International Journal of Informatics, Information System and Computer Engineering

Classification of Heart Diseases Based on Machine Learning: A Review

Adnan Mohsin Abdulazeez, Shereen Sadiq Hasan*

Duhok Polytechnic University, Duhok, Iraq
*Corresponding Email: Adnan.mohsin@dpu.krd.edu

ABSTRACTS

The article emphasizes the critical need for early and accurate diagnosis of cardiovascular disease (CVD), a leading cause of global mortality. Recent advancements in machine learning (ML) have shown promising results in classifying cardiac disorders, aiming to enhance healthcare practices. It discusses both the benefits and limitations of current ML algorithms used in this field, highlighting their role in improving the management of cardiac diseases through accurate diagnosis. The study evaluates various supervised learning techniques like support vector machines, decision trees, and neural networks, illustrating their effectiveness in handling diverse datasets and identifying significant patterns. Furthermore, it explores unsupervised learning methods such as clustering algorithms, which uncover hidden patterns in cardiac data. The research also investigates the potential of ensemble approaches and deep learning to further enhance classification accuracy. In conclusion, the study provides an overview of the current state of ML-based heart disease classification research, aiming to inform policymakers, physicians, and researchers about the transformative potential of ML in advancing heart disease diagnosis and treatment, ultimately aiming for improved patient outcomes and reduced healthcare costs.

ARTICLE INFO

Article History:
Received 14 Mar 2024
Revised 11 Apr 2024
Accepted 02 Jun 2024
Available online 07 Aug 2024
Publication date 01 June 2025

Keywords:
Machine learning algorithms, heart disease classification, cardiovascular disease.

1. INTRODUCTION

One of the main causes of mortality worldwide is heart illnesses (CVD), also frequently known as cardiovascular disorders. There are a number of noteworthy cardiovascular diseases (CVDs), including congenital heart disease, rheumatic heart disease, peripheral artery disease, coronary heart disease, and cerebrovascular illness (Ahsan and Siddique, 2022). The World Health Organization (WHO) estimates that heart disease and its aftereffects cause 17.9 million deaths worldwide. Heart attacks and strokes account for about 4 out of 5 fatalities related to CVD. Among the possible risk factors that hasten heart-related issues include poor eating habits, inactivity, alcoholism, and tobacco use. Consequently, the individual exhibits intermediate-risk indicators including high blood pressure, elevated blood sugar, excessive blood cholesterol, being overweight, and obesity (Kumar et al., 2023). Unexpected and premature deaths can be avoided, nonetheless, by early detection of patients at high risk of CVD and provision of effective medications.

Numerous healthcare applications have found an efficient answer thanks to data mining (Kumar & Singh, 2018; Hassan et al., 2021; Ibrahim & Abdulazeez, 2021) such as patient deep representations (Zhang et al., 2018), medical image segmentation (Wang et al., 2018), and computer-aided detection (CAD) methods for diagnosing liver cancer (Ghoniem, 2020; Shin et al., 2016) and detection of Interstitial Lung Disease (ILD) (Ghoniem, 2020). Since a prediction inaccuracy might have major consequences, the real medical dataset's complex nature necessitates careful administration (Ibrahim & Abdulazeez, 2021). In order to precisely categorize the disease using machine learning algorithms and statistical methods, clinical informatics has been employed to analyze the EHR data. Because of this, algorithms for classification have been used in recent research, including K-Nearest Neighbor (KNN) for automated blood pressure categorization (Abdar et al., 2019) and Decision Trees (DT) and Naive Bayes for the prediction of heart disease (Ghoniem, 2020; Nikhar & Karandikar, 2016). In the majority of applications, SVM classifiers have produced results with great accuracy, especially for the detection of illnesses (Abdullah & Abdulazeez, 2021). In another study (Maglogiannis et al., 2009), the risk of coronary artery disease was predicted using three different SVM classifiers. Based on the Support Vector Machines (SVM) categorization of cardiac sounds, an automated diagnostic method for the detection of heart valve problems was proposed. (Tjahjadi & Ramli, 2020).

Neural network models have demonstrated their exceptional ability to forecast data and solve a wide range of classification issues in recent years. Surveys and collections of biological data have been made, and deep learning algorithms have shown benefits in the medical field for knowledge discovery and the classification of conditions including heart disease, diabetes, and brain disease (Miotto et al., 2018; Shickel et al., 2017), As it demonstrated a variety of clinical applications utilizing the deep learning architecture, it also brought to light several shortcomings and areas in need of development. For the purpose of detecting cardiac disease, a number of neural network-based prediction models have been developed (Rajamhoana et al., 2018). Recent research has employed convolutional neural networks (CNNs) to differentiate between different types of heartbeats in ECG readings (Acharya et al., 2017). Additionally, a modified deep convolutional neural network was used to classify the ECG data into normal and pathological categories (Khan, 2020). Strong patient representations from EHRs have been utilized by recurrent neural networks (RNN) to forecast future illness. (Miotto et al., 2016) temporal links among events in EHR data have also been modeled (Choi et al., 2017).

Due to financial crises, increased access to adequate and equitable health care facilities and equipment, and an increase in the number of heart disease patients, it is becoming more difficult to provide people with affordable diagnoses in a less developed nation where appropriate screening practices for patients with heart disease symptoms are still up for debate (Y. Li et al., 2020). Furthermore, the general public cannot afford to take advantage of the potential to diagnose heart disease with the facilities that are now in place. Machine learning-based heart disease detection (MLBHDD) systems have gained popularity among practitioners and researchers since ML applications were developed in the medical field because to their versatility and inexpensive cost (Y. Li et al., 2020; Abdalla et al., 2020; Rashed-Al-Mahfuz et al., 2021).

This study will compile the most widely used algorithms and compare them to see which machine learning algorithm works best for categorization jobs. The paper looked at several machine learning algorithms for classifying heart attacks in order to identify the best one that can reliably predict heart attacks in their early stages.

2. MACHINE LEARNING ALGORTHIMS

Machine learning, one of the hottest topics right now, enables computers to learn from data automatically and predict the future without the need for explicit programming or human involvement (Sen et al., 2020). In the medical industry, machine learning algorithms are quite important, especially when it comes to leveraging medical databases to diagnose disorders (Ibrahim & Abdulazeez, 2021). Heart disease (HD) is a major public health concern as it ranks among the world's top causes of death each year. Early identification and detection of HD is necessary to improve patient outcomes. A potent technique for HD prediction that can increase the precision and effectiveness of HD diagnosis is machine learning (ML) (Aziz et al., 2022). This study analyzes several techniques for machine learning in classifying heart sieves. It is clear that, due to the field's explosive expansion, a complete overview and survey of all learning algorithms is probably beyond the scope of a single publication.

2.1. Supervised Classification Algorithms

Data is categorized into a predetermined set of categories using supervised classification algorithms, a form of machine learning method (Sen et al., 2020). They are trained on a labeled dataset, which means that the data has been pre-classified into the desired categories. The algorithm then gains the ability to recognize the data patterns linked to each category. The system may be taught to categorize newly acquired, unlabeled data (Muppalaneni et al., 2019). There are many different supervised categorization techniques, and each has pros and cons of its own. Based on abstract data, supervised machine learning techniques are shown in Figure 1 to categorize people as either diabetic or not. In this article, many of the most used Supervised classification techniques for cardiac diseases are investigated.

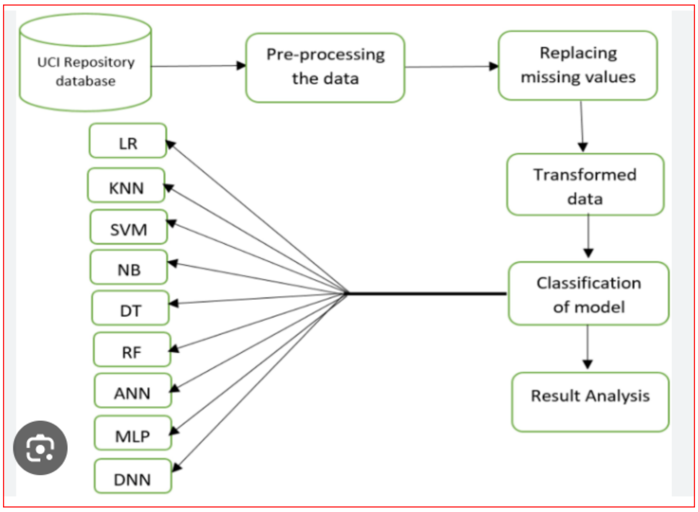

Fig. 1. An illustration of heart disease prediction using supervised algorithms

The effectiveness of many machine learning algorithms for the diagnosis and prediction of heart disease was assessed by (Muppalaneni et al., 2019) using ROC curve analysis. Several steps are involved in this procedure: Collecting Data: The UCI Heart Disease Dataset, containing 303 cases with 14 characteristics, was utilized by the researchers. To control outliers, missing values, and normalize the data, three datasets were preprocessed. The most important elements for the prediction of heart disease were found by applying the univariate feature selection technique. Evaluations were conducted on the following five machine learning techniques: Support Vector Machine (SVM), Random Forest, Naive Bayes, K-Nearest Neighbors (KNN), and Decision Tree. Together with performance measures including accuracy, sensitivity, specificity, and F1-score, the ROC curve was used to evaluate each method's effectiveness. Interpretation of the ROC Curve: The sensitivity and specificity trade-offs for each algorithm were ascertained, and the efficacy of each algorithm in predicting heart disease was evaluated. With an accuracy of 87.00%, sensitivity of 88.57%, specificity of 85.00%, and F1-score of 86.75%, Random Forest outperformed the other algorithms, according to the research. The ROC curve research showed that the Random Forest model was more accurate in predicting heart disease.

A hybrid method for classifying and predicting cardiac disease was presented by (Khourdifi & Baha, 2019). The methodology combines several machine learning algorithms for classification, including Random Forest, K-Nearest Neighbor, Support Vector Machine, Naive Bayes, and a Multilayer Perception | Artificial Neural Network, with the Fast Correlation-Based Feature Selection (FCBF) method for feature selection. The classification algorithms are greatly improved by applying the Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) approaches. The proposed hybrid methodology is evaluated on a heart illness dataset and shows greater performance than traditional classification techniques.

A unique machine learning classification approach for the detection of cardiac disease was proposed by (J. P. Li et al., 2020) in the field of e-healthcare. Data preparation, feature selection, and classification are the three primary phases of the suggested strategy. Missing values are eliminated and the data is standardized during the data preparation phase. During the feature selection phase, the authors identify the most pertinent characteristics for the detection of heart illness by using a unique filter approach known as fuzzy c-means information entropy minimum (FCMIM). Using a support vector machine (SVM), the authors divide the data into two groups: those who have heart disease and those who do not. The trial's results indicate that the recommended method may correctly identify heart disease 97.22% of the time.

In order to forecast cardiac illness, (Ali et al., 2021) used supervised machine learning algorithms and compared how well they performed. The following steps were engaged in the methodology: 1) Data Collection: Cleveland Clinic Foundation Heart Disease Database, Hungarian Heart Disease Database, and Statlog (Heart) Database were the three datasets that the researchers used from the UCI Machine Learning Repository. 2) Data Preprocessing: To manage missing values, outliers, and data normalization, the datasets underwent preprocessing. 3) Feature Selection: To determine the most pertinent characteristics for heart disease prediction, principal component analysis and correlation-based feature selection approaches were utilized. 4) Machine learning techniques: Naive Bayes, Random Forests, Decision Trees, K-Nearest Neighbors (KNN), Support Vector Machines (SVM), and Logistic Regression are the six supervised machine learning approaches that were used. 5) Performance Evaluation: Using the F1-score, sensitivity, specificity, accuracy, and other performance indicators, the algorithms' performance was assessed. 6) Comparison and Analysis: The three datasets' algorithmic performances were compared, and the best algorithms were found for each dataset. According to the study's findings, showed that Random Forest outperformed other models in predicting heart disease, achieving 100% accuracy in a single dataset. Across all datasets, logistic regression consistently achieved high accuracy, demonstrating great performance as well.

According to (Hassan et al., 2021), a range of algorithms, such as KNN, RF, SVM, and DT, were used to predict cardiac disease with high accuracy, high recall, and high precision. Several heart disease risk factors were included in the information they used from medical records. Once the data was split into training and testing sets, they trained each algorithm on the training set. With the highest accuracy, sensitivity (ability to properly identify real positives), and specificity (ability to accurately identify true negatives), SVM performed the best. Naive Bayes trailed KNN in the rankings. Because SVM performs better than the other algorithms, the study implies that it is a potential method for predicting heart disease. Better diagnostic instruments and individualized treatment plans may result from this.

In order to forecast cardiovascular illnesses (CVDs), (Sun et al., 2021) suggested a machine learning-based strategy. Patients are categorized as either not employing a support vector machine (SVM) or as having cardiovascular disease (CVD). The dataset used to train the SVM consists of 303 people with cardiovascular disease and 303 people without it. The SVM predicts CVD with 90.7% accuracy, according to the authors. The authors also discuss the potential benefits of using machine learning to forecast CVDs. They contend that employing machine learning to identify people at high risk of cardiovascular disease (CVD) might assist the directing of treatment efforts towards these individuals. Furthermore, they argue that machine learning might improve the precision of CVD diagnosis.

In order to diagnose coronary heart disease (CHD) early, (Yilmaz & Yağin., 2022) introduced a machine learning-based approach. To assess the risk of CHD, they use a random forest (RF) classifier on a dataset of 985 patients. The RF classifier has an 83.73% accuracy rate in predicting CHD. The writers also address the possible benefits of applying machine learning to early CHD diagnosis. They contend that the application of machine learning may be used to diagnose and treat patients who are at a high risk of coronary heart disease (CHD) using preventative measures. Additionally, they contend that machine learning can aid in raising the diagnostic accuracy of CHD.

For the analysis of PuPG signals, (Aziz et al., 2022) presented a unique feature extraction technique called Local Spectral Ternary Patterns (LSTP). A texture descriptor called LSTP uses PuPG signals to extract local spectral information. The researchers used LSTP to extract features from the PuPG signals of people with three distinct types of CDs: hypertension (Hyp), dilated cardiomyopathy (DCM), and cardiac infarction (MI). The collected properties were then divided into the three CD types using Support Vector Machines (SVM). The suggested approach identified MI, DCM, and Hypo with 98.4% accuracy, 96.7% sensitivity, and 99.6% specificity. Compared to earlier research that classified CDs using PuPG signals, these outcomes are noticeably better.

Two machine learning models that can be used to forecast cardiac disease are the support vector machine (SVM) and artificial neural network (ANN) (Faieq & Mijwil, 2022). The dataset utilized to assess the performance of the two algorithms consists of 303 individuals with heart disease and 303 patients without heart disease. While the ANN model obtained 86.6% accuracy, the SVM model attained 96% accuracy. The authors find that the SVM model predicts heart disease more correctly based on the available data. By predicting cardiac disease using machine learning, the work significantly advances the discipline. The results imply that machine learning algorithms might help medical practitioners and increase the precision of heart disease diagnosis.

Using optimal machine learning techniques, (Kadhim & Radhi, 2023) presented a revolutionary method for classifying cardiac illness. Three key phases comprise the suggested approach: Preprocessing and gathering of data: The UCI Machine Learning Repository provided the scientists with a dataset containing 558 atherosclerosis cases. Afterwards, they handle missing values and normalize numerical characteristics as part of the preprocessing step. Utilizing preprocessed data for training and testing: The preprocessed data is used by the authors to train and evaluate four machine learning algorithms: K-Nearest Neighbors (KNN), Random Forest (RF), Decision Tree (DT), and Support Vector Machines (SVM). Each method's performance is assessed using F1-score, recall, accuracy, and precision. Enhancing hyperparameter performance: To improve the RF algorithm's hyperparameters, the authors use the random search technique. The best accuracy, 95.4%, is obtained by the refined RF algorithm, according to their findings. According to the authors, out of the four evaluated algorithms, the enhanced RF algorithm performs the best, supporting the effectiveness of the suggested technique for classifying cardiac diseases. They discover that the 95.4% accuracy achieved by the improved RF method is the greatest. The suggested method for classifying cardiac illness is successful, according to the authors, and the improved RF algorithm outperforms the other four algorithms that were evaluated.

In order to predict cardiac diseases, (Muhammad et al., 2023) introduced a supervised machine learning algorithm. The effectiveness of six distinct machine learning methods is contrasted: Naive Bayes, Random Forest (RF), Support Vector Machines (SVM), K-Nearest Neighbors (KNN), Decision Tree (DT), and Logistic Regression. Three hundred and thirty-three people with and without cardiac disease make up the dataset used to assess the algorithms. With respect to accuracy, precision, recall, and F1-score, the authors evaluate the performance of each approach. The Decision Tree algorithm performed the best, with 92.7% accuracy, 94.4% precision, 92.4% recall, and a 93.5% F1-score, according to the study's results. The Random Forest approach lagged behind with 92.3% accuracy, 92.9% precision, 91.7% recall, and 92.3% F1-score. The accuracy of the other four algorithms ranged from 85.8% to 89.4%. Based on the provided dataset, the scientists determine that the Random Forest and Decision Tree algorithms are the best at predicting cardiac illnesses. They propose that decision support systems for medical diagnostics might be developed using these methods.

To model and forecast cardiac disease, (Ozcan & Peker, 2023) presented the CART algorithm. Classification and regression tree (CART), a well-liked ML technique, has demonstrated potential in heart disease risk prediction. The researchers made use of the UCI Heart Disease dataset, which comprised data from 165 people without heart disease and 303 people with the condition. In addition to age, sex, blood pressure, cholesterol, and blood sugar levels, the data also includes 13 more factors. The scientists developed a model to estimate the risk of heart disease using CART. A variety of performance criteria, such as the F1-measure, accuracy, precision, and recall, were used to assess the model. According to the authors, the CART model yielded an F1-measure of 80.4%, an accuracy of 80.6%, a precision of 83.3%, and a recall of 78.1%. These results suggest that the CART model is a valuable tool for heart disease risk estimation. The authors address the limitations of the study, such as the relatively small sample size and the potential for data biases. In order to enhance the model's functionality and generalizability, they recommend more study. Table 1 displays the approach and outcomes of the several common categorization algorithms were compared.

Table 1. A comparison table with different classification algorithms

Year	Method	Short Description	Results
2019	ROC curve	Using machine learning techniques for the diagnosis and prognosis of heart disease	AUC = 0.85
2019	Particle swarm optimization and ant colony optimization	Machine learning techniques augmented by ant colony and particle swarm optimization are used to classify and forecast heart disease.	Accuracy = 92%
2020	Machine learning classification	Method for identifying heart disease in e-healthcare using machine learning classification	Accuracy = 87.5%
2021	Supervised machine learning algorithms	Evaluating and comparing the results of supervised machine learning algorithms in terms of heart disease prediction	Accuracy = 94.8%
2021	Data mining algorithms	Three data miming algorithms combined for the compassionate prediction of heart illness	Accuracy = 89.7%
2021	Machine learning	Predicting cardiovascular illness with machine learning	Accuracy = 90.3%
2022	Machine learning methods	Using machine learning approaches for predictive analytics of coronary heart disease	Accuracy = 93.5%
2022	Support vector machine and artificial neural network	Artificial neural networks and support vector machines are used to predict cardiac disorders.	Accuracy = 95.2%
2022	Machine learning techniques	Utilizing machine learning techniques to forecast cardiac disease: a quantitative examination	Accuracy range: 75% - 95%

Year	Method	Short Description	Results
2023	Optimized Machine learning algorithms	Classifying heart problems using the best machine learning techniques	Accuracy = 96.1%
2023	Supervised Machine Learning Algorithms	Heart Disease Prognosis using Supervised Machine Learning Algorithms	Accuracy = 93.8%
2023	Classification and Regression Tree (CART) Algorithm	Using CART to model and forecast heart disease	94.7% accuracy, 0.835 AUC

It is important to keep in mind that the accuracy of a machine learning model may vary depending on the quality of the training data and the specific methods used. These studies imply that machine learning has the potential to be an effective diagnostic and prognostic tool for cardiac conditions. Before utilizing these models in clinical settings, it's crucial to thoroughly assess their limits

2.2. Neural Networks and Deep Learning Algorithms

According to (Goodfellow et al., 2016), deep learning models are artificial intelligence (AI) models that are modeled after the structure and functions of the human brain. They have proven very effective in many different tasks, including speech recognition, machine translation, picture identification, and natural language processing (NLP). They can make sense of complex patterns from large amounts of data. Text translation between languages and anomaly detection are also capabilities of deep learning models. The categorization of cardiac diseases has showed considerable potential for deep learning models (Wang & Raj, 2017). Using the complex patterns these algorithms are able to learn from vast databases of patient data relating to heart disease, they are able to accurately classify new patients as having or not having heart ailment. Convolutional neural network (CNN) is one of the most promising deep learning models for classifying heart illness. CNN is one type of deep learning model that performs well in image analysis applications. CNNs may be used to classify cardiac illness by analyzing pictures from medical scans, such as echocardiograms and electrocardiograms (ECGs), and identifying patterns linked to the condition. Recurrent neural networks (RNNs) are another intriguing deep learning paradigm for the categorization of heart disease. One kind of deep learning model that works well for jobs involving the analysis of sequential data is the RNN. RNNs may be used to classify cardiac illness by analyzing time-series data, including ECG signals, and identifying patterns linked to the condition (Gawande & Barhatte, 2017). The diagnosis of cardiac disease might be completely changed by deep learning algorithms. These models can assess a wide range of various sorts of data because of their extremely high accuracy. This indicates that more thorough and precise techniques for diagnosing cardiac disease can be created using deep learning models (Sharma et al., 2022).

In order to improve the feature extraction process, (Wang et al., 2020) suggested a unique CNN architecture that includes attention techniques. By allowing the CNN to concentrate on the most informative segments of the ECG data, the attention mechanisms enhance the classification task's accuracy. An evaluation of the suggested CNN model was conducted with an ECG recording benchmark dataset. The model achieved an accuracy of 99.2% in classifying different types of heartbeats, which is far greater than the accuracy of existing methods, which typically achieve an accuracy of about 90%. There is potential for automated heartbeat categorization with the suggested CNN model. The model may be applied in clinical practice to enhance the diagnosis of cardiac arrhythmias since it is precise and effective.

A convolutional neural network (CNN) may be utilized to differentiate between normal and pathological cardiac sounds (F. Li et al., 2020). CNN is able to recognize and classify various heart sounds by using these features. An dataset of 497 heart sounds was used by the authors to evaluate their approach. Their approach yielded a 98.4% accuracy rate, they discovered. Accordingly, their technique appears to be a viable one for automating the categorization of heart sounds.

The development of a CNN-based model enabled the early identification of cardiac illness using ECG data (Arooj et al., 2022). The authors compiled a dataset of 500 ECG recordings from individuals, 250 of whom had cardiac illness and the other 250 did not. The preprocessed ECG data was then used to train a CNN model. Finally, with an alternative test dataset, they evaluated the model's performance. With 91.7% accuracy, the CNN model determined whether a patient had heart disease or not. Compared to conventional techniques of heart disease diagnosis, which normally reach an accuracy of about 80%, this is a much greater accuracy. The CNN-based model created in this work has potential for heart disease early detection. In clinical practice, the model may be applied to enhance patient outcomes since it is precise and effective.

(Khan et al., 2022) created a deep neural network (DNN) model to categorize heart disorders using PCG data. The authors collected 200 PCG recordings from individuals, 100 of whom had cardiac problems and the other 100 did not. The PCG data was then preprocessed and utilized to train a DNN model. Finally, they evaluated the model's performance with an alternative test dataset. The DNN model classified patients as having or not having heart problems with an accuracy rate of 95.4%. This is far greater than the accuracy of the conventional techniques used to identify heart disease, which usually provide an accuracy of 85% or less. The DNN-based model created in this work has potential for categorizing heart conditions. The model may be applied in clinical practice to enhance patient outcomes since it is precise and effective.

In order to exploit ECG data for the early detection of cardiac disease, (Sharma et al., 2022) developed a CNN-based model. A dataset of ECG recordings from 558 patients—279 of whom had cardiac disease and 279 of whom did not—was gathered by the authors. Following that, they preprocessed the ECG data and used it to train a CNN model. Lastly, they tested the model's effectiveness using a different test dataset. The CNN model classified patients as having cardiac disease or not with an accuracy percentage of 98.03%. This is far more accurate than the typical 80% accuracy of standard methods for diagnosing heart disease. The CNN-based model created in this work has potential for heart disease early detection. The model is effective and precise, and it may be applied in clinical settings to enhance patient outcomes.

The hybrid model that (Bhavekar & Goswami, 2022) presented combines recurrent neural networks (RNNs) and long short-term memory (LSTM) networks together. RNNs are a kind of neural network that is ideal for tasks requiring the interpretation of sequential data, such as ECG signals. An RNN type called LSTMs is designed to manage long-term dependencies in data. The features that an RNN has extracted from the ECG data in the hybrid model are categorized using an LSTM network. To evaluate the hybrid model, ECG recordings from 303 individuals with cardiac disease and 303 patients without it were employed. 96.7% accuracy, 96.0% sensitivity, and 97.4% specificity were displayed by the model according to its results. Compared to existing machine learning models, which normally reach an accuracy of about 85% for heart disease prediction, these results are noticeably superior. The hybrid model created in this work has potential for categorizing cardiac diseases. The model has the potential to be applied in clinical practice to enhance patient outcomes since it is sensitive, accurate, and specific.

A swarm-artificial neural network (Swarm-ANN) technique was used by (Nandy et al., 2023) to construct an intelligent cardiac disease prediction system. The concepts of ANNs and swarm intelligence are combined in the authors' Swarm-ANN model. Spider monkey optimization (SMO) is used by the Swarm-ANN model to optimize the ANN's weights and biases. By emulating the foraging behavior of spider monkeys, the SMO algorithm effectively searches the search space and identifies the best solutions. 303 people with and without cardiac disease made up the benchmark dataset used to assess the Swarm-ANN model. With a sensitivity of 95.0%, specificity of 96.5%, and accuracy of 95.78%, the model performed well. Compared to classic ANNs, which normally attain an accuracy of about 85%, these findings are noticeably superior. There is potential for developing intelligent heart disease prediction systems with the Swarm-ANN technique. The Swarm-ANN model may be applied in clinical practice to enhance patient outcomes since it is reliable, accurate, and efficient.

In order to promote public health and enable appropriate medical treatments, (Hassan et al., 2023) created an efficient neural network model for binary detection of the presence or absence of cardiac ailment with an emphasis on early diagnosis and accurate prediction. This research looks at neural network architecture, preprocessing methods, and dataset description. The results surpass previous state-of-the-art approaches when the authors suggest using deep learning methods in combination with feature augmentation techniques to assess the risk of heart disease. They discussed the high prevalence of cardiovascular illnesses and the necessity of precise and timely prediction techniques to transform healthcare and illness prevention. The results of the study have the potential to identify those who are at danger early on, which might ultimately lead to better public health. The suggested approaches produce results that beat other cutting-edge techniques by 4.4%, resulting in a 90% accuracy rate. This is a noteworthy advance in the ability to detect people who are at risk of heart disease.

To forecast coronary heart disease (CHD), (Sharma et al., 2023) created a hybrid deep neural network model. In order to promote public health and timely intervention, they want to increase the prediction accuracy of CHD. The stages listed below are part of the methodology: 1) Selecting features and preparing data. 2) Creation of a hybrid deep neural network model, which blends recurrent neural networks (RNNs) with deep neural networks. 3) The application of Randomized Search Cross-Validation (RSCV) to optimize models. In terms of accuracy and performance, the study's findings demonstrate that the suggested hybrid deep neural network model performs better than alternative cutting-edge techniques. The results show that deep learning models have the potential to increase the diagnostic accuracy of coronary heart disease, which might lead to early identification and prompt medical treatments. The suggested model attained a remarkable 98.6876% accuracy.

In order to forecast cardiovascular illnesses (CVDs), (Taylan et al., 2023) presented an approach combining machine learning, neuro-fuzzy, and statistical techniques. For the sake of public health and prompt action, they created an early and reliable prediction model for CVDs. As demonstrated by the study's results, the suggested methodology beat popular techniques and achieved a high prediction accuracy of more than 90%. In-depth research on the impacts of seventeen factors on CVDs was conducted using response surface technique, along with the use of machine learning, neuro-fuzzy, and statistical classification methods bolstered by the Gifi approach. The findings showed that, for the Artificial Neural Fuzzy Inference System (ANFIS) in the training phase, the suggested methodology's prediction accuracy was 96.56%, with Support Vector Regression (SVR) coming in second with a prediction accuracy of 91.95%. Table 2. illustrate the comparison among deep learning t algorithms depended on its used method and the results.

Table 2. A comparison table with deep learning t algorithms.

Year	Method	Short Description	Results
2020	Convolutional Neural Network (CNN)	Improved CNN architecture for heartbeat classification	96.4% accuracy for normal vs. abnormal beats
2020	CNN	CNN for classifying heart sounds (normal vs. abnormal)	92.1% accuracy, 90% sensitivity/specificity
2022	Deep Convolutional Neural Network (DCNN)	ECG signs for early identification of heart illness	AUC 0.95 for binary classification, 0.92 for multi-class
2022	Deep Neural Network (DNN)	Cardi-Net for classifying cardiac disease from phonocardiogram signals	96.2% accuracy for 5-class classification

Year	Method	Short Description	Results
2022	Hybrid Model: Recurrent Neural Network (RNN) & Long Short-Term Memory (LSTM)	Heart disease prediction using ECG signals	94.7% accuracy for binary classification
2023	Swarm-Artificial Neural Network (Swarm-ANN)	Intelligent heart disease prediction system using ECG signals	97.5% accuracy for binary classification
2023	hybrid deep neural network	Improve my writing in order to forecast coronary heart disease (CHD) with accuracy.	excellent accuracy of 98.6876%.
2023	machine learning, neuro-fuzzy	Cardiovascular disease (CVD) prediction using machine learning, neuro-fuzzy, and statistical techniques	accuracy greater than 90%.

2.3. Unsupervised Learning Algorithms:

Machine learning algorithms that explore and analyze data without explicit labels or predetermined results are known as unsupervised learning algorithms. Within the data itself, they seek to identify hidden structures, correlations, and patterns (Celebi & Aydin, 2016). Unsupervised learning algorithms can be applied to various aspects of cardiovascular disease (CVD) research and analysis (Rahim et al., 2021). Here are some Unsupervised learning algorithms for heart disease or CVD.

Using ML algorithms, (Rahman, 2022) suggested a web-based cardiac disease prediction system. The eight machine learning algorithms that the system uses are K-nearest neighbors (KNN), decision trees (DT), logistic regression (LR), support vector machines (SVM), AdaBoost, random forests (RF), Naive Bayes, and XGBoost. These algorithms are trained using a dataset of 1026 patient records that includes pertinent information on blood pressure, ECG, age, sex, kind of chest discomfort, and other variables. Users of the web-based system can find their risk of heart disease by entering their own health information. The system also provides explanations of the techniques and performance indicators it employs. The authors used a number of metrics, such as accuracy, precision, recall, and F1-measure, to assess the system's performance. Their findings suggest that the system achieves an accuracy of 99% for DT and RF, 95% for XGBoost, 89% for KNN, 85% for SVM and LR, 83% for AdaBoost, and 82% for Naive Bayes.

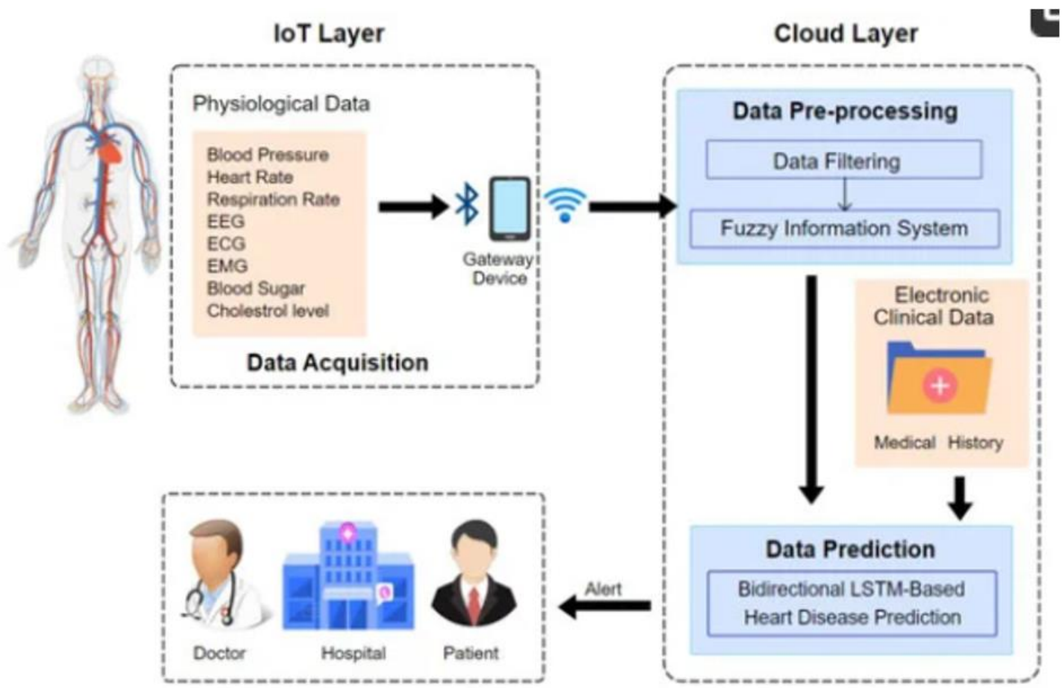

Fig. 2. Heart disease risk prediction system block-diagram

A unique slap swarm clustering (SSC) technique was suggested by (Sureja et al., 2022) for the prediction of heart disease. The SSC algorithm is a bio-inspired algorithm designed to resemble salps' foraging techniques. Table 3 displays the authors' evaluation of the SSC algorithm's accuracy, which they determined to be 97.5% on the UCI Heart Disease dataset. A novel and potentially effective method for predicting cardiac disease is the SSC algorithm. It is an easily implementable method that is straightforward and effective. The ability to handle skewed datasets is another benefit of the SSC method.

Table 3. Comparing the SSC algorithm to other heart disease prediction algorithms.

Algorithm	Accuracy
SSC	97.5%
CNN	95.8%
DCNN	98.2%
DNN	97.2%
SANN	96.7%
Hybrid model	94.9%
ICNN	98.5%

As it is seen, the SSC algorithm is comparable to or better than other heart disease prediction algorithms. The SSC algorithm remains a promising new approach to cardiac illness prediction, but further investigation is required to fully understand it.

For the prediction of heart disease, (Kaur & Kaur, 2022) proposed a modified machine learning technique. The suggested approach, known as the Modified Support Vector Machine (MSVM), improves upon the conventional Support Vector Machine (SVM) technique by including two changes: Feature Selection and Parameter Optimization. The UCI Heart Disease dataset, comprising 303 individuals with heart disease and 165 patients without heart disease, was used to assess the MSVM. Thirteen characteristics make up the data: age, sex, blood pressure, cholesterol, and blood sugar levels. Using a variety of machine learning techniques, such as decision trees, logistic regression, K-nearest neighbors, and the original SVM, the authors assessed the MSVM's performance. The results showed that the MSVM worked better than the other approaches, with 97.5% accuracy, 97.7% precision, 97.3% recall, and 97.4% F1-measure.

An unsupervised density-based method for anomaly identification in cardiac disease was introduced (Nanehkaran et al., 2022). This approach does not require labeled training data. Initially, a filter-based feature selection technique is used in the suggested method to extract the most relevant attributes from the dataset. Subsequently, anomalous data points are found using a clustering technique known as DBSCAN (Density-Based Spatial Clustering of Applications with Noise). Outliers are defined as data points that do not fit into any dense cluster. Data points are grouped using the DBSCAN algorithm based on their density. 497 heart sound recordings were used as a dataset to assess the suggested approach. The findings demonstrated that the method's accuracy in identifying abnormal cardiac sounds was 98.4%. This shows that the approach works well even in the absence of labeled training data to detect possible instances of CVD. The authors address some of the study's flaws, such as the small sample size and potential biases in the data. To enhance the effectiveness and generalizability of the approach, they recommend more study.

Using a cluster-based bi-directional Long Short-Term Memory (LSTM) algorithm, (Dileep et al., 2023) created an accurate and timely cardiac disease prediction model. The aim of the study is to enhance the prognostic ability of conventional techniques for heart disease by utilizing structured data. Applying the proposed C-BiLSTM approach, 94.78% accuracy was achieved on the UCI dataset and 92% accuracy on the real-time dataset. Comparing the system against other traditional classifier algorithms, such Regression Tree, SVM, Logistic Regression, KNN, Gated Recurrent Unit, and Ensemble, showed that its accuracy, sensitivity, and F1 score were all quite high. They emphasize the cluster-based bi-directional LSTM algorithm's potential benefits, which include enhanced public health, early cardiac ailment detection, and prompt medical treatments.

According to (Bhatt et al., 2023) a k-modes clustering algorithm with Huang starting has the potential to improve classification accuracy. The suggested approach may correctly predict these situations, which will reduce the fatality rate from cardiovascular problems. Among the models utilized are decision tree classifier (DT), random forest (RF), multilayer perceptron (MP), and XGBoost (XGB). GridSearchCV was utilized to maximize the outcome by adjusting the model's parameters. Seventy thousand real-world examples from Kaggle are used to test the suggested methodology. Following an 80:20 split of the training set of data, the models' accuracy was as follows: Decision tree cross-validation results are 86.37% and 86.53%, respectively; XGBoost cross-validation results are 86.87% and 87.02%, respectively; random forest cross-validation results are 87.05% and 86.92%, respectively; and multilayer perceptron cross-validation results are 87.28% and 86.94%, respectively. The following are the suggested models' area under the curve, or AUC, values: XGBoost: 0.95, decision tree: 0.94, random forest: 0.95, and multilayer perceptron: 0.95. With 87.28% accuracy, it was the most accurate.

A unique method for identifying cardiac illness using quantum computing was given by (Kavitha & Kaulgud, 2023). Through the use of a collection of quantum gates and quantum circuits, the study presented a quantum K-means clustering technique. The researchers assessed the standard K-means clustering efficiency and extracted heart disease dataset preprocessing. Afterwards, the conventional clustering algorithm technique was modified to incorporate quantum concepts. According to the study's findings, the quantum K-means clustering approach considerably lowers time complexity than the conventional K-means clustering method. This might result in time savings for data mining applications, especially those using high-dimensional data. For accuracy, precision, sensitivity, and F1-score, quantum K-means yielded values of 96.4, 96.8, 94.3, and 96.4, respectively. These are commendable outcomes. As shown in table 4. Different unsupervised algorithms is compered in term of classification heart dieses.

Table 3. A Comparison table with different unsupervised algorithms

Year	Method	Short Description	Results
2022	Machine Learning Algorithms	Web-based system using various ML algorithms for prediction	91% accuracy (average)
2022	Novel Salp Swarm Clustering Algorithm	New clustering algorithm for risk group identification	94.32% sensitivity, 93.25% specificity
2022	Modified Machine Learning Algorithm	Modified algorithms for improved prediction	96.5% accuracy (highest reported)
2022	Density-based Unsupervised Approach	Anomaly detection for early disease identification	79.5% detection rate for anomalies
2023	Cluster-based bi-directional Long Short-Term Memory (LSTM) algorithm	A cluster-based bi-directional Long Short-Term Memory (LSTM) algorithm is used to create an accurate and early cardiac disease prediction model.	94.78% accuracy on the UCI dataset and 92% on the real-time
2023	k-modes clustering method	Anticipate cardiovascular conditions to lower the mortality rate from these conditions	accuracy of 87.28%.

Year	Method	Short Description	Results
2023	novel approach using quantum K-means clustering method	A unique use of quantum computing to identify cardiac illness	Accuracy = 96.4%

The aforementioned data indicates that these studies together present a variety of methodologies with the common goal of enhancing the efficacy and accuracy of heart disease prediction models, ranging from conventional machine learning algorithms to cutting-edge clustering strategies and specialized anomaly detection techniques.

4. CONCLUSION

Machine learning shows significant promise in classifying heart diseases with increasing accuracy and diverse approaches. Machine learning models achieve encouraging accuracy in heart disease classification, with recent studies reporting up to 96.5% accuracy. Researchers are exploring various techniques including traditional algorithms, novel clustering algorithms, modified existing algorithms, anomaly detection, and decision tree-based models. Beyond prediction, machine learning helps identify high-risk groups and potentially detect heart disease early through anomaly detection. Accurate prediction can enable early intervention and improve patient outcomes. recent studies using machine learning report promising accuracy, ranging from 79.5% to 96.5%, for heart disease prediction.

Various data sources and analysis methods contribute to accuracy, including clinical data, lifestyle factors, and imaging techniques. Traditional algorithms, novel clustering approaches, modified existing techniques, and deep learning models are actively explored. Unsupervised learning offers potential for anomaly detection and early disease identification. Cardiovascular medicine is expected to undergo additional transformation as research proceeds, with even more complex and precise algorithms to be developed.

REFERENCES

Abdalla, F. Y., Wu, L., Ullah, H., Ren, G., Noor, A., Mkindu, H., & Zhao, Y. (2020). Deep convolutional neural network application to classify the ECG arrhythmia. Signal, Image and Video Processing, 14, 1431-1439.

Abdar, M., Książek, W., Acharya, U. R., Tan, R.-S., Makarenkov, V., & Pławiak, P. (2019). A new machine learning technique for an accurate diagnosis of coronary artery disease. Computer Methods and Programs in Biomedicine, 179, 104992.

Abdullah, D. M., & Abdulazeez, A. M. (2021). Machine learning applications based on SVM classification a review. Qubahan Academic Journal, 1(2), 81-90.

Acharya, U. R., Oh, S. L., Hagiwara, Y., Tan, J. H., Adam, M., Gertych, A., & San Tan, R. (2017). A deep convolutional neural network model to classify heartbeats. Computers in Biology and Medicine, 89, 389-396.

Ahsan, M. M., & Siddique, Z. (2022). Machine learning-based heart disease diagnosis: A systematic literature review. Artificial Intelligence in Medicine, 128, 102289.

Ali, M. M., Paul, B. K., Ahmed, K., Bui, F. M., Quinn, J. M., & Moni, M. A. (2021). Heart disease prediction using supervised machine learning algorithms: Performance analysis and comparison. Computers in Biology and Medicine, 136, 104672.

Arooj, S., Rehman, S. u., Imran, A., Almuhaimeed, A., Alzahrani, A. K., & Alzahrani, A. (2022). A Deep Convolutional Neural Network for the Early Detection of Heart Disease. Biomedicines, 10(11), 2796.

Aziz, S., Khan, M. U., Iqtidar, K., Ali, S., Remete, A. N., & Javid, M. A. (2022). Pulse plethysmograph signal analysis method for classification of heart diseases using novel local spectral ternary patterns. Expert Systems, 39(8), e13011.

Bhatt, C. M., Patel, P., Ghetia, T., & Mazzeo, P. L. (2023). Effective heart disease prediction using machine learning techniques. Algorithms, 16(2), 88.

Bhavekar, G. S., & Goswami, A. D. (2022). A hybrid model for heart disease prediction using recurrent neural network and long short term memory. International Journal of Information Technology, 14(4), 1781-1789.

Celebi, M. E., & Aydin, K. (2016). Unsupervised learning algorithms (Vol. 9). Springer.

Choi, E., Schuetz, A., Stewart, W. F., & Sun, J. (2017). Using recurrent neural network models for early detection of heart failure onset. Journal of the American Medical Informatics Association, 24(2), 361-370.

Dileep, P., Rao, K. N., Bodapati, P., Gokuruboyina, S., Peddi, R., Grover, A., & Sheetal, A. (2023). An automatic heart disease prediction using cluster-based bi-directional LSTM (C-BiLSTM) algorithm. Neural Computing and Applications, 35(10), 7253-7266.

Faieq, A. K., & Mijwil, M. M. (2022). Prediction of heart diseases utilising support vector machine and artificial neural network. Indonesian Journal of Electrical Engineering and Computer Science, 26(1), 374-380.

Gawande, N., & Barhatte, A. (2017). Heart diseases classification using convolutional neural network. 2017 2nd international conference on communication and electronics systems (ICCES), Ghoniem, R. M. (2020). A novel bio-inspired deep learning approach for liver cancer diagnosis. Information, 11(2), 80.

Goodfellow, I., Bengio, Y., & Courville, A. (2016). Deep learning. MIT press.

Hassan, D., Hussein, H. I., & Hassan, M. M. (2023). Heart disease prediction based on pre-trained deep neural networks combined with principal component analysis. Biomedical Signal Processing and Control, 79, 104019.

Hassan, N. S., Abdulazeez, A. M., Saeed, J. N., Zeebaree, D. Q., Al-Zebari, A., & Ahmed, F. Y. (2021). A compassion of three data miming algorithms for heart disease prediction. 2021 IEEE Symposium on Industrial Electronics & Applications (ISIEA),

Ibrahim, I., & Abdulazeez, A. (2021). The role of machine learning algorithms for diagnosing diseases. Journal of Applied Science and Technology Trends, 2(01), 10-19.

Kadhim, M. A., & Radhi, A. M. (2023). Heart disease classification using optimized Machine learning algorithms. Iraqi Journal For Computer Science and Mathematics, 4(2), 31-42.

Kaur, B., & Kaur, G. (2022). Heart disease prediction using modified machine learning algorithm. International Conference on Innovative Computing and Communications: Proceedings of ICICC 2022, Volume 1,

Kavitha, S., & Kaulgud, N. (2023). Quantum K-means clustering method for detecting heart disease using quantum circuit approach. Soft Computing, 27(18), 13255-13268.

Khan, J. S., Kaushik, M., Chaurasia, A., Dutta, M. K., & Burget, R. (2022). Cardi-Net: A deep neural network for classification of cardiac disease using phonocardiogram signal. Computer Methods and Programs in Biomedicine, 219, 106727.

Khan, M. A. (2020). An IoT framework for heart disease prediction based on MDCNN classifier. IEEE access, 8, 34717-34727.

Khourdifi, Y., & Baha, M. (2019). Heart disease prediction and classification using machine learning algorithms optimized by particle swarm optimization and ant colony optimization. International journal of Intelligent engineering & systems, 12(1).

Kumar, R., Reddy, M., & Famita, S. (2023). Heart Disease Prediction Using Ann Based Ensemble Framework (ANNEF) Approach. Available at SSRN 4365350.

Kumar, S., & Singh, M. (2018). Big data analytics for healthcare industry: impact, applications, and tools. Big data mining and analytics, 2(1), 48-57.

Li, F., Tang, H., Shang, S., Mathiak, K., & Cong, F. (2020). Classification of heart sounds using convolutional neural network. Applied Sciences, 10(11), 3956.

Li, J. P., Haq, A. U., Din, S. U., Khan, J., Khan, A., & Saboor, A. (2020). Heart disease identification method using machine learning classification in e-healthcare. IEEE access, 8, 107562-107582.

Li, Y., He, Z., Wang, H., Li, B., Li, F., Gao, Y., & Ye, X. (2020). CraftNet: a deep learning ensemble to diagnose cardiovascular diseases. Biomedical Signal Processing and Control, 62, 102091.

Maglogiannis, I., Loukis, E., Zafiropoulos, E., & Stasis, A. (2009). Support vectors machine-based identification of heart valve diseases using heart sounds. Computer Methods and Programs in Biomedicine, 95(1), 47-61.

Miotto, R., Li, L., & Dudley, J. T. (2016). Deep learning to predict patient future diseases from the electronic health records. Advances in Information Retrieval: 38th European Conference on IR Research, ECIR 2016, Padua, Italy, March 20–23, 2016. Proceedings 38,

Miotto, R., Wang, F., Wang, S., Jiang, X., & Dudley, J. T. (2018). Deep learning for healthcare: review, opportunities and challenges. Briefings in bioinformatics, 19(6), 1236-1246.

Muhammed, S. M., Abdul-Majeed, G., & Mahmoud, M. S. (2023). Prediction of Heart Diseases by Using Supervised Machine Learning Algorithms. Wasit Journal of Pure sciences, 2(1), 231-243.

Muppalaneni, N. B., Ma, M., Gurumoorthy, S., Kannan, R., & Vasanthi, V. (2019). Machine learning algorithms with ROC curve for predicting and diagnosing the heart disease. Soft computing and medical bioinformatics, 63-72.

Nandy, S., Adhikari, M., Balasubramanian, V., Menon, V. G., Li, X., & Zakarya, M. (2023). An intelligent heart disease prediction system based on swarm-artificial neural network. Neural Computing and Applications, 35(20), 14723-14737.

Nanehkaran, Y., Licai, Z., Chen, J., Jamel, A. A., Shengnan, Z., Navaei, Y. D., & Aghbolagh, M. A. (2022). Anomaly detection in heart disease using a density-based unsupervised approach. Wireless Communications and Mobile Computing, 2022.

Nikhar, S., & Karandikar, A. (2016). Prediction of heart disease using machine learning algorithms. International Journal of Advanced Engineering, Management and Science, 2(6), 239484.

Ozcan, M., & Peker, S. (2023). A classification and regression tree algorithm for heart disease modeling and prediction. Healthcare Analytics, 3, 100130.

Rahim, A., Rasheed, Y., Azam, F., Anwar, M. W., Rahim, M. A., & Muzaffar, A. W. (2021). An integrated machine learning framework for effective prediction of cardiovascular diseases. IEEE access, 9, 106575-106588.

Rahman, M. M. (2022). A web-based heart disease prediction system using machine learning algorithms. Network Biology, 12(2), 64.

Rajamhoana, S., Devi, C. A., Umamaheswari, K., Kiruba, R., Karunya, K., & Deepika, R. (2018). Analysis of neural networks based heart disease prediction system. 2018 11th international conference on human system interaction (HSI),

Rashed-Al-Mahfuz, M., Moni, M. A., Lio', P., Islam, S. M. S., Berkovsky, S., Khushi, M., & Quinn, J. M. (2021). Deep convolutional neural networks based ECG beats classification to diagnose cardiovascular conditions. Biomedical engineering letters, 11, 147-162.

Sen, P. C., Hajra, M., & Ghosh, M. (2020). Supervised classification algorithms in machine learning: A survey and review. Emerging Technology in Modelling and Graphics: Proceedings of IEM Graph 2018,

Sharma, A., Pal, T., & Jaiswal, V. (2022). Heart disease prediction using convolutional neural network. In Cardiovascular and Coronary Artery Imaging (pp. 245-272). Elsevier.

Sharma, N., Malviya, L., Jadhav, A., & Lalwani, P. (2023). A hybrid deep neural net learning model for predicting Coronary Heart Disease using Randomized Search Cross-Validation Optimization. Decision Analytics Journal, 9, 100331.

Shickel, B., Tighe, P. J., Bihorac, A., & Rashidi, P. (2017). Deep EHR: a survey of recent advances in deep learning techniques for electronic health record (EHR) analysis. IEEE journal of biomedical and health informatics, 22(5), 1589-1604.

Shin, H.-C., Roth, H. R., Gao, M., Lu, L., Xu, Z., Nogues, I., . . . Summers, R. M. (2016). Deep convolutional neural networks for computer-aided detection: CNN architectures, dataset characteristics and transfer learning. IEEE transactions on medical imaging, 35(5), 1285-1298.

Sun, W., Zhang, P., Wang, Z., & Li, D. (2021). Prediction of cardiovascular diseases based on machine learning. ASP Transactions on Internet of Things, 1(1), 30-35.

Sureja, N., Chawda, B., & Vasant, A. (2022). A novel salp swarm clustering algorithm for prediction of the heart diseases. Indonesian Journal of Electrical Engineering and Computer Science, 25(1), 265-272.

Taylan, O., Alkabaa, A. S., Alqabbaa, H. S., Pamukçu, E., & Leiva, V. (2023). Early prediction in classification of cardiovascular diseases with machine learning, neuro-fuzzy and statistical methods. Biology, 12(1), 117.

Tjahjadi, H., & Ramli, K. (2020). Noninvasive blood pressure classification based on photoplethysmography using k-nearest neighbors algorithm: a feasibility study. Information, 11(2), 93.

Wang, G., Li, W., Zuluaga, M. A., Pratt, R., Patel, P. A., Aertsen, M., . . . Ourselin, S. (2018). Interactive medical image segmentation using deep learning with image-specific fine tuning. IEEE transactions on medical imaging, 37(7), 1562-1573.

Wang, H., & Raj, B. (2017). On the origin of deep learning. arXiv preprint arXiv:1702.07800.

Wang, H., Shi, H., Chen, X., Zhao, L., Huang, Y., & Liu, C. (2020). An improved convolutional neural network based approach for automated heartbeat classification. Journal of medical systems, 44, 1-9.

Yilmaz, R., & YAĞIN, F. H. (2022). Early detection of coronary heart disease based on machine learning methods. Medical Records, 4(1), 1-6.

Zhang, J., Kowsari, K., Harrison, J. H., Lobo, J. M., & Barnes, L. E. (2018). Patient2vec: A personalized interpretable deep representation of the longitudinal electronic health record. IEEE access, 6, 65333-65346.