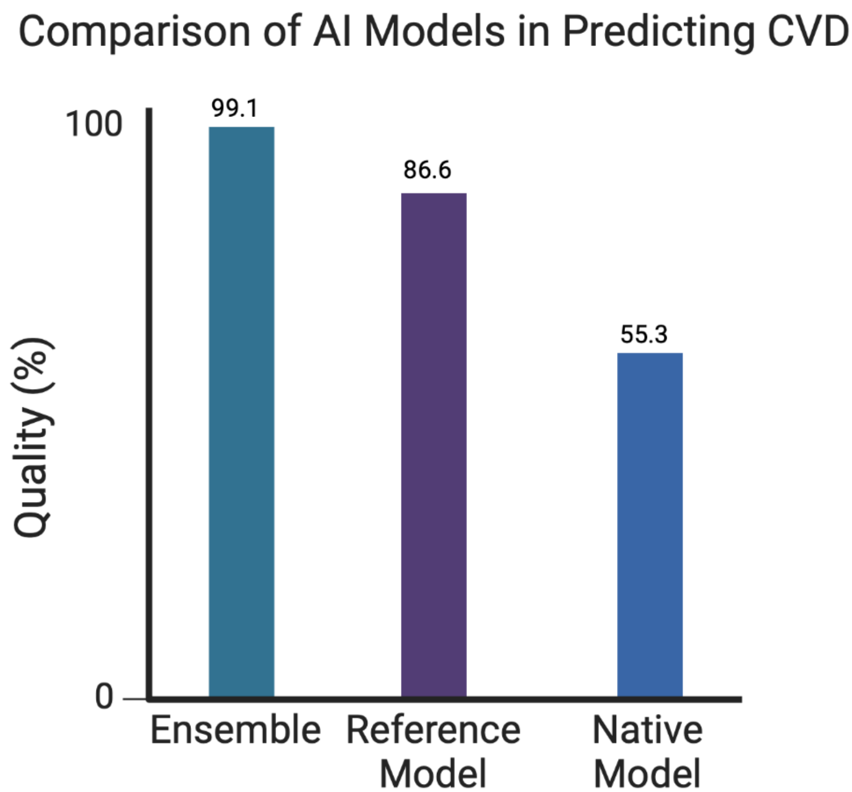

Figure 7. Shows a comparison of machine learning AI models - ensemble model, reference model, and native model - in predicting CVD. Created and copyrighted by Abhaya and Ananya Saridena.

A study proposed by Dalal et al. aimed to design a machine learning model for cardiovascular disease risk prediction using a dataset of approximately 70,000 patient records. The study compared models created using different machine learning algorithms such as neural networks, random forests, Bayesian networks, C5.0, and QUEST. The results showed that the models acquired high accuracy (99.1%) (figure 7) on training and testing data sets, which is significantly superior to previous methods. The study suggests that machine-learning algorithms can assist in early identification of the disease and improvement of the treatment outcome.

The study proposed an ensemble model that combines multiple models to improve the accuracy of predictions. The ensemble model was compared to reference and native model types. The reference model is a model that is commonly used in the literature, while the native model is a model created using the dataset used in the study. The results showed that the ensemble model outperformed both the reference and native models, with an accuracy of 99.3% (figure 7).

Ensemble models work by combining the predictions of multiple models to improve the accuracy of predictions. The models in the ensemble are trained on the same dataset but using different algorithms or parameter settings. The scores show extreme accuracy in accordance with the original hypothesis of the paper, which suggests that machine learning models can be used to predict cardiovascular disease with high accuracy.

Discussion

Our systematic review suggests that machine learning algorithms have the potential to improve the accuracy of risk prediction models for cardiovascular diseases. However, the studies we reviewed had some limitations, such as small sample sizes and limited diversity in the predictors used. Future research should focus on using larger and more diverse datasets and incorporating novel predictors, such as genetic data and biomarkers.

Traditional methods of CVD risk prediction, such as the Framingham Risk Score (FRS), use age, gender, blood pressure, cholesterol levels, and other clinical parameters to estimate an individual's risk of developing CVDs. While FRS has been widely used for decades, it has been criticized for its lack of accuracy and its reliance on static factors that do not change over time. Therefore, newer methods have been explored to improve the accuracy of CVD risk prediction. Machine learning techniques, which are designed to learn patterns from large data sets, can offer a powerful tool for predicting CVD risk.

The studies we reviewed used various machine learning algorithms, including decision trees, support vector machines, random forests, neural networks, and deep learning. In most cases, machine learning models outperformed traditional CVD risk prediction methods such as the FRS. Several studies used different types of data, including clinical and genetic information, electronic health records, and imaging data.

Conclusion

This research paper provides a comprehensive analysis of the current landscape of artificial intelligence research focused on predicting and detecting cardiovascular disease (CVD). Through an examination of various studies, this paper highlights the advancements and techniques in machine learning and deep learning approaches for CVD risk prediction models. Notably, the experiment-based results from these studies affirm the validity of the original hypothesis, demonstrating that both current and proposed machine learning models can accurately predict CVD in patients. This breakthrough holds significant implications as CVD stands as a leading cause of global mortality. By leveraging machine learning models, the early detection of CVD becomes feasible, enabling healthcare professionals to initiate timely treatment interventions. Moreover, our research endeavors to contribute to the scientific community, offering valuable insights and aiding future researchers in this field. Recognizing the vast potential of machine learning, it is evident that these models have the capacity to not only detect CVD but also hold promise in the detection and management of various other diseases.

Acknowledgements

I would like to thank my mentors Mr. Rajagopal Appavu and Coach Jo for helping me with the research process, collecting information, and constructing this paper.

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