SCOPE AND CHALLENGES OF ARTIFICIAL INTELLIGENCE (AI) IN ELECTROCARDIOGRAPHY (ECG):

(Soumya Bandi[1], Medical content writer and Dr. Pranjal Bordoloi, SVP Medical and Clinical Affairs[2]Jodas Expoim Pvt. Ltd)

ABSTRACT:

Cardiovascular disease (CVD) is still a major health issue in contemporary life. The electrocardiogram (ECG) is one of the most trustworthy non-invasive tools for identifying heart problems. ECG interpretation, however, takes a lot of effort and expertise. AI is being used in the diagnosis and prognosis of arrhythmias, such as atrial fibrillation, by analysing the electrical activity of the heart. Traditional CVD diagnosis relies on individual patient's medical history and clinical examinations, which are inefficient due to heterogeneous data. Computer Aided Diagnosis Systems (CADS) provide reliable, automatic, and low-cost systems for monitoring and diagnosis. Regular 12-lead ECGs have been subjected to AI analysis, making ECGs more affordable and accessible in limited resources. The article presents the various technologies of AI such as Machine learning and deep learning that are applied in the interpretation of ECG and diagnosis of cardiovascular diseases and the challenges associated with it.

Key words: Artificial intelligence, Electrocardiogram, cardiovascular diseases, machine learning, deep learning, atrial fibrillation

INTRODUCTION:

CARDIOVASCULAR DISEASES:

Since 1990, cardiovascular diseases (CVDs) have been the primary cause of mortality worldwide. In 2021, there were 20.5 million fatalities from CVDs, or one-third of all deaths worldwide. This represents a considerable increase from the 12.1 million deaths in 1990.[1]An irregular pulse rhythm that can occur at any age due to aberrant electrical activity in the heart is called a cardiac arrhythmia. ECG is a non-invasive technique that is used to find these irregularities. Nevertheless, noise, non-stationary signal shape, and irregular heartbeats in the ECG make it challenging for doctors to diagnose arrhythmias.[2,3]

The most prevalent long-lasting heart arrhythmia is atrial fibrillation (AF). Atrial fibrillation often progresses from short episodes of arrhythmia to increasingly prolonged, regular events. Even in those who are symptomatic, asymptomatic episodes are not uncommon.[4] AF is a persistent arrhythmia linked to cardiovascular diseases, diagnosed using ECG. Symptoms include irregular ventricular excitation, dys-synchronous atrial contraction, and high-frequency excitation.

AI in ECG:

The electrocardiogram (ECG), which analyses the electrical activity of the heart, is a useful tool for diagnosing arrhythmias which; however, can be difficult to diagnose, particularly in the case of atrial fibrillation (AF), that can have a number of asymptomatic and transitory forms. Furthermore, the time series analysis and extraction techniques from ECG singularities and their dynamics have some limits. AI is used in the diagnosis and prognosis of disorders like arrhythmia in order to overcome these shortcomings.[5]

Traditional CVD diagnosis relies on individual patient's medical history and clinical examinations. However, this method is inefficient due to heterogeneous data and requires extensive analysis. In developing countries, this issue becomes more significant. Healthcare providers are increasingly demanding reliable, automatic, and low-cost systems for monitoring and diagnosis. Computer Aided Diagnosis Systems (CADS) provide portable, straightforward solutions for individuals to monitor and evaluate their health conditions.[6]

An essential tool in clinical medicine, the electrocardiogram (ECG) offers important diagnostic hints for systemic diseases. Although human interpretation differs according to background and skill, regular 12-lead ECGs have been subjected to AI analysis, leading to fully automated models that closely resemble human interpretation. This advancement makes ECGs more affordable and accessible in environments with limited resources by providing increased diagnostic fidelity and workflow efficiency over conventional rule-based computer interpretations.[7]

MACHINE LEARNING TECHNIQUES OF AI IN ECG INTERPRETATION:

ECG data is analysed by machine learning algorithms to diagnose cardiovascular diseases. The field of cardiovascular medicine is increasingly using machine learning (ML), a branch of artificial intelligence (AI). Computers are used to evaluate data and categorise activities, either under human supervision or without. The framework of ML employs models that predict outcomes, ranging from favourable to unfavourable, using mathematical optimisation and statistical analysis.[8]

These algorithms use waveform or tabular ECG data and extract relevant characteristics. Once the model runs well, additional ECG data may be evaluated and validated for diagnostic reasons. Collecting ECG data in different forms, dividing it into training and testing datasets, and building and improving prediction models using different algorithms are the steps involved in the process.[9]

DEEP LEARNING TECHNIQUES OF AI IN ECG INTERPRETATION:

AI-based techniques, particularly deep learning (DL) techniques, have demonstrated notable advancements in the field of cardiovascular image segmentation. A medical image, volume, or series of images or volumes is the input for the content extraction process known as segmentation, which creates related forms like 2D contours or 3D meshes.[10].

Deep Learning (DL) is the study of extracting knowledge, making predictions, making intelligent decisions, or, to put it another way, identifying complex patterns from a set of data, called training data. As larger networks or training datasets typically yield more accuracy than smaller ones, (Deep convolutional neural networks) CNNs are more scalable when compared to classical learning techniques.[6]

Advanced performance in speech recognition, computer vision, image/video processing, gaming, and medical diagnosis is exhibited by deep learning (DL), a subtype of machine learning (ML). Without the need for manual feature engineering, it provides a versatile method of representing complex raw input data. Artificial neural networks, which alter and transform incoming data into a data representation, are the foundation of deep learning.[11]

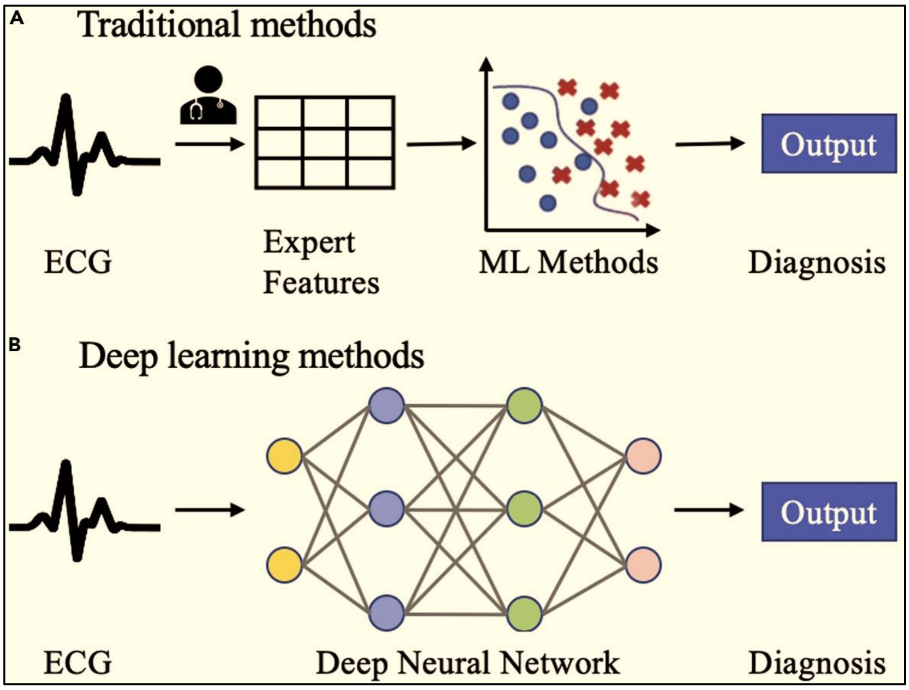

Fig 1[12]: Comparison of machine learning and deep learning methods in ECG diagnosis for Cardiac abnormalities.

CNNs, which evaluate unprocessed input data such as pictures and ECGs to predict categorised output, are the main building block of deep learning (DL). Convolutional layers, which make up CNNs, identify data features and produce feature maps via the application of convolution filters. These maps are subsampled by a pooling layer, which acquires higher-level information and builds hierarchical representations. CNNs then create global data classifications using fully connected layers. CNNs are now the main network architecture for enhanced ECG prediction according to recent studies.[11]

NEURAL NETWORKS IN DETECTING ATRIAL FIBRILLATION:

Atrial fibrillation (AF) is a common persistent arrhythmia linked to various cardiovascular diseases. ECG, invented in 1872, is widely used for clinical diagnosis of AF and other arrhythmias. The symptoms of atrial fibrillation (AF) include irregular ventricular excitation, dys-synchronous atrial contraction, and high-frequency atrial excitation. Though comorbid diseases are increasingly being discovered, they can occur without known problems and produce a distinct AF substrate or atrial cardiomyopathy.[13] AF increases the risk of poor quality of life, stroke, and heart failure, resulting in frequent hospitalisations and inpatient stays. Undiagnosed paroxysmal AF affects 15% of individuals with unexplained embolic stroke, which can be difficult to detect due to asymptomatic and unusual symptoms.[7]

Convolutional neural networks (CNNs) and recurrent neural networks (RNNs) have been widely used to detect AF with excellent results. CNNs perform well in feature extraction and image classification, while RNNs take the time series of data into account while processing data. Researchers have developed algorithms for automatically detecting AF signals from ECG signals, converting ECG signals into 2D images using short-time Fourier transform. The short-time Fourier transform (STFT) can convert a 1-D signal into a 2-D spectrogram and encapsulate the time and frequency information within a single matrix.[14] However, researchers have not addressed the long-term dependence between ECG data and the time of processing and transmitting data.[15]

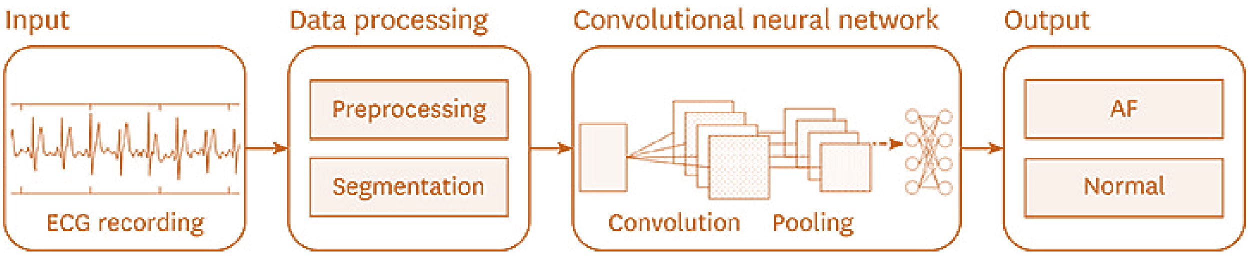

Fig 2[16]: Process of AF diagnosis by CNN

AF= Atrial fibrillation; CNN= Convolutional neural network

CHALLENGES AND LIMITATIONS OF AI IN ECG ANALYSIS:

There are several challenges facing the present research on deep learning algorithms for ECG analysis:

- First, it might be difficult to assess the models' performance when illnesses vary by race or geography since there is no external evaluation mechanism in place. Regulating concerns and the requirement for consistent performance across several datasets have prevented any of the algorithms from being deployed in medical contexts, even though experiment performance has been outstanding.

- Deep learning approaches in wearables demand a lot of processing power, which makes it challenging for edge computing devices to manage such tasks locally.
- Data processing requires remote servers or cloud-based software, which presents privacy and security issues.
- Not all diseases or health problems have big, balanced datasets, therefore imbalanced and limited labelled datasets are also a cause for worry.
- The lack of clear guidelines or understandable explanations for CNNs, which are sometimes referred to as "black boxes," raises important concerns about interpretability and openness.
- The acceptance and application of AI-based diagnostic tools in clinical settings may be hampered by this lack of interpretability.[9]

DISCUSSION:

Six million people in the US suffer with atrial fibrillation, a common heart arrhythmia that raises the risk of stroke. Due to its paroxysmal nature, 700,000 people may have fibrillation that goes undetected. In high-risk individuals, conventional cardiac monitors or implanted devices can identify atrial fibrillation.[17]

Although ECG analysis is essential for identifying and classifying arrhythmias, it has drawbacks, including labour-intensive analysis, sensitivity problems, and the possibility of patient pain. Accuracy may also be impacted by the requirement for distant access and physical contact points. Because ECG signals might contain noise and artefacts, sophisticated signal processing methods are required. Automated, low-cost methods utilising machine learning and deep learning models are being developed to solve these problems. These technologies provide more precise interpretation, standardisation, and ongoing, real-time monitoring, all of which have the potential to enhance patient outcomes.

CONCLUSION:

Cardiovascular disease remains a significant issue, and the electrocardiogram (ECG) is a reliable non-invasive tool for identifying heart problems. However, traditional diagnosis relies on individual patient's medical history and clinical examinations, which are inefficient due to heterogeneous data.

AI is being used to diagnose and prognosis of arrhythmias, such as atrial fibrillation, by analysing the electrical activity of the heart. Machine learning algorithms are increasingly used in cardiovascular medicine to analyse ECG data, with deep convolutional neural networks (CNNs) being the main building block. However, challenges such as assessing models' performance across different datasets, processing power demand, privacy and security issues, imbalanced and limited datasets, and lack of clear guidelines for CNNs raise concerns about interpretability and openness, potentially hindering the acceptance and application of AI-based diagnostic tools in clinical settings.

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