A comprehensive review on heart disease prognostication using different artificial intelligence algorithms

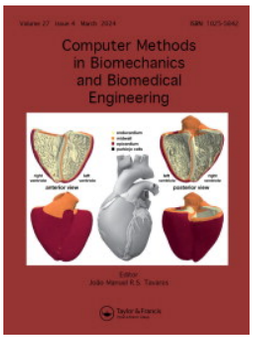
Article *in* Computer Methods In Biomechanics & Bio Engineering · February 2024

DOI: 10.1080/10255842.2024.2319706

2 authors, including:

Jainul Fathima
The Francis Xavier Engineering College
22 PUBLICATIONS **100** CITATIONS

SEE PROFILE



Taylor & Francis
Taylor & Francis Group

Computer Methods in Biomechanics and Biomedical Engineering

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/gcmb20

A comprehensive review on heart disease prognostication using different artificial intelligence algorithms

A. Jainul Fathima & M. M. Noor Fasla

To cite this article: A. Jainul Fathima & M. M. Noor Fasla (29 Feb 2024): A comprehensive review on heart disease prognostication using different artificial intelligence algorithms, Computer Methods in Biomechanics and Biomedical Engineering, DOI: 10.1080/10255842.2024.2319706

To link to this article: https://doi.org/10.1080/10255842.2024.2319706

Published online: 29 Feb 2024.

COMPUTER METHODS IN BIOMECHANICS AND BIOMEDICAL ENGINEERING
https://doi.org/10.1080/10255842.2024.2319706

A comprehensive review on heart disease prognostication using different artificial intelligence algorithms

A. Jainul Fathima[a] and M. M. Noor Fasla[b]

[a]Assistant Professor, IT Francis Xavier Engineering College, Tirunelveli - 627003, India; [b]Research scholar, Anna University, Chennai, India

ABSTRACT

Prediction of heart diseases on time is significant in order to preserve life. Many conventional methods have taken efforts on earlier prediction but faced with challenges of higher prediction cost, extended time for computation and complexities with larger volume of data which reduced prediction accuracy. In order to overcome such pitfalls, AI (Artificial Intelligence) technology has been evolved in diagnosing heart diseases through deployment of several ML (Machine Learning) and DL (Deep Learning) algorithms. It improves detection by influencing with its capacity of learning from the massive data containing age, obesity, hypertension and other risk factors of patients and extract it accordingly to differentiate on the circumstances. Moreover, storage of larger data with AI greatly assists in analysing the occurrence of the disease from past historical data. Hence, this paper intends to provide a review on different AI based algorithms used in the heart disease prognostication and delivers its benefits through researching on various existing works. It performs comparative analysis and critical assessment as encompassing accuracies and maximum utilization of algorithms focussed by traditional studies in this area. The major findings of the paper emphasized on the evolution and continuous explorations of AI techniques for heart disease prediction and the future researchers aims in determining the dimensions that have attained high and low prediction accuracies on which appropriate research works can be performed. Finally, future research is included to offer new stimulus for further investigation of AI in cardiac disease diagnosis.

ARTICLE HISTORY
Received 30 January 2023
Accepted 12 February 2024

KEYWORDS
Heart disease; prediction; artificial intelligence; machine learning; deep learning

1. Introduction

Heart disease prediction at an earlier stage is essential to prevent the severe progression of the disease and reduces the rate of mortality (Rajdhan et al. 2020). Many conventional methods in detection of heart diseases have been found to be expensive and lacked with the generalization ability when new data is being loaded into the training dataset (Mathew et al. 2018). In addition to that, the process of diagnosis with larger dataset is still complex in analysis since the rapid improvement in digital technology has increased the utilization of database for storing large amounts of data. In order to extract and perform efficient processing, AI based algorithms play an important role in analysing different data from clinics. The methods and algorithms of AI derive significant inferences from the dataset. AI based CDSS (Clinical Decision Support System) has the ability to assist physicians for diagnosis of heart failure (Ghiasi et al. 2020). The application of AI in medicine has the potential of predicting the heart problems in advance in order to prevent death. Suggested study has utilized decision tree based learning method named as CART (Classification and Regression Tree) model for early diagnosis and prognostication of heart failure. CAD (Coronary Artery Disease) is one among the heart diseases which has been reliably diagnosed through CART structure and achieved accuracy in diagnosis and has classified normal and CAD patients through the dataset. The classification technique utilized in the recommended study has developed the decision taking system in diagnosing CAD.

In order to achieve better performance in classification, ensemble based learning and classifiers have been used. Recommended study has concentrated on ensemble classifiers used for classification (Mienye et al. 2020). It has been operating through majority voting process for the prediction of appropriate components. It has used homogeneous ensemble learning with weighted aging classifiers. Moreover, the method has involved mean based splitting process for

CONTACT Dr. A. Jainul Fathima jainulfathima@francisxavier.ac.in; M. M. Noor Fasla azyfas1612@gmail.com

partitioning datasets into smaller group of subsets. The risk of heart diseases has been effectively predicted through the ensemble approach. Many machine learning and deep learning algorithms have been widely used in the healthcare sectors for the effective diagnosis of diseases nowadays. The complexity of processing massive data has been solved through ENDPP (Enhanced New Dynamic Data Processing) for the prediction of early stages of heart diseases (Rao and Prasad 2021). Quality of decisions taken through medical diagnosis has been improved through the considered technique.

Data processing method has considerably reduced the complexity and has the potential to figure out the similar hidden patterns in the huge volume of data which eliminated utilization of conventional methods for analysis. Optimal solution with accuracy remains to be a problem in complex datasets. In order to overcome the difficulty, considered research on data mining for accurate prediction of heart diseases has utilized the combined approach of MOPSO (Multi Objective Particle Swarm Optimization) and RF (Random Forest) algorithm (Asadi et al. 2021). It has produced diverse decision trees for the determination of optimality. Several training datasets with different samples and features for training each tree has been generated and acquired solutions have improvised accuracy.

To forecast the disease in its earlier stages along with the factors leading to the disease, DL has proved its efficiency in several health applications. Suggested study has utilized the DL based method namely RFRF-ILM (Recursion Enhanced Random Forest with Improved Linear Model for the diagnosis of heart diseases (Guo et al. 2020) and has diagnosed factors that leads to the disease. With the use of DL algorithms, the study has predicted significant features for the prediction of cardiovascular diseases and also has added various combined form of features and classification methods. It has achieved better level of prediction in terms of precision. Through data analysis and comparison of certain variables, it has indicated that CAD has been developed often at older age people. In addition to that, high levels of blood pressure and diabetes also remains to be the reason for the disease outbreak.

Even though studies have performed diagnosis with different methods for cardiac failure, the system must be robust and should be portable and adaptable to all type of computing devices in order to serve the remote area people where there is a lack of medical experts. Diagnosis of cardiac disorders in the recommended study has used CNN (Convolutional Neural Network) for diagnosing multiple cardiac diseases and has been effectively worked on all devices which has been found to be helpful in remote health care centres (Baghel et al. 2020). It has the ability of predicting the heart diseases through the heart sounds. It has utilized the data augmentation methodologies for accuracy even under noisy atmosphere and for classification of various cardiac diseases. Due to its reduced time complexity, the system has the potential to be applied in real time applications. Along with that, CNN has been combined with BI-LSTM (Bi-directional Long Short Term Memory) architecture for accuracy enhancement (El-Shafiey et al. 2021). Along with that, utilization of Bayesian optimization for the hyper-parameter tuning has increased the accuracy level in prediction. It has been validated with performance metrics specifically ROC (Receiver operating characteristic) curve for determination of presence or absence of cardiac disease with the optimal value. Several studies have been conducted in the same way for heart disease prediction and have implemented various algorithms and techniques for improving the accuracy rate of cardiac disease prediction. This review paper intends to discuss about role of some traditional methods and influence of different AI algorithms in prognosticating heart diseases along with its challenges. The main contribution of the paper is

- To deliberate the need for early diagnosis of heart diseases.
- To address the conventional methods used for cardiac disease prognostication and the challenges faced in the medical field.
- To deliver the progress of AI with its evolving methods and its influence in prediction of heart related diseases.
- To perform the comparative analysis of various machine learning and deep learning algorithms utilized for diagnosis.
- To execute critical assessment in prediction accuracy of various AI algorithms.

2. Compelling necessity for early heart disease diagnosis

Heart failure occurs due to high blood pressure, high level of cholesterol or atrial fibrillation. Lower density lipo-protein cholesterol levels, smoking, diabetes, obesity and unhealthy diet practices are determined as certain features lead to heart diseases. Reducing the use of tobacco, reduction of salt in diet with intake of vegetables and fruits reduce the risk of cardiac disease. Social, economic and cultural changes along

with hereditary factors influence heart diseases greatly. Appropriate treatments on diabetes, high level of blood-lipids and hypertension reduces the risk of attacks. Certain common important features of heart failure are included with swollen ankles, dyspnoea, physical metabolic intolerance and fatigue. Shortness of breath, wheezing and irregular heart-beat are also certain symptoms involved and diagnosing such clinical features at an earlier stage is adequate to reduce further complications.

Heart attacks, heart valve issues, stroke and arrhythmia are certain forms of cardiovascular disease complications. Failure in the functioning of heart reduces the supply of adequate amount of blood to other body parts needed to complete the basic functionalities of organs (Elhoseny et al. 2021). Early diagnosis of cardiac failure is predominantly important in order to reduce the disease progression or otherwise ultimately ends up in mortality. Through being conscious about the early signs of the heart disease, persons used to gain a better chance in grasping threats early on. It is highly complex for predicting heart disease since it requires appropriate experience and adequate knowledge. Computing devices in healthcare systems provided diagnosis and prognostication of heart diseases (Miao and Miao 2018).

The life threatening cardiac diseases have certain symptoms included with chest pain, swollen feet, breathing difficulties, body weakness and the risk of chronic disease increases due to unhealthy diet, higher level of cholesterol, deficiency in exercises or smoking habits. The lifestyle of humans play a major role in preventing from the risk of heart related diseases (Kumar et al. 2020). Heart diseases are classified into congenital heart disease, congestive heart failure, heart rhythm complications and cardiovascular diseases. Echocardiography is the diagnosis method which helps in the assessment of the acute or dynamic changes that occurs due to the disease. Hypertensive cardiac diseases lead to organ damage with robust independent prognostic implication (Alhassan and Wan Zainon 2020).

Myocardial functions have to be assessed regularly to identify cardiac alterations in patients with hypertensive difficulties. The left ventricular hypertrophy is the initial stage in the development of stroke, heart failure and sudden death (Wang et al. 2020). Heart failure is the problem commonly occurs in the elder person but diagnosis is often not taken. Patients with heart failure needs to diagnosed with valvular disease, haemodynamic and myocardial functions. The contagious heart disease occurs with cardiac symptoms that happens to the dynamic changes in the health of the person. Those significant changes pave the way for several severe cardiac problems when it has not been treated properly or misdiagnosed. Early prediction minimizes the risk of cardiac failure. Several studies have found that cardiac arrest has been observed due to various changes and factors like older age, smoking or alcohol habits, stress related issues or due to diabetes or high blood pressure (Manogaran et al. 2018). Conventional diagnosing methods have suffered with difficulties which have been overwhelmed with AI.

3. Traditional clinical procedures for predicting heart disease

This particular section discusses on various diagnosing methodologies practices in earlier days. Traditional way of heart disease diagnosis and conclusions from the findings have been derived from the fundamental statistics and later, predictions have been analysed with various methods like logistic regression, linear regression and other techniques according to the severity of the problem. CVD has been detected through plasma ceramides. These elements accumulate into the tissues during metabolic mis-function and has been found to be the predictor of cardiac diseases in the considered study (Meeusen et al. 2018). It has taken four types of ceramides for verification of severe cardiac events to various group of patients who has been referred for angiography. The presence of plasma ceramides has been measured before the process of angiography. It has been inferred that ceramides have not only been associated with the coronary artery disease but also has been linked with stroke, myocardial-infarction and coronary artery diseases. The concentration of ceramides increases with high cholesterol level, age factors, serum glucose levels, hypertension and family history of cardiac diseases (Lu et al. 2020).

Plasma ceramides demonstrates potential implications in predicting cardiac events (Asadi et al. 2021). Ceramides are considered as type of lipid molecule which play a huge role in different cellular processes that are relate to CVD. It has been revealed that, higher levels of plasma ceramides are associated to increased risk of developing severe cardiac events. However, by measuring the plasma ceramide levels, healthcare professionals can detect the individuals who are at higher jeopardy of undergoing unembellished cardiac events. Thus, this information can aid taking preventive measures like medication interventions, lifestyle modifications and many more. Traditional diagnostic approaches use plasma

ceramide for gauging cardiovascular risk offer an additional layer of information by reflecting underlying cellular processes associated with CVD. The amalgamation of traditional diagnostic methods and plasma ceramides can deliver much more assessment of individual cardiovascular (Guo et al. 2020) health and performing in identifying patients who are the risk of suffering from heart diseases.

The FFR (Fractional Flow Reserve) which has been considered the conventional clinical procedure for assessment of heart problems has faced problems in the evaluation of separate stenosis in group of diseased vessels. Suggested study (Modi et al. 2019) has concentrated on the assessment of individual stenosis with the utilization of non-invasive and invasive FFR pullback along with FFRCT (FFR through computed tomography). Accuracy has been subsequently tested with the model for prediction of every single stenosis. Before application of PCI (Percutaneous Coronary Intervention), patients have been taken hyperaemic pressure in order to derive the contribution of FFR at each stenosis. The distal impacts of every *LESIONS HAVE BEEN* assessed. Mean values obtained from the evaluation has predicted the presence of coronary artery disease. It has predicted the FFR impact of every stenosis in the cardiac disease.

CTA (Computed Tomography Angiography) has been another traditional approach of medical diagnosis in heart diseases. It has been developed as the diagnostic tool for patients who has suspected with the CVD. Considered method (Collet et al. 2018) has applied myocardial revascularization approach for the enhancement of survival rate in patients. The choice of either surgical or catheter form of therapy has been decided by the preference of patients or according to the clinical complexities of the disease (Terrada et al. 2020). It has also performed decision making approach in regarded to revascularization technique within separate heart teams and has evolved that invasive-coronary angiography has been recommended for the assessment in degree of severe range of coronary artery disease. Diagnostic performance has been used for further bypass surgery procedures for patients. Another method of diagnosis which has been used traditionally was hs-CRP (Serum high-sensitivity C-reactive protein) for the prediction of CAD. Severity and risk factors of CAD has been predicted through the suggested technique (Tajfard et al. 2019). When the level of hs-CRP has been inferred higher, then that has been regarded as the symptom of severe CAD. Obstruction in arteries has determined the risk in heart which has been detected through serum levels and laboratory methods. Sensitivity and specificity has been calculated for the serum level determination method of heart disease prediction.

In traditional medical practice, patients with heart failure have been classified based on the LV (Left Ventricular) ejection fraction. Patients scanned with improper functioning of LV filling or either rejection of blood has been detected, then filling the pressure and applying LV forward flow has been performed (Meller et al. 2020). It has been detected through echocardiography which has been the widely used technique for disease diagnosis. Classification depending on the ejection fraction has been replaced with the haemodynamic characterization of heart disease patients since prediction of LV haemodynamics has been evaluated with feasibility. Volume of LA (Left Artrial) also has been considered as the indicator of prognosis in heart diseases. Recommended study (Carluccio et al. 2018) has investigated on the determinants and impacts of LA functioning for heart impaired patients with reduced range of ejection fraction. Index value has been calculated for dynamic changes and certain functional parameters of LA *HAVE BEEN* predicted as the outcome with the peak value of atrial longitudinal strain. During heart failure diagnosis with the reduced level of ejection fraction, the volume of LA with the left ventricular contraction associated with the LA function has been assessed with the atrial strain value which has made prognostication of the heart disease. Some of the common challenges in conventional medical diagnosis of heart diseases include,

- The traditional medical diagnosis often faces different challenges, in which one of the primary medical difficulties include complexity and variability of the heart disease (Rajdhan et al. 2020) symptoms, which makes the process tedious and problematic to precisely diagnose the condition. Further, dependence on physical examination and subjective assessment may result in a level of subjectivity and potential for human error in the diagnostic process.
- Besides, heart diseases can often present with atypical symptoms, making it daunting to detect in its early stages. This can result in hindered diagnoses and unexploited opportunities for early intervention and treatment.
- Likewise, another challenge is the restricted accessibility of diagnostic tools and technologies in certain healthcare sectors where accessibility of advanced imaging techniques like CT scans, MRI scans are denied or limited which ultimately leads to delays or inaccuracies in the diagnosis.

Sometimes, manual challenges require extensive medical history, which includes lifestyle factors like previous conditions, family history, medical conditions and many more, this obtaining and organizing the data can be considered to be time consuming and prone to errors (Mathew et al. 2018). Thus, manual prediction models can be challenging for healthcare professionals.

- Assimilating and understanding multiple risk factors can be complex as it require high level expertise and skilled medical professional for accurately assessing the risk of heart diseases. Thus, manual techniques are not considered to be reliable for precise prediction of heart disease. Figure 1 shows the limitations in pictorial representation.

Besides these factors, increases in population also impacted the conventional clinical methods, as higher the population, higher the demand for healthcare services (Ghiasi et al. 2020) which leads to different challenges like inadequate resources like limited bed or medical supplies, unavailability of medical professionals, longer wait times and man more. Thus, conventional clinical methods may struggle to keep up with the growing demand and result in potential delay in accessing care and reduced quality of service.

Further, increasing population additionally increases varying healthcare needs. This diversity needs healthcare providers to get used to different circumstances and medical conditions in order to treat patients. Hence, in order to overcome these challenges, AI powdered techniques, EHR (Electronic Health Records) and other approaches can be used as they are effective and reliable than the traditional clinical approaches.

3.1. Challenges in the conventional medical diagnosis

Heart diseases are experienced at all ages in recent years. Even though traditional methods have taken much of their efforts in diagnosis, prevention and treatment, premature death occurs around the world (Vallée et al. 2019). Due to the increasing population, the traditional clinical methods have faced many difficulties in the accurate prediction of heart disease. The following are the challenges that have been faced with the conventional cardiac diagnosis techniques.

- The major difficulty that has been faced with the traditional approaches were the consequent arrival of larger amount of data for analysis in cardiology. The data processing platforms have failed in effective operation with the newer data into the datasets (Ramalingam et al. 2018). The process of sequential extraction and reorganization of data has helped in returning valuable output which has been found to be a drawback in the traditional data storage and retrieval strategies in the cardiovascular therapies. There are numerous information needed directly from the patients in order to make diagnosis of their healthcare effectively. The data related to health, medical imaging and diagnosed information along with lifestyle related data are highly beneficial in the heart disease diagnosis. Privacy is an important factor for both individuals and also to groups in order to maintain confidential identity which also has to be considered while sharing information.
- The traditional diagnosis method namely 12-lead ECG (Electrocardiography) has faced the difficulty of lower level of sensitivity in prediction of cardiac diseases. It also has examined with the lower predictive value of left ventricular systolic dysfunction and screening results have resulted with severe progression of heart failure (Silverio et al. 2019).
- Clinical measurements depending on plasma ceramides concentration randomly alone has not been able to figure out the accurate disease prediction. Certain smaller volumes of plasma inhibitors of enzymes in ceramide synthesis have been

Figure 1. Limitations of manual techniques.

investigated for proper prediction of heart diseases (Eleid et al. 2018).

- In order to investigate and classify on both the common and rare forms of cardiac diseases, conventional methods has found difficulty in larger sample size in providing better analysis and to produce valuable results (Reddy et al. 2019).
- Even though non-invasive evaluation of the CRF (coronary reserve flow) in patients with emission of positron tomography has resulted in independent diagnostic information, the increased diagnostic value of cardiac magnetic resonance imaging derived with CRF value has been seemed to be unclear (Indorkar et al. 2019).
- Acute cardiac allograft rejection has been detected with myocardial biopsy and CMR (Cardiac Magnetic Resonance) with multiple parameters but has limited to its capacity for the specific myocardial structure and functional characterisation. Acute ACAR still has needed an advanced development for the multi-parameter CMR for surveillance on transplantation (Dolan et al. 2019).
- The LA function has found difficulty with the characterization of poor quality images and has not been recommended for the assessment. The minimal signal to noise ratio, occurrence of certain appendages along with pulmonary veins has made the LA strain images difficult for evaluation. Improper estimation might have led to increased risk of cardiac problems or even to death (Carluccio et al. 2018).
- Diagnosis of RHD (Rheumatic heart Disease) has required simplified prediction models and has needed screening for the characterization of low level, medium and high level of risk and earlier prediction of cardiac disease progression. The three cohorts with simplified score method has been utilized for diagnosis of RHD and can be modified for further diagnosis of other types of heart diseases (Nunes et al. 2019).
- The appropriate identification of thicker heart walls and the prediction of changes in the heart chambers considerably predict the disorders in heart. It has to be accomplished with the advanced learning systems to predict the changes in the health of human body (Diller et al. 2019).

4. Evolution and advancements of AI in medicine

In order to overcome all challenges addressed in traditional techniques, AI has been evolved and advancements in AI algorithm has found effective outcomes in prediction. Since heart failure occurrence has increased and the complex disease syndrome has resulted from the functional disorders in heart and its proper diagnosis has been a challenging task. Many conventional methods have attempted for diagnosing the disease with minimal level of prediction accuracy (Wang et al. 2021). Proper diagnosis of the disease is significant for providing proper treatment. In order to overcome the issues, AI has initiated an important role in cardiology. It has thrown out huge advancements in the technology such as easier storage, data acquisition and recovery of data (Siddique Ibrahim and Sivabalakrishnan 2020). The decision making feature in AI algorithms has provided decision tree algorithms for making clear clinical decisions. AI (Artificial Intelligence) is the broad group of computational algorithms that have the ability of mimicking the intelligence of humans in the way of learning, making decisions and also the potential of solving problems (Siddique Ibrahim and Sivabalakrishnan 2020).

AI has made some tremendous and substantial advancements in the field of cardiology due to its ability to detect heart diseases, treat strokes faster and more accurate than the traditional approaches. For instance, CAD (Coronary Artery Diseases) risk assessment fundamental in the efforts to reduce the future CVD events (Mienye et al. 2020). Traditional prediction methods have limitations which includes disparities among the validation cohorts and absence of important variables. Thus, need for robust prediction tools for accurate prediction of CAD burden and the recent advancements in AI led to development of ML based risk prediction models. ML algorithm was superior to the conventional risk prediction score in both moderate and high risk for CAD groups.

Furthermore AI has been utilized for developing predictive models to gauge the risk of CVD. Implementation of AI algorithms can generate the personalized risk score by assisting the clinicians to detect the patients who are on the verge of higher risk of heart disease. By doing so, early intervention and preventive measures can be taken and potentially shrinks the incidence of CVD events.

AI models possess the capability of analyzing patient data, clinical guidelines, medical records, due to the utilization of numerous effective ML and DL approaches thereby providing most suitable treatment options (Rao and Prasad 2021) for individual patients and assisting the healthcare providers in making informed decisions and optimizing patient outcomes.

In recent times, AI powdered wearable devices and remote monitoring systems have emerged, allowing incessant monitoring of cardiac parameters outside of clinical setup. These AI powdered wearable devices can detect irregularities in heart rhythm, check the vital signs of patients and provide real time alerts to both medical team and patients. This remote monitoring capability improves the early detection of cardiac events and facilitates early intervention of impending problems.

Thus, AI has significantly advanced the field of cardiology by enhancing the prediction rate, ability to assist medical professionals effectively and by facilitating remote monitoring. These advancements have the potential of enhancing patient care, optimizing resource allocation and ultimately enhance the outcome for individuals with heart disease. Some of the dimensions of AI in clinical therapies includes, s

- Discovery and Development of drugs – AI accelerates the discovery of drugs by examining huge amount of biomedical data, detecting potential drug targets and helps in predicting the efficient drug candidates. AI can also optimize clinical trial design and patients selection which leads to more effective drug development.
- Diagnostic support – AI models can heavily aid medical professionals in diagnosing diseases by examining medical images, data of patients and lab results like angiogram, echocardiograms and detect the abnormalities presented in the lab reports. Thus, AI based approaches aids in improving the accuracy and efficacy in diagnosis.
- Planning of treatment – AI algorithms can examine patient of the data, treatment guidelines and clinical research for developing personalized treatment plans for heart disease patients. AI methods also helps in optimizing the medication choices, surgical intervention, adjustments of dosages depending on the characteristics and response patterns obtained using AI techniques.
- Risk prediction – As AI algorithms can analyze huge amount of patient data which includes medical records, lifestyle factors and genetic information, it become extremely helpful for identifying the aberrations developing in patient's heart.

Hence, these are some of the dimension of AI in clinical therapies for heart diseases. Figure 2 Advanced medical diagnosis approach of AI compared to traditional methods.

Prompt development of AI technology in the medical field has attracted medical experts to provide reliable and efficient treatment methods with good quality health care. Particularly to cardiac medicine as depicted in Figure 1, imaging has been considered to be the main focus of detection and management of patients in healthcare. Most of the traditional methods *HAVE BEEN* designed on the focus of average group of patients and however the general rules which has been designed has found to be inadequate due to certain complexities. But such guidelines would not work efficiently to all patients. There came the need and evolution of AI in medicine. Therefore, AI techniques are used, as AI technology has the ability to enhance the detection and prediction accuracy for heart disease prognostication by examining huge amount of patient's data which encompasses of medical records of the patients, test results and scans of the patients. AI techniques possess the capability to detect the patterns and correlations which may not be easily decipherable by manual approaches and medical professionals. AI techniques specifically Machine Learning (ML) and Deep Learning (DL) has helped in the development of predictive structures that subsequently assists the cardiologists with the guidelines specific to particular patients and decision making has been performed accordingly. The applications of AI with ML and DL algorithms have gained popularity due to the improved level of accuracy and efficiency in making predictions (Christo et al. 2022).

4.1. Potential contribution of AI in heart disease prediction

The rapid increase in the development of AI in cardiology has provided set of tools for extending the treatment efficiency. Advancement of AI in health care has progressed due to various reasons (Li et al. 2020). Medical analysis with data involved technologies has required the physicians to interpret and operationalize data from various fields (Alarsan and Younes 2019). Along with that, the patients also have demanded for more personal care and faster curing therapies which has made stage by stage enhancements in AI. The different dimensions of AI in clinical therapies are illustrated in Figure 3.

From Figure 3, it is clear that AI is being used in medical field for numerous purposes. Medical experts in cardiac care specifically needed certain variables for identifying and interpreting relationships among variables in order to initiate heart therapy (Olsen et al. 2020). The conventional methods have utilized various statistical techniques to obtain inference from the

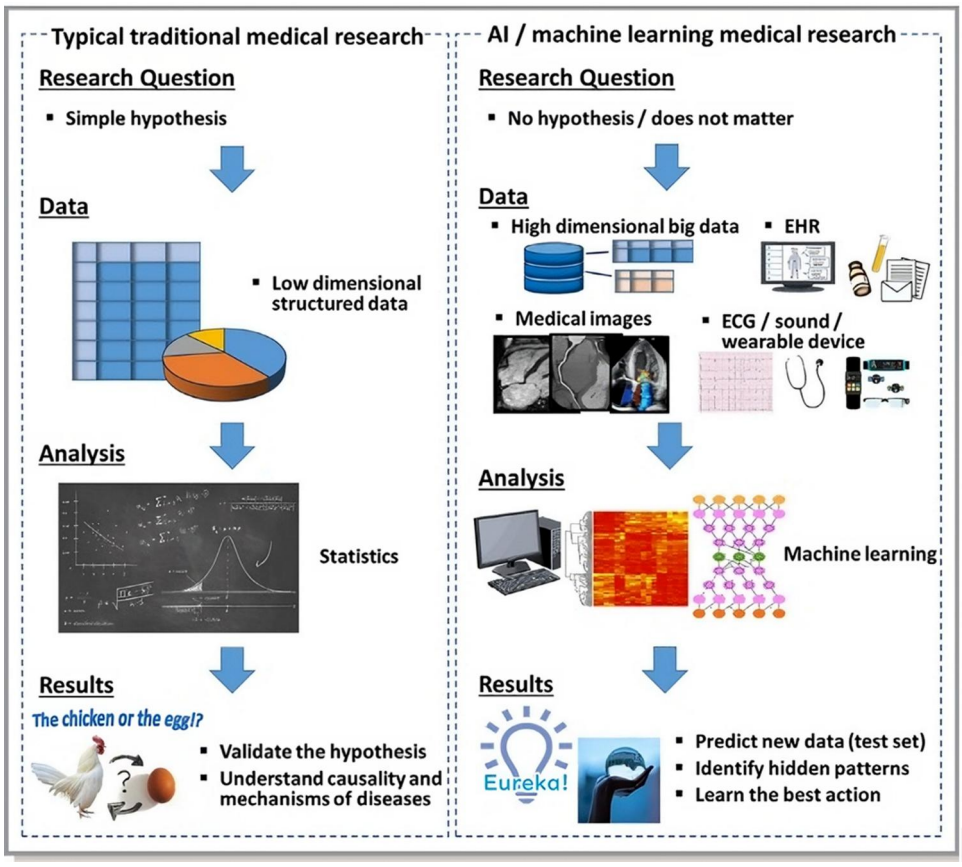


Figure 2. Advanced medical diagnosis approach of AI compared to traditional methods (Kagiyama et al. 2019).

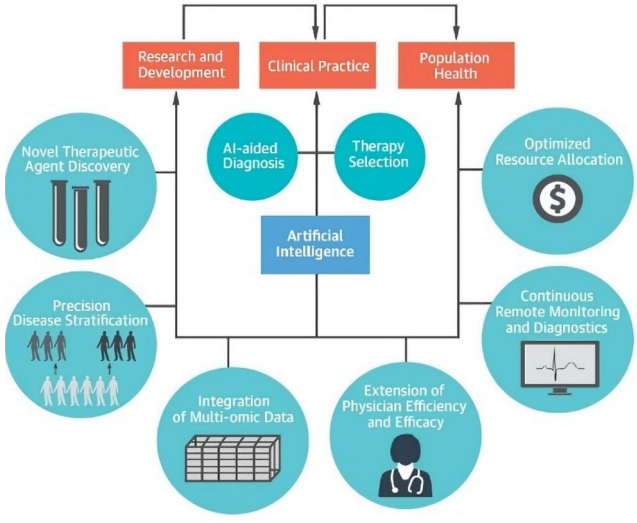


Figure 3. AI in cardiac care unit (Johnson et al. 2018).

sample parameters. It has required various assumptions when logistic regression method has been used for estimating coefficient values that might sometimes infer unrelated data that leads to misvalued conclusions whereas the AI technology has used algorithmic representation of data structure in order to make predictions and classifications quickly and accurately (Nourmohammadi-Khiarak et al. 2020). AI has played its role in cardiovascular diseases through utilization of algorithms in the following ways

- **Diagnosis of the cardiac disease:** Detecting the cardiac problem at its earliest and identifying those which is at the high risk of developing into adverse heart disease.
- **Heart condition monitoring and self-care:** AI has the potential to monitor patients with heart related diseases and predicts symptoms of either heart failure or cardiac arrest at its earliest. AI algorithms for analysing ECG recordings make an early detection and predict differences between the normal heart beat and arrhythmia and minimizes the chronic cardiac failure.
- **Selection of appropriate and early treatment:** AI techniques help in selecting appropriate treatment for various categories of cardiac patients who have suffered with either cardiac attack or narrowing of arteries. Treatments included with artificial valves, blood pressure medications or heart surgery would be recommended to patients according to the cardiac problems.
- **Several cardiac events monitoring and detection:** Physicians have used sensors for predicting the

risk using real time data. The strength of AI lies in the ability of analysing at larger scale and making accurate decisions faster. ML algorithms have the potential of detecting adverse events with the higher degree of accuracy rate. DL algorithms have the ability of detecting and monitoring the adverse cardiac actions in real time and could be able to track the abnormalities. It also allows clinicians to monitor patients remotely. Development of various ML and DL algorithms provided advancement in the treatment procedures.

5. Different AI algorithms for predicting heart disease

AI is the technical concept of constructing intelligent machines that has ability to think like humans and can learn from the observations and execute actions without direct instructions. ML and DL algorithms are subsets of AI which has been used at every phases of patient heart care from discovery of disease through diagnosis to selection of appropriate therapies (Abdar et al. 2019). It has provided efficient, convenient and effective treatment. After ML, DL has been arrived which also comes under the family of learning algorithms which has been utilized for learning complex prediction structures. Problems with multi-layer neural network can be solved with DL efficiently. Particularly in heart diseases, CNN (Convolutional Neural Network) has the potential of mapping image data into the output which helps out in better prediction and classification of type of cardiac disease (Gupta et al. 2020). Under DL, there are subset of learning algorithms which is categorised based on their learning capability such as supervised, semi-supervised, and unsupervised and reinforcement learning which is represented under Figure 4.

ML and DL strategies are broadly classified into supervised or unsupervised learning methods as given in Figure 3. The unsupervised form of learning methods intends to discover the underlying structure or critical relationships between the variables in the dataset. The supervised learning technique is involved with the classification of observation into one or more categories. It needs a dataset with the predictor parameters and labelled outputs. In cardiac therapy, predictive modelling is significantly needed for labelling cases and controls and such observations has been made with the associated features like age, gender and clinical variables (Reddy et al. 2019). The reinforcement AI learning is able to learn with the trial and error method. This algorithm is operated

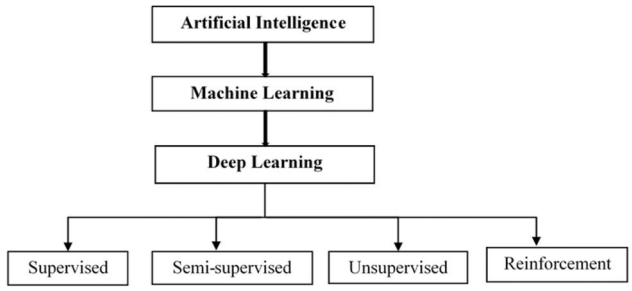


Figure 4. Major types of AI algorithms used for cardiac healthcare.

with the intelligent agent being interacted with the environment and provides decision making accordingly.

5.1. Machine learning algorithms for cardiac disease detection

ML utilizes many algorithms for the prognostication of heart diseases. All types of cardiovascular syndromes can be prevented through earlier diagnosis and considerably mitigates the rate of mortality. ML algorithms have performed the process of figuring out the risk factors through effective learning strategies (Ali et al. 2023). Suggested study (Ghosh et al. 2021) has designed a system and performed collection of data, pre-processing of those data and transformation being done on the collected data for creating accurate input data in order to train the model. Through effective training, ML systems gain knowledge and execute accordingly. It has used LASSO (Least Absolute Shrinkage and Selection Operator) technique for feature selection and gradient boosting with bagging methods has been used for the classification purposes. The LASSO and RELIEF technique has achieved better performance with the smaller coefficient values. Minimum selection and shrinking ability of the system has removed the negative and zero coeffecients and higher coefficient value has been stored in the chosen group of features. The ensemble learning model in (Gao et al. 2021) has mixed different classifiers of DT (Decision Tree) in order to achieve better classification accuracy. It has used a compact form of correlated feature set which has been used along with various other ML algorithms and it has achieved accuracy with high impact features.

ML has provided effective support in diagnosing large volume of data. Different types of ML methods for diagnosis are depicted in Figure 5. It explains the entire process flow of the diagnosis structure starting with data refining followed by pre-processing and performs the classification process which yields out

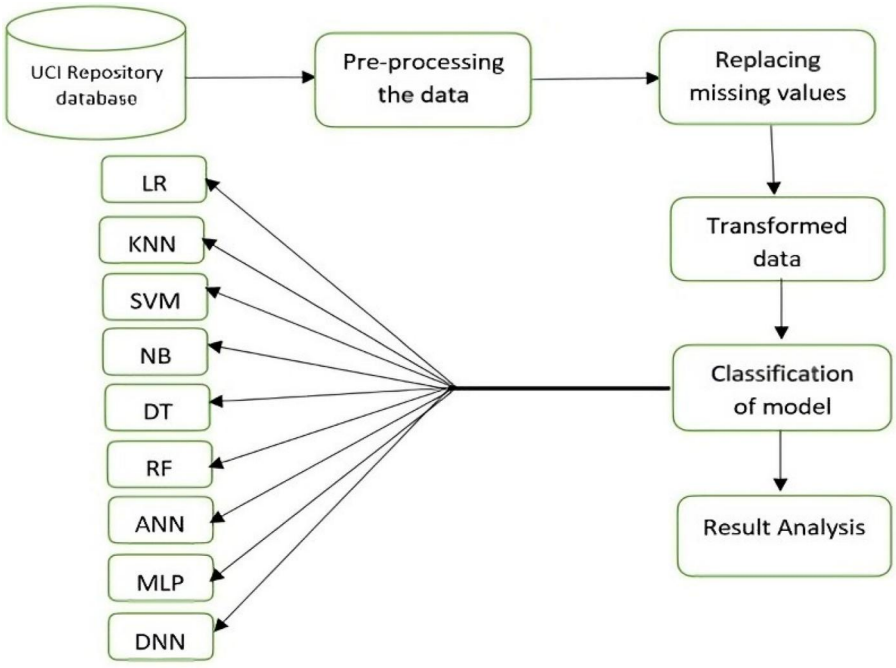


Figure 5. Different ML algorithms for heart disease prognostication (Katarya and Meena 2021).

the better prediction output. Analysis of larger datasets requires numerous resources and higher execution time. Small amount features present in the dataset cannot yield better solution for the problem and hence effective feature selection algorithms for extracting more significant features aid in the diagnosis of the heart disease (Nourmohammadi-Khiarak et al. 2020). Recommended study has utilized metaheuristic algorithms for effective prediction with less time. It has utilized PSO (Particle Swarm Optimization) for removing irrelevant features and also to extract numerous important features from the dataset. With the help of SVM (Support Vector Machine) with the PSO, optimal weights have been identified based on the population diversity and tuning function. Generally, ML algorithms operate by predicting the outcome of the problem based on the existing data. From the suggested research (Latha and Jeeva 2019) it has investigated on the method of ensemble based classification in order to improve the accuracy of the weaker algorithms through integration of different classifiers.

With the help of ML algorithms, heart related diseases can be easily diagnosed inn shorter time period and also in less cost. The suggested study (Absar et al. 2022) has adopted four different ML methods such as RF (Random Forest), DT (Decision Tree), AB (AdaBoost) and K-NN (Nearest Neighbour) for the detection of cardiac diseases. The considered study has designed a system named as Streamlit, a cloud based platform for the analysis of relevant attributes that has contributed in the prediction of heart diseases. The computation on those strength scores has been indicated as the important predictors in the prognostication of Cardiac diseases. Moreover, recommended research (Ansarullah et al. 2022) have focused on developing the risk-evaluation structure based on hyper-parameter based optimization using ML algorithms. Group of risk parameters has been selected and has been ranked through recursive process of feature elimination. Such assigned rank and value on every attribute has been validated with the enhancement of deploying various algorithms like RF, K-NN, SVM and DT. Outcomes have revealed that optimized model of risk evaluation has achieved higher accuracy and greater efficiency. In addition to that, cardiac disease prediction has been handled through risk-evaluation structure in (Ansarullah et al. 2022) with the assistance of significant invasive and non-invasive risky parameters such as BP, age, physical activities, alcohol, smoking and hereditary elements. Reliability of the prediction model has been assessed through various feature-selection methodologies. The groups of ML techniques like DT, NB, K-NN and SVM have been evaluated with the risk factors and error has been analysed. Moreover, disorders in cardiovascular system have been identified through knowledge mining methodology and ML techniques (Ansarullah and Kumar 2019).

Different ML algorithms are incorporated due to the ability of the ML classifiers deliver better outcome. Therefore, suggested study has utilized hybrid ML

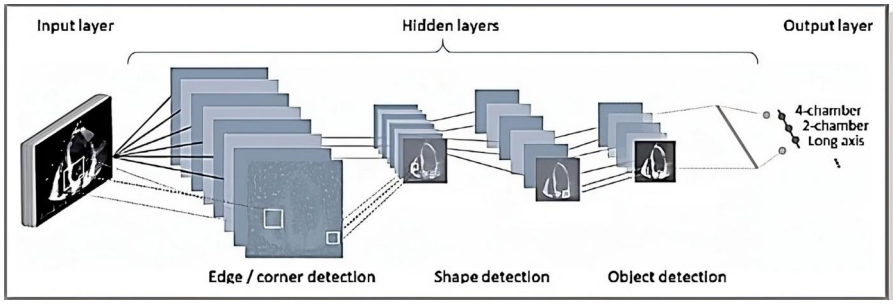


Figure 6. DL algorithms for cardiac disease diagnosis (Xiao et al. 2020).

algorithms for prediction CVD, in which the hybrid ML algorithm encompassed of DT, LR, RF, NM and SVM algorithms. The dataset utilized in the studies include SVD data, which consist of different attributes like BMI, age, gender, height, cardiovascular disease and other attributes. From the experimental images, it was detected that, RF algorithm delivered highest accuracy rate of 85.01% than the existing algorithms (Khan et al. 2023).

5.2. Deep learning algorithms for heart disease prediction

DL architectures are generally composed of numerous hidden layers of neurons in which the algorithms run through all layers and each layer passes a simple representation of data to the next succeeding layer (Ali et al. 2020). It has the ability to learn more progressively about an image when it passes through every layer. Each and every layer has the potential to detect lower level features like edges and consequent layers are combined from the earlier layers into a complete representation (Velusamy and Ramasamy 2021). Middle layers or hidden layers has the ability in identifying edges in order to detect parts of the object whereas the deep layer figures out the complete object. The skill of processing larger number of features makes the DL algorithms more powerful in dealing out with the unstructured data (Shorewala 2021) (Figure 6).

DL architectures are consisted with three layers such as input layer, hidden layers and output layers and each layer performs detection with a more refined way as depicted in Figure 5. The input layer initially performs the edges and corner detection followed by the hidden layers which performs shape detection and the final output layer performs object detection (Pan et al. 2020). In the existing DL algorithms, CNN is considered as one of the commonly used algorithms for prediction of diseases. Convolutional neural networks (CNNs) are extensively used for image receptions and analysis because of their capacity to handle enormous amounts of unstructured data and retrieve significant characteristics automatically (Rajdhan et al. 2020). The application of DL algorithms in diagnosis of heart diseases not only aids patients to prevent it but also helps the physicians to learn more about the root causes of the heart failure and prevents before actual occurrence. In (Mehmood et al. 2021), it has incorporated one of the DL methods namely CNN for heart failure prediction at its earlier stage. It also has performed diagnosis through heart sounds. Training and multiple classification of heart diseases have been performed through data augmentation methods in order to make the system robust. It has the capacity of automatic interpretation of medical imaging to assist clinicians. Moreover, in (Madani et al. 2018) has utilized DL based classifiers in the task of prediction in cardiology. The pipeline form of supervised structure has focused relevant features and has developed network structures that has learned from both forms of labelled and unlabelled data in a more generalized manner (Avanzato and Beritelli 2020). The prospects of DL in predicting disease at an earlier stage and classifying its stages have yielded efficient accuracy. Similarly CNN utilized in predicting and classifying Alzheimer's disease have predominantly achieved better classification outcomes (Mohi Ud Din Dar et al. 2023).

6. Comparative analysis of conventional AI based algorithms in prediction

The present review paper performs comparison of both ML and DL algorithms in terms of accuracy in order to determine the efficacy of the algorithm. Table 1 depicts the comparative analysis with respective to Methods, datasets and number of samples considered by the existing studies.

6.1 Accuracy estimation graph analysis for both ML and DL algorithms

The estimation graph analysis accomplished through involvement of ML and DL techniques with better

Table 1. Comparative analysis.

S.No	Reference	Type	Methods	Dataset	Number of samples	Findings
1	Ahamad et al. (2023)	ML Algorithms	LR, KNN, SVM, DT, RF classifier, and extreme gradient boosting	• Dataset I - UCI Kaggle Cleveland dataset • Dataset II - Comprehensive UCI Kaggle Cleveland dataset	Dataset I – 303 samples Dataset II- 1025 samples	Extreme gradient boosting classifier provides better accuracy rate by attaining 99.03%
2	Sarra et al. (2022)	DL Algorithms	GAN-1D-CNN and GAN-Bi-LSTM	• Cleveland, • Statlog dataset • Comprehensive dataset (Hungarian, Cleveland, long beach VA, Statlog, Switzerland)	Cleveland dataset – 303 samples Statlog – 240 samples Comprehensive dataset – 1190 samples	The proposed GAN-1D-CNN model delivered accuracy rate of 99.10% and GAN-BiLSTM model obtained an accuracy rate of 99.30%.
3	Almulihi et al. (2022)	ML and DL Algorithms	CNN-LSTM, CNN-GRU and Stacked SVM	• Dataset I - Large Heart disease dataset • Dataset II - Cleveland dataset	Large Heart disease dataset – 57,373 Cleveland dataset – 1025	Accuracy obtained by the first dataset is 78.81 and accuracy obtained for Cleveland dataset is 97.17%
4	Ramesh et al. (2022)	ML Algorithms	DT, NB, RF, KNN, SVM, LR	• Cleveland data source	303 samples	Experimental results proved that KNN attained highest accuracy of 94%
5	Bhatt et al. (2023)	ML and DL Algorithms	RF, DT, MLP, and XGBoost	• Cardiovascular Disease dataset	70,000 samples	MLP model delivered an accuracy rate of 87.23%.
6	Pathan et al. (2022)	ML and DL Algorithms	LR, DT, NB, RF, MLP	• CVD dataset • Framingham dataset	4240 samples 29072 samples	Multi-Layer Perceptron (MLP) delivered better accuracy rate of 0.73%.
7	Absar et al. (2022)	ML Algorithms	RF, DT, AB, and KNN	• CHSLB (Cleveland, Hungary, Switzerland, and Long Beach) • Cleveland dataset	1025 samples	In terms of CHSLB dataset, DT algorithm delivered 100% accuracy rate for prediction of heart disease.
8	Gupta et al. (2022)	ML Algorithms	KNN, DT, LR NB, and SVM	• UCI repository dataset	303 samples	LR has delivered better accuracy rate of 92.30% when compared to other existing models

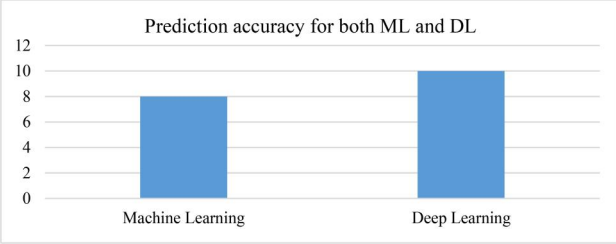


Figure 7. Assessment based on AI based algorithms.

efficiency achieved has been outlined in the following graph.

From Figure 7, it is very clear that, prediction of cardiac diseases using DL algorithms have higher accuracy level than ML based algorithms. The higher accuracy rate in DL is mainly due to its numerous layers in the architecture which has detected the disorders sharply.

7. Applications of AI

AI technology is utilized in cardiac care for better treatment and assessment of patients which have been performed in order to provide patients with finest possibilities (Acharya et al. 2019). The following are the list of heart care sections where AI is used in diagnosis. It has numerous benefits in cardiology in the process of automatic diagnosis. AI is providing its utmost uses in the process of making automatic decisions and accurate suggestion on the clinical therapies (Soh et al. 2020). Its one of the biggest advantage is the minimal cost for diagnosis. Since conventional methods are highly expensive in diagnosis, poor patients suffered a lot and AI has taken efforts in providing effective diagnosis methods at minimal cost (Wang et al. 2020). There are various kinds of heart related diseases and AI is being used for diagnosis and prevention of such heart diseases. The following are some of the heart problems in which AI techniques are effectively utilized.

- **Cardiac arrythymias**
  The detection of the particular cardiac arrhythmias is considered to be one of the significant uses of AI algorithm in cardiology (Gennari et al. 2018). The prediction model has utilized different subprocesses such as extracting most relevant features, pre-processing of signals and classification techniques. Detection has been performed through direct analysis of images and signals of various types of arrhythmia (Xiao et al. 2020). AI methods considerably reduce the risk of death from this particular kind of cardiac disease.

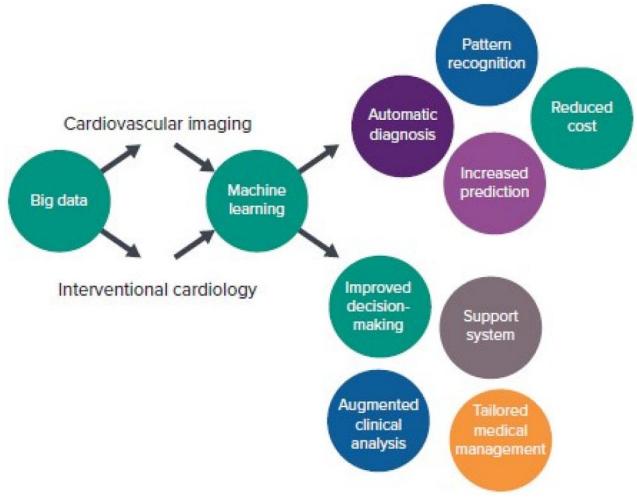


Figure 8. Applications of AI in cardiac care (Seetharam et al. 2021).

- **Ischemic heart disease**
  AI is estimating the risk of the disease from the population using the electronic clinical data for assessment (Yao et al. 2020). Additionally, the specific type of ischemic and coronary artery syndrome is being detected and tested using supervised learning AI methods through exploring findings from the datasets. Larger sample sizes with the various findings provided higher level of prediction results (Shaker et al. 2020).

AI is providing its utmost uses and it is clearly shown in Figure 8, in the process of making automatic decisions and accurate suggestion on the clinical therapies (Soh et al. 2020). Its one of the biggest advantage is the minimal cost for diagnosis. Since conventional methods are highly expensive in diagnosis, poor patients suffered a lot and AI has taken efforts in providing effective diagnosis methods at minimal cost (Wang et al. 2020). There are various kinds of heart related diseases and AI is being used for diagnosis and prevention of such heart diseases. The following are some of the heart problems in which AI techniques are effectively utilized.

- **Cardiac arrythymias**
  The detection of the particular cardiac arrhythmias is considered to be one of the significant uses of AI algorithm in cardiology (Gennari et al. 2018). The prediction model has utilized different subprocesses such as extracting most relevant features, pre-processing of signals and classification techniques. Detection has been performed through direct analysis of images and signals of various types of

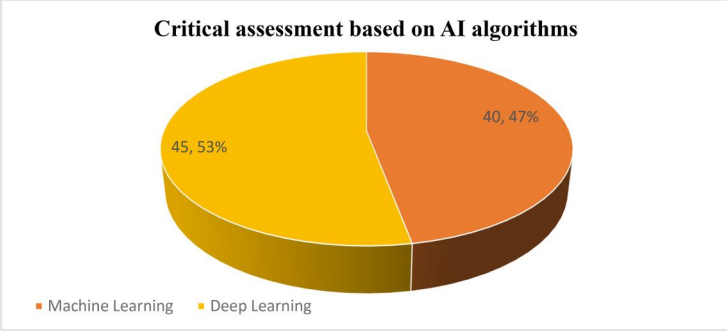


Figure 9. Critical assessment based on AI algorithms.

arrhythmia (Xiao et al. 2020). AI methods considerably reduce the risk of death from this particular kind of cardiac disease.

- **Ischemic heart disease**
  AI is estimating the risk of the disease from the population using the electronic clinical data for assessment (Yao et al. 2020). Additionally, the specific type of ischemic and coronary artery syndrome is being detected and tested using supervised learning AI methods through exploring findings from the datasets. Larger sample sizes with the various findings provided higher level of prediction results (Shaker et al. 2020).
- **Heart Failure**
  ML and DL methods provide earlier diagnosis and avoid hospitalisation due to occurrence of heart failure. It identifies accurately more than the conventional risk estimating scales. It utilizes the telemonitoring management system for patients with HF (Fujita and Cimr, 2019). It effectively been utilized in the heart transplantation process and forecasts the likelihood of the disease earlier successfully. AI algorithms also have been used in the prediction of diastolic dysfunction with the data from ECG (Li et al. 2019).
- **Cardiac Imaging**
  The advancements in DL approaches have increased the growth of analysis in cardiac imaging. AI computes in a shorter span of time (Sun et al. 2019). Cardiovascular intervention is being considered as the basic therapies for the heart related diseases. It has the advantage of identifying atherosclerotic plaques with the help of learning. It also the ability of interpreting the ECG images computing with the size of the chamber measurements and evaluations in the functions of left ventricular area. The remarkable growth of cardiovascular image evaluations considerably enhances the need of medical procedures and reduces the missed level of diagnoses. AI improves the patient care at every level of the imaging chain with the availability and utilization off larger databases. The advanced ML and DL methods are used in the categorization of valuvular sickness. From the clinical images obtained by diagnosis with AI, it is easier for diseases to be detected and to make further processing on the treatment. It also has been integrated with the data such as metabolomics, genomes, biomarkers and genomes with the data from the images for enhancements on the predictive value (MAlnajjar and Abu-Naser 2022).

8. Critical assessments

From the Figure 9, it is very clear that, both ML and DL have been utilized in the process of diagnosing heart diseases. Both have equal importance in the field of medicine. It is shown that both the algorithms are utilized in cardiology for accurate diagnosis purposes.

9. Challenges of AI

The digital transformation in healthcare is providing enormous benefits to both physicians as well as patients. Particularly, AI has developed intelligent systems which has numerous advantages such as higher level of computing power, increased data storage capacity and learning capabilities altogether has enabled the systems to learn faster than humans and has the capacity of taking suitable actions at the particular situation. In order to develop such kind of intelligent mechanisms, however AI algorithms require dynamic learning abilities in co-ordination with the changing conditions (Fan et al. 2018). It has been taking many forms including with psychology, physiology, neuroscience, physics and even as mathematical optimisation for solving many kinds of problems. Even though AI has sophisticated techniques for exceeding the performance of humans, still AI needs advancements for providing perfect solution to all possible problems to reach

a level of super-intelligence. AI based algorithms must be able to predict, diagnose and provide recommendations in treatment of complex medical conditions. Effective algorithms can be combined competently for effective cardiac diagnosis and feeding appropriate data into the system can potentially solve highly complex data than humans (Ma et al. 2021). AI has faced certain barriers in sharing data contained in electronic health records around the world. There has been certain regulations for the data protection in the medical department and has been following numerous restrictions on sharing health care related data and also been considering on effective data accessibility in the health care organizations.

10. Future scope and recommendations

AI methods in disease prediction have developed intelligent models for early diagnosis but since then, to develop a still more accurate system, data related to the diseases and about the patient can be collected form dynamic sources with more number of variables for diagnostic computation with higher accuracy. Large amount of data has been stored using electronic health record system with the help of AI techniques and such data collected from various sources can be effectively processed or interpreted into a distinctive format with image processing algorithms, character recognition systems and other natural language processing models. Certain significant prospects of ML with identification of heart disease using rule based expert systems with better tracking ability improved the diagnosis process which have been evidently revealed through DT, NB, LR and RF methodologies. However, longer memory space required for computation and longer time for testing the model has been identified as the areas of improvement in ML. Moreover, DL model have provided efficacy in estimation of probability occurrence of the disease over a particular period of time but still improving decision making by discovering the hidden patterns and interactions from databases enhances the prediction model effectively. The future scope of employing different DL models, is to make precise and accurate predictions for effective heart disease prediction. In addition, Powerful computational approaches will be utilized for training CNN model effectively. Furthermore, the future work also emphasizes on utilizing Transfer learning techniques with pre-trained model as CNN alone can be computationally expensive, therefore utilizing these models can lower the cost of training CNN model for medical imaging diagnosis while simultaneously enhancing the performance of the model.

11. Conclusion

The present review analysis was performed in accordance to various AI algorithms in the perspective of diagnosing the heart disease. From the analysis, it was found that ML algorithms used in heart disease prediction was utilized at maximum rate of 53%. Integration of several ML methods yielded greater accuracy of 99%. In contrast, the analysis of DL utilization in heart disease prediction has found limited attention at the rate of 47%. Thus, the critical analysis performed in present research benefits future researchers in focusing on areas to which further enhancements could be undertaken. Along with that, research gaps and future recommendations emphasized through this study have conclusively claimed that applications of AI in medicine have been evolving and continuous explorations on cardiac prediction certainly offer better outcomes. The major findings of the paper emphasized on the evolution and continuous explorations of AI techniques for heart disease prediction. From the various existing that has been reviewed, it can be examined that, AI techniques performed well for Cardio vascular prediction it is primarily due to the capability of the AI approaches for handling huge amount of patients data and its ability to recognize subtle correlations and hazardous elements that are related to heart disease. Besides these existing factors, AI models can also provide more comprehensive assessment of risk profile of a patient by considering numerous factors concurrently due to implementation of effective AI algorithms. Finally, this review has offered new inspiration for researchers in assisting them to bring new innovations in the study AI in cardiac therapies.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) reported there is no funding associated with the work featured in this article.

References

Abdar M, Książek W, Acharya UR, Tan R-S, Makarenkov V, Pławiak P. 2019. A new machine learning technique for an accurate diagnosis of coronary artery disease. Comput Methods Programs Biomed. 179:104992. doi: 10.1016/j.cmpb.2019.104992.

Absar N, Das EK, Shoma SN, Khandaker MU, Miraz MH, Faruque MRI, Tamam N, Sulieman A, Pathan RK. 2022. The efficacy of machine-learning-supported smart system for heart disease prediction. Healthcare. 10(6):1137. doi: 10.3390/healthcare10061137.

Acharya UR, Fujita H, Oh SL, Hagiwara Y, Tan JH, Adam M, Tan RS. 2019. Deep convolutional neural network for the automated diagnosis of congestive heart failure using ECG signals. Appl Intell. 49(1):16–27. doi: 10.1007/s10489-018-1179-1.

Ahamad GN, Shafiullah, Fatima H, Imdadullah, Zakariya SM, Abbas M, Alqahtani MS, Usman M. 2023. Influence of optimal hyperparameters on the performance of machine learning algorithms for predicting heart disease. Processes. 11(3):734. doi: 10.3390/pr11030734.

Alarsan FI, Younes M. 2019. Analysis and classification of heart diseases using heartbeat features and machine learning algorithms. J Big Data. 6(1):1–15. doi: 10.1186/s40537-019-0244-x.

Alhassan AM, Wan Zainon WMN. 2020. Taylor bird swarm algorithm based on deep belief network for heart disease diagnosis. Appl Sci. 10(18):6626. doi: 10.3390/app10186626.

Ali A, Ramachandra H, Ramakrishnan N, Murtugudde G. 2023. Prognosis of chronic kidney disease using ML optimization techniques. In: 2023 International Conference on Advances in Electronics, Communication, Computing and Intelligent Information Systems (ICAECIS); IEEE. pp. 459–463. doi: 10.1109/ICAECIS58353.2023.10170077.

Ali F, El-Sappagh S, Islam SMR, Kwak D, Ali A, Imran M, Kwak K-S. 2020. A smart healthcare monitoring system for heart disease prediction based on ensemble deep learning and feature fusion. Information Fusion. 63:208–222. doi: 10.1016/j.inffus.2020.06.008.

Almulihi A, Saleh H, Hussien AM, Mostafa S, El-Sappagh S, Alnowaiser K, Ali AA, Refaat Hassan M. 2022. Ensemble learning based on hybrid deep learning model for heart disease early prediction. Diagnostics. 12(12):3215. doi: 10.3390/diagnostics12123215.

Ansarullah SI, Kumar P. 2019. A systematic literature review on cardiovascular disorder identification using knowledge mining and machine learning method. Int J Recent Technol Eng. 7(6S):1009–1015.

Ansarullah SI, Mohsin Saif S, Abdul Basit Andrabi S, Kumhar SH, Kirmani MM, Kumar D. 2022. An intelligent and reliable hyperparameter optimization machine learning model for early heart disease assessment using imperative risk attributes. J Healthc Eng. 2022:9882288. doi: 10.1155/2022/9882288.

Ansarullah SI, Saif SM, Kumar P, Kirmani MM. 2022. Significance of visible non-invasive risk attributes for the initial prediction of heart disease using different machine learning techniques. Comput Intell Neurosci. 2022:9580896. doi: 10.1155/2022/9580896.

Asadi S, Roshan S, Kattan MW. 2021. Random forest swarm optimization-based for heart diseases diagnosis. J Biomed Inform. 115:103690. doi: 10.1016/j.jbi.2021.103690.

Avanzato R, Beritelli F. 2020. Automatic ECG diagnosis using convolutional neural network. Electronics. 9(6):951. doi: 10.3390/electronics9060951.

Baghel N, Dutta MK, Burget R. 2020. Automatic diagnosis of multiple cardiac diseases from PCG signals using convolutional neural network. Comput Methods Programs Biomed. 197:105750. doi: 10.1016/j.cmpb.2020.105750.

Bhatt CM, Patel P, Ghetia T, Mazzeo PLJA. 2023. Effective heart disease prediction using machine learning techniques. Algorithms. 16(2):88. doi: 10.3390/a16020088.

Carluccio E, Biagioli P, Mengoni A, Francesca Cerasa M, Lauciello R, Zuchi C, Bardelli G, Alunni G, Coiro S, Gronda EG, et al. 2018. Left atrial reservoir function and outcome in heart failure with reduced ejection fraction: the importance of atrial strain by speckle tracking echocardiography. Circ Cardiovasc Imaging. 11(11):e007696. doi: 10.1161/CIRCIMAGING.118.007696.

Christo VE, Nehemiah HK, Brighty J, Kannan A. 2022. Feature selection and instance selection from clinical datasets using co-operative co-evolution and classification using random forest. IETE J Res. 68(4):2508–2521. doi: 10.1080/03772063.2020.1713917.

Collet C, Onuma Y, Andreini D, Sonck J, Pompilio G, Mushtaq S, La Meir M, Miyazaki Y, de Mey J, Gaemperli O, et al. 2018. Coronary computed tomography angiography for heart team decision-making in multivessel coronary artery disease. Eur Heart J. 39(41):3689–3698. doi: 10.1093/eurheartj/ehy581.

Diller G-P, Lammers AE, Babu-Narayan S, Li W, Radke RM, Baumgartner H, Gatzoulis MA, Orwat S. 2019. Denoising and artefact removal for transthoracic echocardiographic imaging in congenital heart disease: utility of diagnosis specific deep learning algorithms. Int J Cardiovasc Imaging. 35(12):2189–2196. doi: 10.1007/s10554-019-01671-0.

Dolan RS, Rahsepar AA, Blaisdell J, Suwa K, Ghafourian K, Wilcox JE, Khan SS, Vorovich EE, Rich JD, Anderson AS, et al. 2019. Multiparametric cardiac magnetic resonance imaging can detect acute cardiac allograft rejection after heart transplantation. JACC Cardiovasc Imaging. 12(8 Pt 2):1632–1641. doi: 10.1016/j.jcmg.2019.01.026.

Eleid MF, Tweet MS, Young PM, Williamson E, Hayes SN, Gulati R. 2018. Spontaneous coronary artery dissection: challenges of coronary computed tomography angiography. Eur Heart J Acute Cardiovasc Care. 7(7):609–613. doi: 10.1177/2048872616687098.

Elhoseny M, Abed Mohammed M, Mostafa SA, Hameed Abdulkareem K, Maashi MS, Garcia-Zapirain B, Awad Mutlag A, Suliman Maashi M. 2021. A new multi-agent feature wrapper machine learning approach for heart disease diagnosis. Comput Mater Contin. 67(1):51–71. doi: 10.32604/cmc.2021.012632.

El-Shafiey MG, Hagag A, El-Dahshan E-SA, Ismail MA. 2021. A Hybrid Bidirectional LSTM and 1D CNN for Heart Disease Prediction. IJCSNS. 21(10):135.

Fan X, Yao Q, Cai Y, Miao F, Sun F, Li Y. 2018. Multiscaled fusion of deep convolutional neural networks for screening atrial fibrillation from single lead short ECG recordings. IEEE J Biomed Health Inform. 22(6):1744–1753. doi: 10.1109/JBHI.2018.2858789.

Fujita H, Cimr D. 2019. Computer aided detection for fibrillations and flutters using deep convolutional neural network. Inf Sci. 486:231–239. doi: 10.1016/j.ins.2019.02.065.

Gao X-Y, Amin Ali A, Shaban Hassan H, Anwar EM. 2021. Improving the accuracy for analyzing heart diseases

prediction based on the ensemble method. Complexity. 2021:1–10. doi: 10.1155/2021/6663455.
Gennari C, Lago M, Bögre B, Meszaros I, Calliari I, Pezzato L. 2018. Microstructural and corrosion properties of cold rolled laser welded UNS S32750 duplex stainless steel. Metals. 8(12):1074. doi: 10.3390/met8121074.
Ghiasi MM, Zendehboudi S, Mohsenipour AA. 2020. Decision tree-based diagnosis of coronary artery disease: CART model. Comput Methods Programs Biomed. 192: 105400. doi: 10.1016/j.cmpb.2020.105400.
Ghosh P, Azam S, Jonkman M, Karim A, Shamrat FMJM, Ignatious E, Shultana S, Beeravolu AR, De Boer F. 2021. Efficient prediction of cardiovascular disease using machine learning algorithms with relief and LASSO feature selection techniques. IEEE Access. 9:19304–19326. doi: 10.1109/ACCESS.2021.3053759.
Guo C, Zhang J, Liu Y, Xie Y, Han Z, Yu J. 2020. Recursion enhanced random forest with an improved linear model (RERF-ILM) for heart disease detection on the internet of medical things platform. IEEE Access. 8: 59247–59256. doi: 10.1109/ACCESS.2020.2981159.
Gupta A, Kumar R, Arora HS, Raman B. 2020. MIFH: a machine intelligence framework for heart disease diagnosis. IEEE Access. 8:14659–14674. doi: 10.1109/ACCESS.2019.2962755.
Gupta C, Saha A, Reddy NS, Acharya UD. 2022. Cardiac disease prediction using supervised machine learning techniques. J Phys Conf Ser. 2161(1):012013. doi: 10.1088/1742-6596/2161/1/012013.
Indorkar R, Kwong RY, Romano S, White BE, Chia RC, Trybula M, Evans K, Shenoy C, Farzaneh-Far A. 2019. Global coronary flow reserve measured during stress cardiac magnetic resonance imaging is an independent predictor of adverse cardiovascular events. JACC Cardiovasc Imaging. 12(8 Pt 2):1686–1695. doi: 10.1016/j.jcmg.2018.08.018.
Johnson KW, Torres Soto J, Glicksberg BS, Shameer K, Miotto R, Ali M, Ashley E, Dudley JT. 2018. Artificial intelligence in cardiology. J Am Coll Cardiol. 71(23): 2668–2679. doi: 10.1016/j.jacc.2018.03.521.
Kagiyama N, Shrestha S, Farjo PD, Sengupta PP. 2019. Artificial intelligence: practical primer for clinical research in cardiovascular disease. J Am Heart Assoc. 8(17):e012788. doi: 10.1161/JAHA.119.012788.
Katarya R, Meena SK. 2021. Machine learning techniques for heart disease prediction: a comparative study and analysis. Health Technol. 11(1):87–97. doi: 10.1007/s12553-020-00505-7.
Khan A, Qureshi M, Daniyal M, Tawiah KJH. 2023. A novel study on machine learning algorithm-based cardiovascular disease prediction. Health Soc Care Commun. 2023:1406060. doi: 10.1155/2023/1406060.
Kumar RK, Antunes MJ, Beaton A, Mirabel M, Nkomo VT, Okello E, Regmi PR, Reményi B, Sliwa-Hähnle K, Zühlke LJ, et al. 2020. Contemporary diagnosis and management of rheumatic heart disease: implications for closing the gap: a scientific statement from the American Heart Association. Circulation. 142(20):e337–e357. doi: 10.1161/CIR.0000000000000921.
Latha CBC, Jeeva SC. 2019. Improving the accuracy of prediction of heart disease risk based on ensemble classification techniques. Inf Med Unlocked. 16:100203. doi: 10.1016/j.imu.2019.100203.
Li D, Li X, Zhao J, Bai X. 2019. Automatic staging model of heart failure based on deep learning. Biomed Signal Process Control. 52:77–83. doi: 10.1016/j.bspc.2019.03.009.
Li JP, Haq AU, Din SU, Khan J, Khan A, Saboor A. 2020. Heart disease identification method using machine learning classification in e-healthcare. IEEE Access. 8:107562–107582. doi: 10.1109/ACCESS.2020.3001149.
Lu K, Wang F, Shao L, Li W. 2020. Deep learning for medical image analysis. Neurocomputing. 392:121–123. doi: 10.1016/j.neucom.2019.03.075.
Ma C, Wei S, Chen T, Zhong J, Liu Z, Liu C. 2021. Integration of results from convolutional neural network in a support vector machine for the detection of atrial fibrillation. IEEE Trans Instrum Meas. 70:1–10. doi: 10.1109/TIM.2020.3044718.
Madani A, Ong JR, Tibrewal A, Mofrad MR. 2018. Deep echocardiography: data-efficient supervised and semi-supervised deep learning towards automated diagnosis of cardiac disease. NPJ Digit Med. 1(1):59. doi: 10.1038/s41746-018-0065-x.
MAlnajjar MK, Abu-Naser SS. 2022. Heart sounds analysis and classification for cardiovascular diseases diagnosis using deep learning.
Manogaran G, Varatharajan R, Priyan MK. 2018. Hybrid recommendation system for heart disease diagnosis based on multiple kernel learning with adaptive neuro-fuzzy inference system. Multimed Tools Appl. 77(4):4379–4399. doi: 10.1007/s11042-017-5515-y.
Mathew RC, Löffler AI, Salerno M. 2018. Role of cardiac magnetic resonance imaging in valvular heart disease: diagnosis, assessment, and management. Curr Cardiol Rep. 20(11):119. doi: 10.1007/s11886-018-1057-9.
Meeusen JW, Donato LJ, Bryant SC, Baudhuin LM, Berger PB, Jaffe AS. 2018. Plasma ceramides: a novel predictor of major adverse cardiovascular events after coronary angiography. Arterioscler Thromb Vasc Biol. 38(8):1933–1939. doi: 10.1161/ATVBAHA.118.311199.
Mehmood A, Iqbal M, Mehmood Z, Irtaza A, Nawaz M, Nazir T, Masood M. 2021. Prediction of heart disease using deep convolutional neural networks. Arab J Sci Eng. 46(4):3409–3422. doi: 10.1007/s13369-020-05105-1.
Meller CH, Grinenco S, Aiello H, Córdoba A, Sáenz-Tejeira MM, Marantz P, Otaño L. 2020. Congenital heart disease, prenatal diagnosis and management. Arch Argent Pediatr. 118(2):e149–e161.
Miao KH, Miao JH. 2018. Coronary heart disease diagnosis using deep neural networks. IJACSA. 9(10):1–8. doi: 10.14569/IJACSA.2018.091001.
Mienye ID, Sun Y, Wang Z. 2020. An improved ensemble learning approach for the prediction of heart disease risk. Inf Med Unlocked. 20:100402. doi: 10.1016/j.imu.2020.100402.
Modi BN, Sankaran S, Kim HJ, Ellis H, Rogers C, Taylor CA, Rajani R, Perera D. 2019. Predicting the physiological effect of revascularization in serially diseased coronary arteries: clinical validation of a novel CT coronary angiography–based technique. Circ Cardiovasc Interv. 12(2):e007577. doi: 10.1161/CIRCINTERVENTIONS.118.007577.
Mohi Ud Din Dar G, Bhagat A, Ansarullah SI, Othman MTB, Hamid Y, Alkahtani HK, Ullah I, Hamam H. 2023. A novel framework for classification of different

Alzheimer's disease stages using CNN model. Electronics. 12(2):469. doi: 10.3390/electronics12020469.
Nourmohammadi-Khiarak J, Feizi-Derakhshi M-R, Behrouzi K, Mazaheri S, Zamani-Harghalani Y, Tayebi RM. 2020. New hybrid method for heart disease diagnosis utilizing optimization algorithm in feature selection. Health Technol. 10(3):667–678. doi: 10.1007/s12553-019-00396-3.
Nunes MCP, Sable C, Nascimento BR, Lima EMd, da Silva JLP, Diamantino AC, Oliveira KKB, Okello E, Aliku T, Lwabi P, et al. 2019. Simplified echocardiography screening criteria for diagnosing and predicting progression of latent rheumatic heart disease. Circ Cardiovasc Imaging. 12(2):e007928. doi: 10.1161/CIRCIMAGING.118.007928.
Olsen CR, Mentz RJ, Anstrom KJ, Page D, Patel PA. 2020. Clinical applications of machine learning in the diagnosis, classification, and prediction of heart failure. Am Heart J. 229:1–17. doi: 10.1016/j.ahj.2020.07.009.
Pan Y, Fu M, Cheng B, Tao X, Guo J. 2020. Enhanced deep learning assisted convolutional neural network for heart disease prediction on the internet of medical things platform. IEEE Access. 8:189503–189512. doi: 10.1109/ACCESS.2020.3026214.
Pathan MS, Nag A, Pathan MM, Dev SJHA. 2022. Analyzing the impact of feature selection on the accuracy of heart disease prediction. Healthcare Analytics. 2: 100060. doi: 10.1016/j.health.2022.100060.
Rajdhan A, Agarwal A, Sai M, Ravi D, Ghuli P. 2020. Heart disease prediction using machine learning. Int J Res Technol. 9(04):659–662.
Ramalingam V, Dandapath A, Raja MK. 2018. Heart disease prediction using machine learning techniques: a survey. IJET. 7(2.8):684–687. doi: 10.14419/ijet.v7i2.8.10557.
Ramesh T, Lilhore UK, Poongodi M, Simaiya S, Kaur A, Hamdi M,. 2022. Predictive analysis of heart diseases with machine learning approaches. MJCS. 2022(1):132–148. doi: 10.22452/mjcs.sp2022no1.10.
Rao JN, Prasad DRS. 2021. An enhanced novel dynamic data processing (ENDDP) algorithm for predicting heart disease in machine learning. IJSRCSEIT. 7:94–104. doi: 10.32628/CSEIT206429.
Reddy NSC, Nee SS, Min LZ, Ying CX. 2019. Classification and feature selection approaches by machine learning techniques: heart disease prediction. Int J Innov Comput. 9(1). doi: 10.11113/ijic.v9n1.210.
Sarra RR, Dinar AM, Mohammed MA, Ghani MKA, Albahar MAJD. 2022. A robust framework for data generative and heart disease prediction based on efficient deep learning models. Diagnostics. 12(12):2899. doi: 10.3390/diagnostics12122899.
Seetharam K, Shrestha S, Sengupta PP. 2021. Cardiovascular imaging and intervention through the lens of artificial intelligence. Interv Cardiol. 16:e31. doi: 10.15420/icr.2020.04.
Shaker AM, Tantawi M, Shedeed HA, Tolba MF. 2020. Generalization of convolutional neural networks for ECG classification using generative adversarial networks. IEEE Access. 8:35592–35605. doi: 10.1109/ACCESS.2020.2974712.
Shorewala V. 2021. Early detection of coronary heart disease using ensemble techniques. Inf Med Unlocked. 26: 100655. doi: 10.1016/j.imu.2021.100655.
Siddique Ibrahim S, Sivabalakrishnan M. 2020. An evolutionary memetic weighted associative classification algorithm for heart disease prediction. In: Recent advances on memetic algorithms and its applications in image processing. Springer. Vol 873, p. 183–199. doi: 10.1007/978-981-15-1362-6_9.
Silverio A, Cavallo P, De Rosa R, Galasso G. 2019. Big health data and cardiovascular diseases: a challenge for research, an opportunity for clinical care. Front Med (Lausanne). 6:36. doi: 10.3389/fmed.2019.00036.
Soh DCK, Ng E, Jahmunah V, Oh SL, San Tan R, Acharya UR. 2020. Automated diagnostic tool for hypertension using convolutional neural network. Comput Biol Med. 126:103999. doi: 10.1016/j.compbiomed.2020.103999.
Sun W, Zeng N, He Y. 2019. Morphological arrhythmia automated diagnosis method using gray-level co-occurrence matrix enhanced convolutional neural network. IEEE Access. 7:67123–67129. doi: 10.1109/ACCESS.2019.2918361.
Tajfard M, Tavakoly Sany SB, Avan A, Latiff LA, Rahimi HR, Moohebati M, Hasanzadeh M, Ghazizadeh H, Esmaeily H, Doosti H, et al. 2019. Relationship between serum high sensitivity C-reactive protein with angiographic severity of coronary artery disease and traditional cardiovascular risk factors. J Cell Physiol. 234(7):10289–10299. doi: 10.1002/jcp.27945.
Terrada O, Hamida S, Cherradi B, Raihani A, Bouattane O. 2020. Supervised machine learning based medical diagnosis support system for prediction of patients with heart disease. Adv Sci Technol Eng. Syst J. 5(5):269–277. doi: 10.25046/aj050533.
Vallée A, Petruescu L, Kretz S, Safar ME, Blacher J. 2019. Added value of aortic pulse wave velocity index in a predictive diagnosis decision tree of coronary heart disease. Am J Hypertens. 32(4):375–383. doi: 10.1093/ajh/hpz004.
Velusamy D, Ramasamy K. 2021. Ensemble of heterogeneous classifiers for diagnosis and prediction of coronary artery disease with reduced feature subset. Comput Methods Programs Biomed. 198:105770. doi: 10.1016/j.cmpb.2020.105770.
Wang DD, Qian Z, Vukicevic M, Engelhardt S, Kheradvar A, Zhang C, Little SH, Verjans J, Comaniciu D, O'Neill WW, et al. 2021. 3D printing, computational modeling, and artificial intelligence for structural heart disease. JACC Cardiovasc Imaging. 14(1):41–60. doi: 10.1016/j.jcmg.2019.12.022.
Wang H, Shi H, Chen X, Zhao L, Huang Y, Liu C. 2020. An improved convolutional neural network based approach for automated heartbeat classification. J Med Syst. 44(2):35. doi: 10.1007/s10916-019-1511-2.
Wang Y, Mashock M, Tong Z, Mu X, Chen H, Zhou X, Zhang H, Zhao G, Liu B, Li X. 2020. Changing technologies of RNA sequencing and their applications in clinical oncology. Front Oncol. 10:447. doi: 10.3389/fonc.2020.00447.
Xiao B, Xu Y, Bi X, Zhang J, Ma X. 2020. Heart sounds classification using a novel 1-D convolutional neural network with extremely low parameter consumption. Neurocomputing. 392:153–159. doi: 10.1016/j.neucom.2018.09.101.
Yao Q, Wang R, Fan X, Liu J, Li Y. 2020. Multi-class arrhythmia detection from 12-lead varied-length ECG using attention-based time-incremental convolutional neural network. Information Fusion. 53:174–182. doi: 10.1016/j.inffus.2019.06.024.