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Cardiovascular Disease Prediction for Clinical Data using Deep Learning Technique

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Abstract: Cardiovascular diseases (CVDs) are among the leading causes of mortality worldwide, creating a significant challenge for modern healthcare systems. Early and accurate prediction of cardiovascular diseases is essential for improving clinical decision-making, enabling timely medical intervention, and reducing the risk of severe complications. In recent years, Deep Learning (DL) techniques have gained considerable attention in healthcare analytics due to their ability to automatically extract complex patterns, identify hidden relationships, and learn meaningful representations from large-scale clinical datasets. This review paper presents a comprehensive analysis of various deep learning techniques employed for cardiovascular disease prediction using clinical data. It explores the applications of different architectures, including Artificial Neural Networks (ANN), Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), Long Short-Term Memory (LSTM), and hybrid deep learning models for identifying cardiovascular risk factors and predicting disease occurrence. Furthermore, the review examines important clinical parameters such as age, gender, blood pressure, cholesterol level, blood glucose, heart rate, body mass index, and electrocardiogram (ECG) measurements. Key preprocessing techniques, including data normalization, missing-value handling, feature selection, and class balancing, are also discussed to improve prediction reliability. The performance of existing approaches is critically evaluated using standard assessment metrics, including accuracy, precision, recall, F1-score, sensitivity, specificity, and Area Under the Receiver Operating Characteristic Curve (AUC-ROC). Additionally, this review highlights major research challenges associated with data imbalance, limited clinical datasets, model interpretability, computational complexity, privacy, and generalization across diverse patient populations. Finally, potential future research directions are identified, emphasizing explainable artificial intelligence, attention-based deep learning, multimodal clinical data integration, and privacy-preserving learning approaches. This review aims to provide valuable insights into the development of reliable, interpretable, and clinically applicable deep learning-based cardiovascular disease prediction systems.

Keywords: Cardiovascular Disease Prediction, Clinical Data, Deep Learning, Artificial Neural Network, CNN, LSTM, Healthcare Analytics, Explainable Artificial Intelligence, Risk Prediction.

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I. INTRODUCTION

Cardiovascular diseases (CVDs) represent one of the most significant global public health challenges and are among the leading causes of morbidity and mortality worldwide. Cardiovascular diseases include several disorders affecting the heart and blood vessels, such as coronary artery disease, myocardial infarction, heart failure, arrhythmia, hypertension-related heart disease, and stroke. According to the World Health Organization (WHO), cardiovascular diseases account for approximately 17.9 million deaths annually, representing a substantial proportion of global mortality. The increasing prevalence of cardiovascular diseases is associated with several risk factors, including unhealthy dietary habits, physical inactivity, obesity, smoking, excessive alcohol consumption, diabetes mellitus, hypertension, and elevated cholesterol levels. Furthermore, demographic changes, population aging, urbanization, and lifestyle modifications have contributed to the growing burden of cardiovascular disorders. Therefore, early detection, accurate risk assessment, and timely clinical intervention are essential for reducing cardiovascular-related complications and improving patient survival rates [1, 2].

Traditional cardiovascular disease diagnosis and risk assessment primarily depend on clinical examinations, laboratory investigations, electrocardiogram (ECG) measurements, medical imaging, and established statistical risk prediction models. Healthcare professionals generally evaluate several clinical parameters, including patient age, gender, resting blood pressure, serum cholesterol, fasting blood glucose, maximum heart rate, chest pain characteristics, and family medical history, to determine the probability of cardiovascular abnormalities. Although conventional diagnostic methods are widely implemented in healthcare institutions, they may encounter limitations when analyzing complex relationships among multiple clinical variables. Furthermore, traditional statistical prediction approaches often rely on predefined assumptions and manually selected risk factors, which may limit their ability to capture nonlinear interactions and complicated patterns within heterogeneous clinical datasets. Consequently, intelligent computational techniques have attracted considerable research interest as complementary tools for supporting cardiovascular disease prediction and clinical decision-making [3].

Deep Learning (DL), an advanced subfield of machine learning, has gained considerable attention due to its ability to learn hierarchical feature representations directly from data. Deep learning architectures employ multiple computational layers to transform input information into increasingly abstract representations, enabling the identification of complex relationships that may not be easily captured by traditional statistical methods. In cardiovascular disease prediction, deep learning models can process structured clinical attributes, physiological signals, electronic health records, and medical imaging information to support disease classification and risk estimation. Commonly investigated deep learning architectures include Artificial Neural Networks (ANN),

Deep Neural Networks (DNN), Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), Long Short-Term Memory (LSTM) networks, Gated Recurrent Units (GRU), and hybrid deep learning frameworks. These techniques offer different advantages depending on the structure, complexity, and temporal characteristics of the available clinical data [4, 5].

Artificial Neural Networks and Deep Neural Networks are widely investigated for cardiovascular disease prediction using structured clinical datasets. These architectures consist of interconnected computational neurons organized into input, hidden, and output layers. During model training, network parameters are optimized to minimize prediction errors and identify relationships between cardiovascular risk factors and disease outcomes. Clinical features such as age, blood pressure, cholesterol concentration, glucose level, heart rate, and other patient characteristics can be supplied as input variables to estimate cardiovascular disease risk. CNN architectures, although primarily developed for image processing, have also been explored for extracting meaningful patterns from ECG signals and other physiological measurements. However, their effectiveness for ordinary tabular clinical data depends on the selected representation and network design. Similarly, RNN, LSTM, and GRU architectures are particularly relevant for sequential clinical information, including longitudinal electronic health records, repeated physiological measurements, and time-dependent patient monitoring data. These models can capture temporal dependencies that may be important for identifying changes in cardiovascular health over time [6, 7].

The availability of clinical datasets has played an important role in advancing research on intelligent cardiovascular disease prediction systems. Publicly accessible datasets, including the UCI Heart Disease dataset and other cardiovascular risk datasets, have frequently been employed for developing and evaluating machine learning and deep learning algorithms. These datasets contain clinical attributes associated with cardiovascular conditions and provide useful resources for comparing predictive approaches [8]. Nevertheless, clinical datasets often contain missing values, inconsistent measurements, irrelevant attributes, class imbalance, and variations in patient characteristics. Such issues can significantly influence model performance and reliability. Therefore, appropriate data preprocessing techniques, including missing-value imputation, categorical encoding, feature normalization, feature selection, and class imbalance management, are important components of cardiovascular disease prediction frameworks. Furthermore, careful training, validation, and testing procedures are required to prevent data leakage, overfitting, and misleading performance estimates [9, 10].

Recent research directions have increasingly emphasized the development of hybrid, explainable, and computationally efficient deep learning architectures for cardiovascular risk assessment. Hybrid frameworks may combine neural networks with feature selection methods, optimization algorithms, or ensemble learning strategies to improve predictive performance. Attention-based

architectures and Transformer models are also being investigated for analyzing complex relationships within longitudinal clinical records. Furthermore, federated learning offers a potential approach for training models across multiple healthcare institutions without requiring centralized collection of raw patient data, although it does not eliminate all privacy and security risks. Transfer learning, self-supervised learning, uncertainty quantification, and multimodal data integration represent additional opportunities for improving the adaptability and reliability of cardiovascular prediction systems. However, the effectiveness of these approaches must be established through rigorous comparisons, external validation, and clinically meaningful evaluation [11].

Several research studies have explored the application of deep learning architectures for cardiovascular disease prediction; however, differences in dataset characteristics, preprocessing methods, experimental designs, model architectures, and evaluation procedures make direct comparisons challenging. Some studies emphasize improvements in classification accuracy, while others investigate feature extraction, computational efficiency, model interpretability, or clinical applicability. Furthermore, the use of different validation strategies, including random train-test splitting, k-fold cross-validation, and external testing, can produce substantial differences in reported results. Consequently, there is a need for a systematic and critical review that examines existing deep learning approaches, identifies their methodological strengths and limitations, and highlights unresolved research challenges in cardiovascular disease prediction using clinical data [12, 13].

II. LITERATURE REVIEW

Zayed et al. [1] proposed a hybrid metaheuristic optimization and machine learning framework for cardiovascular disease prediction in smart healthcare systems. The study focused on improving the predictive performance of conventional machine learning algorithms by incorporating optimization-based feature selection techniques. The proposed framework aimed to identify the most informative clinical and lifestyle attributes while eliminating irrelevant, redundant, and noisy features from cardiovascular datasets. Metaheuristic optimization was integrated with machine learning classifiers to improve classification effectiveness, reduce computational complexity, and enhance the interpretability of the prediction process. The study highlighted the importance of selecting relevant patient attributes for early cardiovascular risk identification and intelligent clinical decision support. The proposed framework demonstrated the potential of combining optimization algorithms with machine learning for developing efficient cardiovascular disease prediction systems.

Al-Shammari et al. [2] introduced a Grey Wolf Optimization (GWO)-based neural network with hybrid feature extraction for heart disease prediction. The proposed methodology integrated Support Vector Machine (SVM) and one-dimensional Convolutional Neural Network (1D-CNN) techniques to extract complementary features from clinical datasets. The extracted features were combined and supplied to an Artificial Neural Network (ANN) for cardiovascular disease classification. Furthermore, the GWO algorithm was employed to optimize important ANN parameters, including channel size, dropout rate, and learning rate, using stratified five-fold cross-validation. The experimental evaluation was performed using four UCI heart disease datasets, namely Cleveland, Hungarian, Switzerland, and VA Long Beach. The proposed SVM–CNN+ANN-GWO model achieved classification accuracies of 91.80%, 91.53%, 96.08%, and 87.69%, respectively. The findings demonstrated that hybrid feature extraction combined with metaheuristic optimization can improve prediction performance and model generalization across different clinical datasets.

Sarker et al. [3] presented an explainable multimodal deep learning framework for cardiovascular disease prediction using heterogeneous clinical data. The proposed approach addressed the limitations of conventional cardiovascular risk assessment models by integrating multiple sources of medical information, including Electronic Health Records (EHR), laboratory measurements, Electrocardiogram (ECG) signals, medical imaging, and lifestyle-related parameters. The framework employed modality-specific encoders to extract meaningful representations from structured and unstructured clinical information, followed by a feature fusion mechanism to capture relationships among different data modalities. Additionally, Explainable Artificial Intelligence (XAI) techniques, including SHapley Additive exPlanations (SHAP) and Gradient-weighted Class Activation Mapping (Grad-CAM), were incorporated to identify clinically relevant features and improve model transparency. The study reported an AUC of 0.93, sensitivity of 0.90, and specificity of 0.88 using a dataset containing more than 10,000 patients. The findings indicated that multimodal learning and explainability can support more transparent and comprehensive cardiovascular disease prediction.

Kumar et al. [4] developed a clustering-based Binary Grey Wolf Optimization (BGWO) model integrated with a six-layer Deep Convolutional Neural Network (6LDCNNet) for cardiovascular disease prediction using patient clinical data. The proposed methodology consisted of two major stages: feature selection and deep learning-based classification. Initially, the BGWO algorithm was employed to identify and group important clinical attributes while reducing irrelevant information and computational complexity. Subsequently, the selected features were provided to the 6LDCNNet architecture for extracting hierarchical representations and classifying cardiovascular conditions. The Improved Sailfish Optimization Algorithm (ISFOA) was also

utilized to optimize important network hyperparameters, including learning rate, filter size, and dropout rate. The experimental results demonstrated that the proposed model achieved 96.12% accuracy on clinical data and 98.09% accuracy on echocardiogram imaging data. These findings highlighted the effectiveness of combining metaheuristic feature optimization with deep convolutional neural networks for improving cardiovascular disease classification.

Narasimhan and Victor [5] proposed a hybrid machine learning framework combining metaheuristic optimization algorithms with Random Forest (RF) for improving heart disease prediction. The study investigated the effectiveness of Genetic Algorithm Optimization (GAO), Particle Swarm Optimization (PSO), and Ant Colony Optimization (ACO) for selecting relevant clinical features from the Cleveland Heart Disease dataset. Initially, the SelectKBest feature selection technique was employed using Chi-square, Mutual Information, and F-statistics to identify important attributes. Subsequently, the selected feature subsets obtained through different optimization algorithms were supplied to the Random Forest classifier for cardiovascular disease classification. The experimental results indicated that Genetic Algorithm Optimized Random Forest (GAORF) achieved the highest accuracy of 92%, outperforming PSO-RF and ACO-RF, which achieved 91.8% and 86.88%, respectively. The study demonstrated that metaheuristic-based feature selection can improve the performance of conventional machine learning classifiers and contribute to more effective heart disease prediction.

Sowmiya et al. [6] introduced an optimized heart disease prediction model using metaheuristic feature selection based on an Improved Binary Salp Swarm Algorithm (BSSA) and a stacking classifier. The proposed approach addressed the challenges of irrelevant clinical features and reduced classification performance by integrating an enhanced optimization mechanism with ensemble learning. The improved BSSA incorporated the Wolf Optimizer and opposition-based learning to identify an optimal subset of cardiovascular risk attributes. Furthermore, a two-level stacking classifier was developed, consisting of multiple heterogeneous base classifiers at the first level and a meta-learner at the second level to improve classification reliability. The proposed BSSA-based stacking model achieved 95% accuracy, 92% sensitivity, 97% specificity, 96% precision, and an F1-score of 95%. The model also achieved 87.46% accuracy during validation on larger datasets. The findings indicated that combining optimized feature selection with ensemble classification can improve cardiovascular prediction performance and reduce false-positive and false-negative classifications.

Xia et al. [7] proposed an Intelligent Cardiovascular Disease Diagnosis model based on Ant Colony Optimization with Enhanced Deep Learning (ICVD-ACOEDL) for improving cardiovascular disease classification. The proposed framework integrated data preprocessing, feature selection, and deep learning-based classification to enhance predictive performance.

Initially, Min-Max normalization was applied to standardize the clinical dataset. Subsequently, Ant Colony Optimization (ACO) was utilized to select the most relevant clinical attributes, reducing redundant information and improving the quality of input features. A Deep Learning Enhanced Neural Network (DLENN) was then employed for cardiovascular disease classification, while Bayesian Optimization was incorporated to determine suitable hyperparameters for the neural network. The experimental evaluation demonstrated that the proposed ICVD-ACOEDL model achieved a reported classification accuracy of 99.71%, outperforming several conventional machine learning approaches considered in the study. The research highlighted the importance of integrating bio-inspired optimization algorithms with deep learning architectures for developing accurate and efficient cardiovascular disease prediction systems.

Subramani et al. [8] investigated cardiovascular disease prediction by incorporating machine learning techniques with deep learning approaches. The study emphasized the importance of intelligent healthcare technologies and Internet of Things (IoT)-based monitoring systems for analysing patient health information and identifying cardiovascular risk conditions. Different machine learning classification algorithms were investigated to improve predictive performance by analysing clinical and cardiovascular datasets. The proposed approach combined the Heart Disease dataset with multiple classification models and evaluated their effectiveness using different performance measures. The experimental findings reported approximately 96% prediction accuracy, demonstrating the potential of integrating machine learning and deep learning approaches for cardiovascular disease identification. The authors also highlighted the importance of collecting larger clinical datasets from multiple healthcare institutions to develop more reliable artificial neural network architectures. The study provided a foundation for integrating intelligent computational models with IoT-enabled healthcare systems for early cardiovascular disease prediction and continuous patient monitoring.

III. CARDIOVASCULAR DISEASE

Cardiovascular Disease (CVD) refers to a group of disorders that affect the heart and blood vessels, causing abnormalities in the normal functioning of the cardiovascular system. It is one of the major causes of mortality worldwide and is commonly associated with risk factors such as high blood pressure, elevated cholesterol, diabetes, obesity, smoking, physical inactivity, unhealthy dietary habits, and genetic factors. Cardiovascular diseases include coronary artery disease, heart failure, heart attack (myocardial infarction), stroke, arrhythmia, and peripheral arterial disease. These conditions may develop gradually due to the accumulation of fatty deposits (plaque) inside the arteries, a process known as atherosclerosis, which restricts normal blood circulation and reduces the supply of oxygen to vital organs. Clinical parameters such as age, gender, blood pressure,

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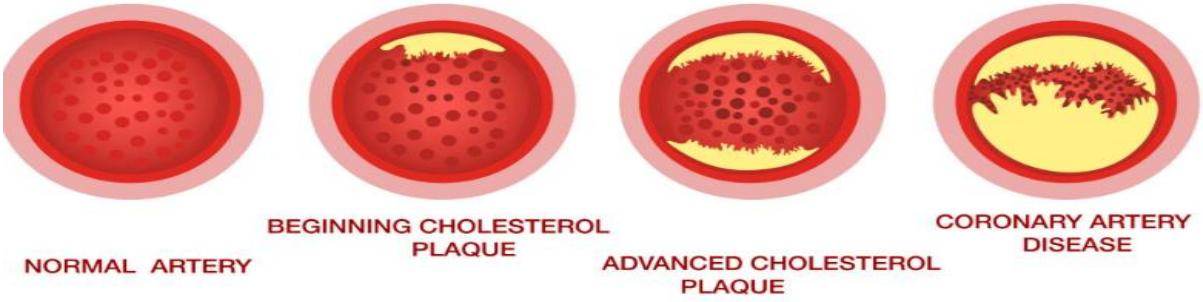
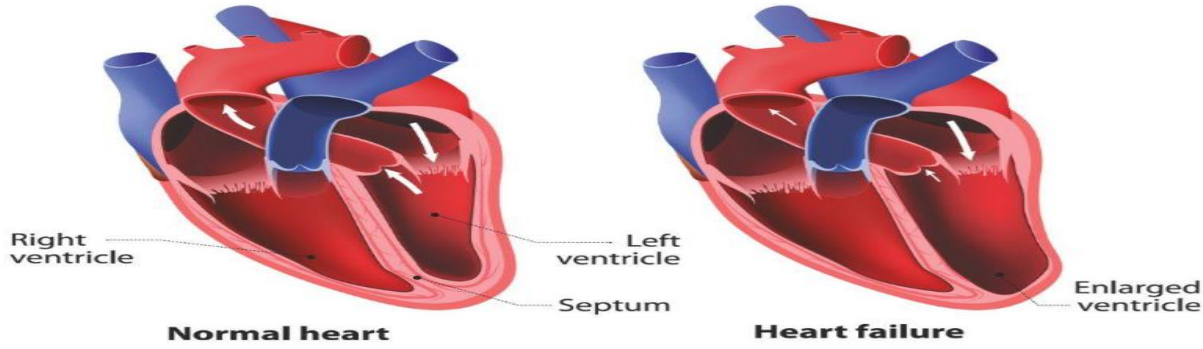
cholesterol level, blood glucose, heart rate, body mass index (BMI), and ECG measurements play an important role in assessing cardiovascular health. Early detection and prediction of cardiovascular diseases are essential for preventing serious complications and improving patient outcomes. In recent years, Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL) techniques have been increasingly used to analyse clinical data, identify hidden patterns, evaluate cardiovascular risk factors, and develop intelligent prediction systems for supporting early diagnosis and clinical decision-making.

3.1 Types of Cardiovascular Diseases

Coronary Artery Disease (CAD): Occurs when plaque accumulates inside coronary arteries, reducing blood supply to the heart muscle.



Heart Failure: A condition in which the heart cannot pump blood efficiently enough to meet the body's requirements.



Myocardial Infarction (Heart Attack): Occurs when blood flow to a portion of the heart muscle becomes severely blocked.

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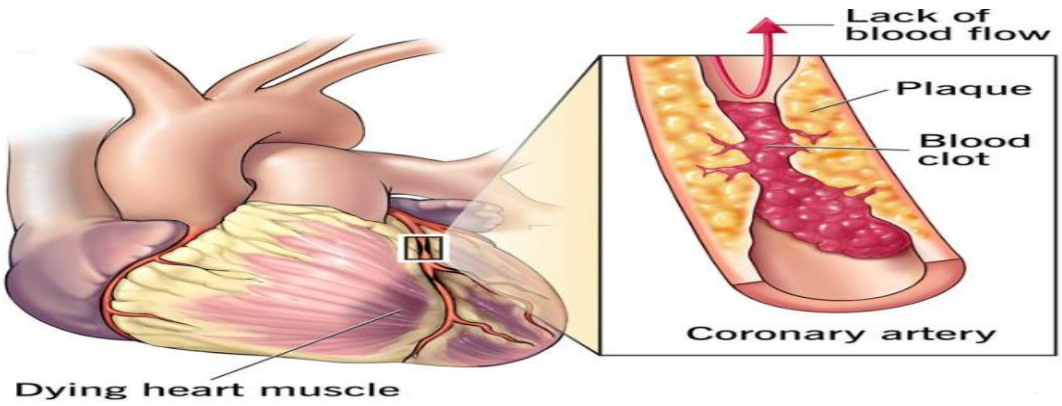
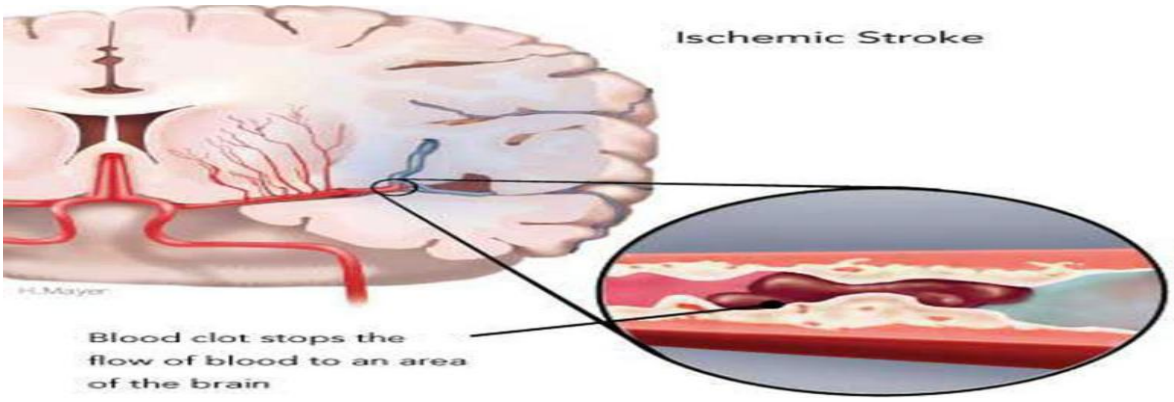


Stroke: Occurs when blood supply to a part of the brain is interrupted or a blood vessel ruptures.



IV. DEEP LEARNING

Deep Learning (DL) is an advanced subfield of Artificial Intelligence (AI) and Machine Learning (ML) that uses multi-layered artificial neural networks to automatically learn complex patterns and relationships from large amounts of data. It is inspired by the structure and functioning of the human brain, where interconnected artificial neurons process information through multiple computational layers. Deep learning models can automatically extract important features from raw data without requiring extensive manual feature engineering. These models consist of three major layers: the input layer, hidden layers, and output layer. The input layer receives information, such as clinical patient records, blood pressure, cholesterol levels, glucose measurements, and ECG signals. The hidden layers perform feature extraction, transformation, and nonlinear learning using activation functions such as ReLU, Sigmoid, and Tanh. Finally, the output layer generates the prediction or classification result. In cardiovascular disease prediction, deep learning techniques such as Artificial Neural Networks (ANN), Deep Neural Networks (DNN), Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), and Long Short-Term Memory (LSTM) are

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used to analyse clinical information, identify hidden cardiovascular risk patterns, and predict the possibility of disease occurrence. These techniques can support early disease identification, improve predictive modelling, and assist healthcare professionals in clinical decision-making.

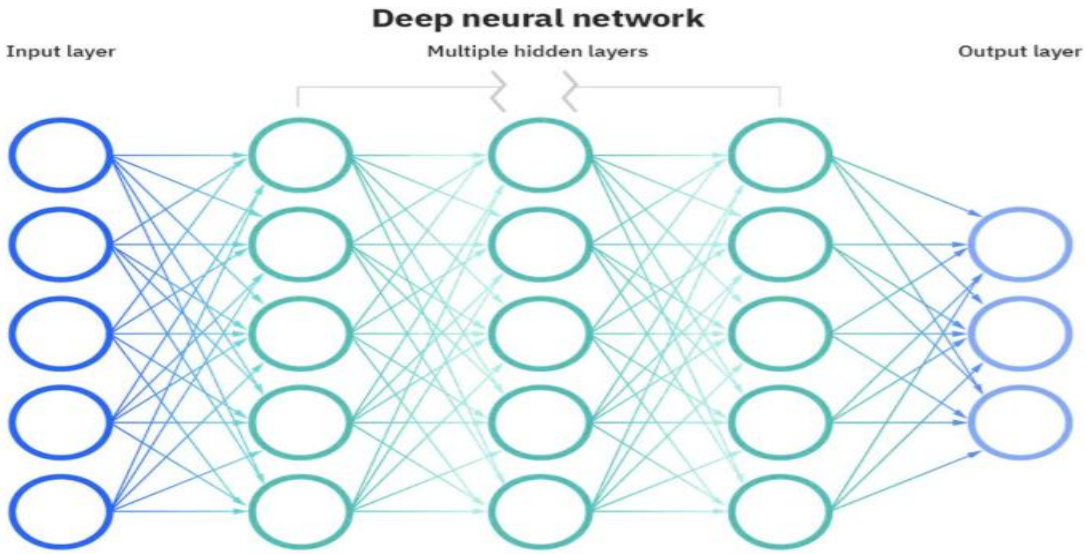

Figure 1: Deep Learning

V. METHODOLOGY

The methodology of cardiovascular disease prediction using deep learning techniques involves a systematic process of collecting clinical patient data, preprocessing the dataset, selecting relevant clinical attributes, developing deep learning architectures, training predictive models, and evaluating their performance. The primary objective is to identify significant cardiovascular risk factors and develop intelligent prediction models capable of classifying patients into cardiovascular disease and non-cardiovascular disease categories. The methodology considers different deep learning techniques, including Artificial Neural Network (ANN), Deep Neural Network (DNN), Convolutional Neural Network (CNN), Recurrent Neural Network (RNN), and Long Short-Term Memory (LSTM). Furthermore, different preprocessing and optimization techniques are examined to improve model reliability, classification performance, and generalization.

VI. CONCLUSION

Cardiovascular diseases (CVDs) represent a major global healthcare challenge, requiring accurate, reliable, and early prediction approaches to reduce disease-related complications and mortality. This review paper has presented a comprehensive investigation of cardiovascular disease prediction using clinical data and advanced Deep Learning (DL) techniques. Different deep learning architectures, including Artificial Neural Networks (ANN), Deep Neural Networks (DNN), Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), and Long Short-Term Memory (LSTM), have been discussed in terms of their applications, capabilities, and suitability for cardiovascular risk assessment. The reviewed studies demonstrate that integrating deep learning models with metaheuristic optimization algorithms, feature selection techniques, and ensemble learning approaches can improve the identification of significant clinical attributes and enhance disease classification performance. Furthermore, preprocessing techniques such as missing-value handling, data normalization, categorical encoding, and dimensionality reduction play an important role in improving model reliability and prediction quality.

The comparative analysis of existing research highlights the growing importance of intelligent healthcare systems for cardiovascular disease prediction. Hybrid approaches combining deep learning with optimization algorithms such as Grey Wolf Optimization (GWO), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), and improved Salp Swarm Optimization have demonstrated promising results in feature selection and model optimization. Additionally, explainable artificial intelligence techniques, including SHAP and LIME, offer opportunities to improve model transparency and support clinical decision-making. However, several challenges remain, including limited clinical datasets, class imbalance, overfitting, computational complexity, data privacy, model interpretability, and insufficient external validation. Therefore, achieving high classification accuracy alone is not sufficient to establish the clinical reliability of a prediction system.

Future research should focus on developing hybrid and attention-based deep learning architectures, integrating heterogeneous clinical information such as electronic health records, ECG signals, laboratory measurements, and medical imaging, and incorporating explainable AI for transparent cardiovascular risk assessment. Federated learning and privacy-preserving computational techniques may also support secure model development across multiple healthcare institutions. Furthermore, the use of real-time wearable monitoring devices and edge-based intelligence could facilitate continuous cardiovascular health assessment and timely identification of abnormal physiological patterns. Overall, deep learning-based cardiovascular disease prediction offers significant potential for advancing intelligent healthcare applications. Nevertheless, rigorous clinical validation, model calibration, interpretability, and generalization across diverse patient

populations are essential for translating these research developments into practical clinical decision-support systems.

REFERENCES

[1] S. M. Zayed, W. El-Shafai, H. Aljasim, M. Alduailij, and F. Khallaf et al., "A hybrid metaheuristic optimization and machine learning framework for smart healthcare based cardiovascular disease prediction," Scientific Reports, Aug. 2026.

[2] S. Abdulateef Al-Shammari et al., "Grey wolf optimized neural network with hybrid feature extraction for heart disease prediction," Scientific Reports, vol. 16, Art. no. 28007, Jun. 2026.

[3] U. Sarker, A. Biswas, P. Das, L. Vaishnav, K. Dhiraj, and K. Kaur, "Explainable multimodal deep learning framework to predict cardiovascular disease with heterogeneous clinical data," Journal of Information Systems Engineering and Management, Apr. 2026.

[4] L. K. Kumar, K. G. Suma, P. Udayaraju, V. Gundu, S. V. Mantena, and B. N. Jagadesh et al., "Clustering-based binary Grey Wolf Optimisation model with 6LDCNNet for prediction of heart disease using patient data," Scientific Reports, vol. 15, Art. no. 1270, Jan. 2025.

[5] G. Narasimhan and A. Victor, "A hybrid approach with metaheuristic optimization and random forest in improving heart disease prediction," Scientific Reports, vol. 15, Art. no. 10971, Mar. 2025.

[6] M. Sowmiya, B. Banu Rekha, and E. Malar, "Optimized heart disease prediction model using a meta-heuristic feature selection with improved binary salp swarm algorithm and stacking classifier," Computers in Biology and Medicine, vol. 191, Art. no. 110171, Jun. 2025.

[7] B. Xia, N. Innab, V. Kandasamy, A. Ahmadian, and M. Ferrara et al., "Intelligent cardiovascular disease diagnosis using deep learning enhanced neural network with ant colony optimization," Scientific Reports, vol. 14, Art. no. 21777, Sep. 2024.

[8] S. Subramani, N. Varshney, M. V. Anand, M. E. M. Soudagar, L. A. Al-Keridis, T. K. Upadhyay, N. Alshammari, M. Saeed, K. Subramanian, K. Anbarasu, and K. Rohini, "Cardiovascular diseases prediction by machine learning incorporation with deep learning," Frontiers in Medicine, vol. 10, Art. no. 1150933, Apr. 2023.

[9] R. Bharti, A. Khamparia, M. Shabaz, G. Dhiman, S. Pande, and P. Singh, "Prediction of Heart Disease Using a Combination of Machine Learning and Deep Learning," Computational Intelligence and Neuroscience, vol. 2021, Art. no. 8387680, Jul. 2021.

[10] Zhou, C., Dai, P., Hou, A., Zhang, Z., Liu, L., Li, A., et al., "A comprehensive review of deep learning-based models for heart disease prediction," *Artificial Intelligence Review*, vol. 57, article 263, 2024.

[11] Yu, J., Yang, X., Deng, Y., Krefman, A. E., Pool, L. R., Zhao, L., et al., "Incorporating longitudinal history of risk factors into atherosclerotic cardiovascular disease risk prediction using deep learning," *Scientific Reports*, vol. 14, article 2554, 2024.

[12] Bhagawati, M., Paul, S., Mantella, L., Johri, A. M., Laird, J. R., Singh, I. M., et al., "Deep learning approach for cardiovascular disease risk stratification and survival analysis on a Canadian cohort," *The International Journal of Cardiovascular Imaging*, vol. 40, pp. 1283–1303, 2024.

[13] Honi, D. G. and Szathmary, L., "A one-dimensional convolutional neural network-based deep learning approach for predicting cardiovascular diseases," *Informatics in Medicine Unlocked*, vol. 49, article 101535, 2024.

[14] Zhou, S., Blaes, A., Shenoy, C., Sun, J., and Zhang, R., "Risk prediction of heart diseases in patients with breast cancer: A deep learning approach with longitudinal electronic health records data," *iScience*, vol. 27, no. 7, article 110329, 2024.

[15] Sadr, H., Salari, A., Ashoobi, M. T., et al., "Cardiovascular disease diagnosis: A holistic approach using the integration of machine learning and deep learning models," *European Journal of Medical Research*, vol. 29, article 455, 2024.

[16] Liu, T., Krentz, A., Lu, L., and Curcin, V., "Machine learning based prediction models for cardiovascular disease risk using electronic health records data: Systematic review and meta-analysis," *European Heart Journal – Digital Health*, vol. 6, no. 1, pp. 7–22, 2025.