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Machine Learning and Deep Learning Methods in Heart Disease (HD) Research

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Abstract

The healthcare environment comprises the enormous amount of data such as clinical information, genetic data, and data generated from electronic health records (EHR). Machine learning, Data mining and deep learning methods provide the methodology and technology to extract valuable knowledge for decision making. Heart disease (HD) is one of the cardiovascular diseases which are diseases of the heart and blood vessel system. Extensive research in all aspects of heart disease (diagnosis, therapy, ECG, ECHO etc.) has led to the generation of huge amounts of data. The aim of the present study is to conduct a systematic review of the applications of machine learning, Deep learning techniques, and tools in the field of Heart disease research with respect to Heart disease complications, Prediction, and diagnosis. In general, 60% of those used were characterized by machine learning techniques and support vector machines and 30% by deep learning approaches. Most of the data used are Clinical datasets. From this survey, it provides insights in electing suitable algorithms and methods to improve accuracy in HD prediction. The selected articles in this study projected in extracting useful knowledge accelerated new hypothesis targeting deeper understanding and further investigation in cardiovascular disease.

Keywords: Machine learning, Deep learning, Data mining, Heart disease, Disease prediction and Diagnosis.

1 Introduction

Significant advance in Big data technology plays a vital role in health care management to evaluate large data sets which can be used to predict, prevent, manage and treat Diseases [1] and [2]. The 5 Vs (volume, velocity, variety, veracity and value) of Big data for huge data processing is difficult using traditional ML methods.ML methodologies itself has to renew itself for big data processing [3]. Health analytics have been proposed using ML to predict accurate patient data analysis [4].

The data produced from health care industry is not mined. data mining techniques can be used to build an intelligent model in medical field using data sets which involves risk factor of patients. The knowledge discovery in database (KDD) is alarmed with development of methods and techniques for making use of data. One of the most important step of the KDD is the data mining. Data mining is the process of pattern discovery and extraction where huge amount of data is involved. Both the data mining and healthcare industry have emerged some of reliable early detection systems and other various healthcare related systems from the clinical and diagnosis data [5].

Heart disease is a term used when functionality of the heart is not in normal condition. HD involves blocked blood vessels which might lead to an angina, heart attack and stroke [35]. If the heart disease found in born babies, then it is called congenital HD. If the disease found at the later ages, then it is called acquired HD. There

are number of possibilities and challenges designed in finding the disease at early stages [36]. The most common types of heart disease are:

a) *Coronary artery disease (CAD)* This occurs when problems arise with the blood vessels due to high cholesterol, diabetes, smoking, high blood pressure and inherit from parents [37]. Angina is a symptom of CAD, which a chest pain and occurs discomfort in neck, arms, shoulders, back and pain even feels like indigestion [38].

b) *Congestive heart failure (CHF)* The function of the heart is to pump blood, CHF is found when heart is not pumping a normal level.

c) *Abnormal heart rhythms* This is a problem in the heart with electrical activity, which makes the heart beat too fast or too slow. Bad rhythm's stops pumping blood in the heart [39].

Heart diseases are also called as silent killers because symptoms are very difficult to detect. Some of the common symptoms are: shortness of breath, uncontrolled heart palpitations, chest pain, skin discoloration, swelling in legs and dizziness. HD can be diagnosed in many ways based on the doctor's recommendation and symptoms. Few of the commonly recommended tests are [40]:

a. Echocardiogram: In this, ultrasound waves are used to monitor the flow of blood through the heart.
b. Holter monitoring (HM): A portable device for 24 to 72hours worn by a patient to record the continuous ECG.
c. Electrocardiogram (ECG): This is used to diagnose the problem related to heart's rhythm.
d. Cardia computerized tomography (CT) scan: In this with the help of an X-ray cross sectional views of the heart is captured.
e. Cardiac magnetic resonance imaging (MRI): In this, powerful magnets and radio waves are used to create an image of the heart and tissues surrounding it.

There are many DM techniques available namely Classification techniques involving Naive Bayes (NB), Decision tree (DT), Neural network (NN), Genetic algorithm (GA), Artificial intelligence (AI) and Clustering algorithms like K-NN, and Support vector machine (SVM)[3]. Cardiovascular sickness is one of the most important human-threatening and life qualities reducing disease. Heart failure is the first cause of admission by healthcare professionals in their clinical practice. Building an effective disease management strategy requires analysis of large amount of data, early detection of the disease, assessment of the severity and early prediction of adverse events. This will inhibit the progression of the disease, will improve the quality of life of the patients and will reduce the associated medical costs. Diagnosis is basically based on patient's Electro cardiogram (ECG), Echocardiography (ECHO) tests results and doctor's experience[6].

Applying machine learning, Deep learning methods in heart disease research is a best approach for disease diagnosis, prediction, management and other related clinical administration aspects. Disease prediction and decision making plays a significant role in medical diagnosis. Hence, in the framework of this study, efforts were made to review the current literature on machine learning and data mining approaches in heart disease research. Efficient data capturing from health records can be achieved using deep learning techniques [7].

The review is organized as follows: Section 2 provides the necessary knowledge on machine learning (ML) Data mining and Deep Learning. Section 3 provides publications reviewed in the study. Section 4 presents a discussion, with Section 5 providing conclusions.

2.Machine Learning and Deep Learning

Machine learning is an application of artificial intelligence (AI) that provides systems the ability to automatically learn and improve from experience without being explicitly programmed. Machine learning is all about developing computational, mathematical and statistical methodologies for identifying patterns in and extracting relevant from data [8]. Machine learning focuses on the development of computer programs that can access data and use it learn for themselves[9]. A more detailed and formal definition of machine learning is given by Mitchel [10]: *A computer program is said to learn from experience E with respect to some class of tasks T and performance measure P, if its performance at tasks in T, as measured by P, improves with experience E.*

Data mining is a term used in a domain of database technologies, machine learning, pattern recognition, statistical analysis, clustering, classification, prediction, visualization and modelling techniques and database technologies. The need of data mining in health care management arises is to mine the data for information processing which benefits health care providers.

The term knowledge discovery in database (KDD) is one of the method of data mining to find knowledge in data. It includes selection, preprocessing, transformation, datamining, interpretation/evaluation depicted in Figure 1. A definition according to Fayyad [12]: *KDD is the nontrivial process identifying valid, novel, potentially useful, and ultimately understandable patterns in data*.

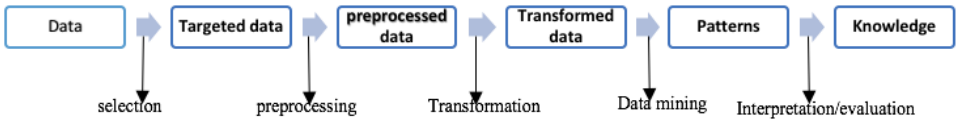

Figure 1 KDD process basic steps

KDD's data transformation step is one of the most important processes which includes feature selection. It is defined as the process of selecting a subset of features from the feature space, which is more relevant to and informative for the construction of a model. The advantages of feature selection for better prediction accuracy, to analyze the data for better visualization and understanding of data. Two main approaches involved in this process, machine learning and independent assessment [11].

2.1. Categories of Machine Learning.

Machine Learning Algorithms divided into categories according to their purpose are shown in the Figure 2 [13].

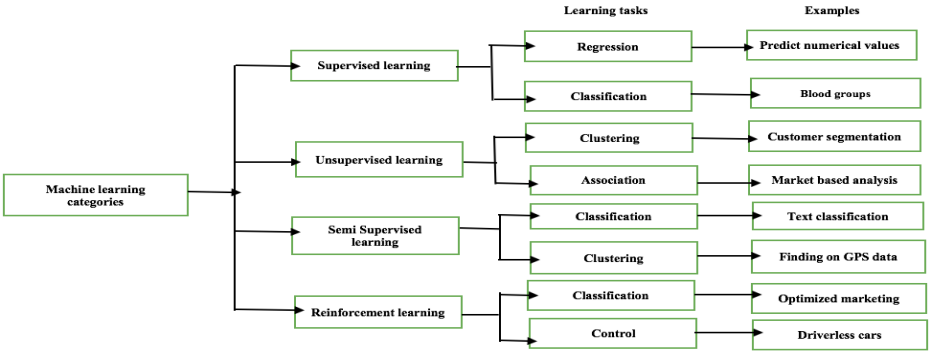

Figure 2 Machine learning categories

2.1.1. Supervised Learning

Supervised learning is the system in which both input and desired output are provided for future data processing. In this there are two kinds of learning tasks: regression and classification. Some of the most common algorithms are Support Vector Machines (SVM), Genetic algorithms, Decision Trees (DT), k-Nearest Neighbors (k-NN) and Artificial Neural Networks (ANN).

2.1.2. Unsupervised Learning

Unsupervised learning is used to draw inferences from datasets consisting of input data without labeled responses. In this there are two learning tasks Association and clustering. To find the correlations in the objects

of a database, Association learning was proposed by Rakesh Agarwal [14]. The most familiar algorithm used in association rule is Apriori and clustering is to group similar kind of datasets [15] and [16]. Some of the most common algorithms are k-means clustering and association rule learning algorithm.

2.1.3. Semi-supervised Learning

Semi-supervised learning is a combination of labeled and unlabeled data, which falls in between supervised and unsupervised learning. This learning mainly used in classification of webpage, genetic sequencing and speech recognition. semi-supervised learning is broadly classified into two learning tasks, classification and clustering [17].

2.1.4. Reinforcement Learning

Reinforcement Learning is a kind of Machine Learning method. It is concerned with how software agents automatically determine the ideal behavior within a specific context, in order to maximize its performance. Reinforcement signal sends the reward feedback for the agent to learn its behavior. It consists of two learning tasks,classification and control. Some applications of the are computer played board games, robotic hands, and self-driving cars. Most commonly used algorithms are Q-learning, Temporal difference, Deep Adversarial Networks [18].

2.2. Deep Learning

The term "Deep Learning" was first introduced to Machine Learning by Dechter[19], and to Artificial Neural Networks (NNs) by Aizenberg[20]. It was further popularized by the development of Convolutional Networks Architecture by Alex Krizhevsky named 'AlexNet' that won the competition of ImageNet in 2012 by defeating all the image processing methods and creating a way for deep learning architectures to be used in Image Processing[21] and [23].

Deep learning is known as deep structured learning or hierarchical learning[22]. Most of the deep learning architectures and algorithms are built with the Artificial neural network (ANN) framework. ANN are composed of neurons(interconnected nodes) as in figure 3. Initially the input layer gets an input and it passes on a modified version of the input to the next layer. The layers between the input and output named as hidden layers and composed of multiple linear and non-linear transformation [23][24][25][26][27]and[28].

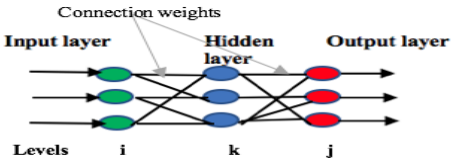

Figure 3 Neural network

Some of the open source tools for working with deep learning algorithms are Deeplearning4j, TensorFlow, Keras, Theano, Torch, Caffe, PyTorch, and CNTK[29].The most common deep learning architectures are multilayer perceptron's (MLPs), Convolution neural networks(CNN) and recurrent neural networks(RNN).

Multilayer perceptron (MLP) is a feedforward artificial neural network characterized by a set of input nodes connected as a directed graph between the input and output layers. It uses backpropagation method for training the network and widely used for solving problems of supervised learning as well as research into parallel distributed processing and computational neuroscience[30].The process of MLP function for the weighted sum of the inputs is defined as[31]:

$$V_j = {}_{ji}x_{i+} \theta_j$$
$$y_j = f_j(V_j)$$

Where,
Vj :The input combinations
θ_j : The bias

W_{ji}: The connection weight between the input and the neuron j
f_j: The function of j neuron
y_j: The output

Convolutional neural networks(CNN) are deep artificial neural networks majorly used to classify images, clustering based on similarity, and object recognition. Related algorithms used to identify faces, street signs, tumours, platypuses and different aspects of visual data[32].

Recurrent neural network (RNN) is an advanced artificial neural network to build on earlier types of networks with fixed-size input vectors and output vectors[33].The RNN is related to deep learning to simulate the neural activity in the human brain. RNNs widely used for Sentiment Classification, Image captioning and language translation[34].

3.Prediction and Diagnosis of Heart Disease through Machine Learning and Deep Learning:

Significant efforts were made to find articles in heart disease research through machine learning, data mining and deep learning techniques which improves accuracy of HD risk prediction[42][43]and[44].Mainly two databases were used to search the related works as on(11 May 2018):The one database is dblp computer science bibliography and PubMed based on the following search topics: a)"Machine learning" and "Heart disease" b) "Datamining" and "Heart Disease" c)"Deep learning " and "Heart Disease". The number of publications per year is shown in Figure 4 according to dblp and PubMed databases[45][46].

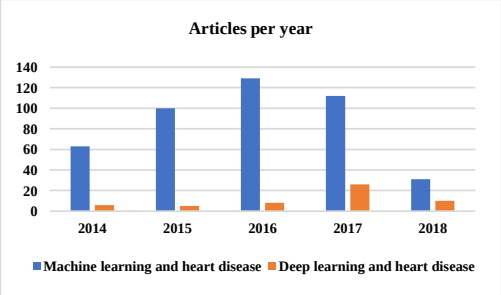

Figure 4 Articles per year in the collection employed

HD prediction takes less time and makes process fast with the collaboration of Machine learning [Ml] and data Mining [47] [48] [49]and [50]. Ml is mainly used for data analysis purpose for accurate learning with less error rate [51]. Machine learning techniques improves accuracy in prediction of HD in the early stage of disease and patients can consult medical practitioners for preventive treatment [52] [53]and [54]. Advancement in technology of bioinformatics provides a powerful tool for classifying datasets [55]. The Cleveland database is the only one in heart disease that has been used by researchers till date [41]. Table 1 describes the 14 attributes of the dataset.

Table 1 Heart disease dataset.

No	Attributes	Values			
1.	Age				
2.	Sex	1=Male	0=Female		
3.	cp: Chest pain type	1=Typical angina	2=Atypical angina	3=Non-anginal pain	4=Asymptomatic
4.	Trestbps: Resting Blood pressure(in mm Hg)				
5.	Chol: Serum cholesterol in mg/dl				
6.	Fbs: fasting blood sugar>120 mg/dl	1=True	0=False		
7.	Restecg: resting electrocardiographic results	0=Normal	1=Having ST-T wave abnormality	2=Showing probable or definite left ventricular hypertrophy	
8.	Thalach: maximum heart rate achieved				
9.	Exang: exercise induced angina	1=Yes	0=No		

10.	Old speak: = ST depression induced by exercise relative to rest			
11.	slope: the slope of the peak exercise ST segment	1= Up sloping	2=Flat	3=Down sloping
12.	ca: number of major vessels (0-3) colored by flourosopy			
13.	Thal: Heart condition summary	3=Normal	6=Fixed defect	7=Reversible defect
14.	Num: Diagnosis of heart disease (angiographic disease status)	0: < 50% diameter narrowing	1: 50% diameter narrowing	

Machine learning algorithms are investigated for assessing and predicting the severity of heart failure by artificial neural networks (ANN), Support vector machine (SVM), classification and regression tree. Finally, out of these algorithms the authors claimed SVM performs better than the other two algorithms [56]. In the heart disease diagnostic significant attempts are made by authors, best approach is SVM which provides an accuracy of 94.60% [57] and also SVM approach is more accurate and less errors in disease prediction [58] and [59].

In HD Prediction 302 instances were compared and investigated using seven machine learning algorithms such as Naïve Bayes, Decision tree, K-Nearest Neighbor, Multilayer perceptron, Radial basis function, single conjunctive learner and SVM. author has done experiment with the instances and resulted SVM method performed well [60]. SVM methods also used for diabetic patients in HD diagnosis [61].

Mobile Machine Learning Model is designed for Monitoring Heart Disease, specially designed for mobile devices which helps to monitor HD. Experimented with clinical datasets of 200 patients and was successful in obtaining an accuracy of 90.5%[62].Research is carried out on performance analysis of various ML algorithms to predict HD[63].HD risk level of a patient is predicted using ML algorithms and also created a centralized System to view the e-health data on cloud for both patients and doctors[64].

A decision tree algorithm is used to find a predictive model for detecting heart disease. Data sets collected from the 1159 healthy members and 1187 from the members who had undergone coronary angiography. finally claimed that the risk factors of coronary heart disease with specificity, sensitivity, accuracy of 87%,96% and 94% respectively [35]. To improve the performance in HD classification and prediction Tree based methods are used [65]. In prediction and classification of Heart failure, conventional logistic regression was able to predict more accurate results among the patients compared to the machine learning and data mining methods [66]and [103].

An accurate hybrid method for the diagnosis of coronary artery disease using genetic algorithm which had increased the performance of neural network by 10%. By using this method on Z-Alizadeh Sani dataset they have achieved specificity, sensitivity, accuracy, sensitivity and specificity rates of 92%,93.85% and 97% respectively [67].

Naïve bayes classifier algorithm was used to develop a predictive model for hypertension patients of Nigeria. The authors have used the 52pateints dataset with 10 attributes, finally claimed that for diagnosis of hypertension patients Naïve bayes classifier is an efficient algorithm [68]. Laplace smoothening technique give more accurate results than Naïve bayes in HD prediction [69]. One of the datamining techniques called weighted associated classifiers proved improved accuracy compared to associative classifiers in HD prediction [70]. To find the HD predictive performance of machine learning algorithms, classifiers are applied on datasets and concluded that Naïve base classifier is considered best as compared to K-Nearest Neighbor, Decision tree and Support Vector Machine [71].

Some attributes of genetic and phenotype factors used to compare the performances of neural network methods in predicting coronary artery disease. Achieved 23.9% improvement using neural network approach on the genes dataset over a single classifier approach [72].

An efficient HD prediction system using data mining techniques also been introduced to help a non-doctor to make for proper decision on HD at risk level [73]. A new system called magnetocardiography has been

developed for HD detection with the two machine learning methods such as direct kernel self-organizing map and back propagation neural network (BNN) [74]. A prediction system on diagnosis using lab reports to prevent diseases using data analytics also used in HD [75]. Machine learning methods is well suited for heart disease diagnosis [76].

In prediction and classification of Heart failure, conventional logistic regression was able to predict more accurate results among the patients compared to the machine learning and data mining methods [77].

Till now most of the research on heart disease were based on machine learning and data mining techniques [101]. Now a days deep learning techniques have achieved good results in processing medical data in an effective manner[78]. The number of publications applying deep learning methods also increasing day to day due to its popularity and for less time consumption for data pre-processing compared to other approaches[79][80][81][82]and[86].Deep learning applications are also widely used in medical image analysis[83] and healthcare has been reviewed by many researchers[84][85]and[86]. Brian et.al discussed the issues and solutions of DL for cardiac computer-aided diagnosis[87].

The artificial neural network is a major component of deep learning for information processing[88].CNN is a type of ANN which attains in detection, segmentation, and recognition of objects and regions within images [89]. One of the methods is proposed for heart disease prediction system by comparing the work of Deep Belief Network classification [DBN] and Convolutional Neural Network [CNN] algorithms. Finally Concluded DBN method provides 90% accuracy in disease prediction[90].

Artificial neural network backpropagation algorithm is proposed with 13 clinical features to predict HD and proved with the accuracy of 95%[91].Stroke is a major symptom in HD patients, deep learning model also used to predict stroke with the predictive analytics technique[92].

A classification system using Multilayer perception with Back- Propagation learning algorithm on UCI dataset with the 8 attributes and achieved the accuracy 80.99% [93]. The two approaches to diagnosis heart disease are ANN and Adaptive neuro fuzzy inference system(ANFSI) and ANN achieved the maximum accuracy of 87.04%[94].

The hybrid classification system is proposed based on the Relief and Rough set (RFRS) for HD diagnosis with the accuracy of 92.59%[95]. MLP and SVM performs better with maximum accuracy in Heart Disease Diagnosis. The use of 3D Convolutional Neural Network is also demonstrated for deep de-aliasing using deep learning in congenital HD[96]. Deep learning architectures used in the automatic segmentation and also tracking of the left ventricle of the heart from ultrasound images[97][98]and[99].

4.Discussion

In this paper, the literature survey was reviewed to applications of deep learning and machine learning methods in heart disease research. World Health Organisation (WHO) estimated that India have lost HD patients up to $237 billion, from 2005-2015 [100]. Deep learning and machine learning approach improve the quality, accurate prediction and effective decision making in heart disease which is explained in the first section.

In the following sections, articles collected from several scientific journals related to the field of heart disease research with respect to prediction and diagnosis in HD and healthcare management. The categorization of each article was done based on the content. The main key aspect of study in the different articles is closely related to the data-driven process in the field of machine learning ,data mining and deep learning in HD. The huge data from clinical, EHR and diagnostic data are not much available to the scientific community.

4.1 Perception of Heart disease research

Machine learning and Deep learning articles in the prediction of HD enhanced accuracy above 80%.the most commonly used in HD are Artificial neural networks, supervised learning approaches in classification, SVM, Bigdata technologies, Deep belief network, Convolutional Neural network ,Data mining algorithms. The most successful methodology for the clinical datasets is SVM in machine learning and ANN in deep learning. In all the research articles, to train and validate the dataset appropriate methodology were used.

Table 2 Comparison of different Machine Learning and deep learning algorithms

Publication	Compared algorithms	Best accuracy
Anbarasi et al.,2010[101]	Naïve Bayes, Genetic algorithm, decision tress	NB 96.5%
Vanisree and Jyothi,2011[102]	Back propagation Neural network	BPNN 90%
Zhang et al.,2012[104]	K-means algorithm, SVM	SVM 97.38%
Elshazly et al.,2014[105]	Genetic algorithm	GA 83.1%
H.D.Masethe and M.A.Masethe,201[106]	J48,REPTREE,Naïve Bayes, Byes net and CART	CART 99.07%
Milan and sunila,2011[107]	ANN, Decision tree and SVM	SVM 84.12%
M.A.Nishara Bhanu ang Gomathu,2013[108]	K-means	89%
Syed umar amin et al.,2013[109]	SVM	89%
Vadicherla and saonawane,2014[110]	RIPPER, Decision tree, ANNs, SVM	SVM 84.12%
Nilakshi and nilima,2014[111]	Genetic Neural Network	98%
Abhishek Taneja ,2013[112]	Naïve Bayes, Decision tree(DT), Neural network	DT 89%
A. Khemphila and V. Boonjing ,2011[93]	MLP	80.17%
M. A. M. Abusharian et al.,2014[94]	ANN,ANFIS	ANN87.04%
X.Liu et al.,2017 [95]	RFRS	92.59%

Several characteristics of the datasets are taken to perform comparative analysis on different machine learning algorithms such as clinical data. The performance varies from one dataset to another dataset in different algorithms. Table 2 compares the algorithms in various datasets in HD. The performance of the algorithms reviewed in the above table is shown in the figure 5.
The overall many techniques and algorithms are used in HD research. The effort on processing the data for the feature selection of the dataset is carried out in many research but the accuracy of the algorithm is totally depending on the type of data.

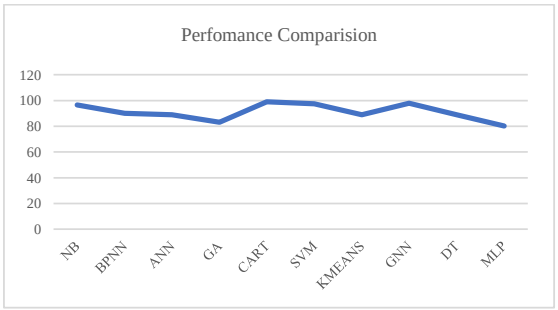

Figure 5 Performance comparison of algorithms.

Machine learning algorithms will use different datasets which is of huge size. Big data technologies are used in processing the data such as EHRs, Clinical and diagnosis data in HD research. Big data is to produce the good quality results and to extract the required knowledge from the data sets.

4.2 Analysis incorporated with Heart disease

Deep learning and machine learning methods are a too early-stage detection of heart disease, it also assesses the possible risk factors, which includes i) Severity reduction, complications delay and quality of life, and ii) Health cost reduction.

The heart disease includes structural problems, diseased vessels, and blood clots. The most common types are coronary heart disease, high blood pressure, cardiac arrest, arrhythmia, strokes, congenital heart disease, heart failure. The major parameter expected in the prediction is high blood glucose levels since it is the first step involved in the diagnosis of the HD patient. The articles related to drugs and therapy in HD majorly includes medication prescriptions. Therefore, there is a lot of scopes to perform research on drug and therapy with the machine learning and data mining methods.

With regard to genetic background and environmental factors in heart disease has the probability to improve the diagnosis and treatment. Carrie Welch and aldons j.lusis.., in [113], deals with genetics forms and identified a novel model in an understanding of genes in heart disease. Finally, Heart disease complications covered in the present study includes Heart failure, heart attack, stroke, aneurysm, peripheral artery disease, sudden cardiac arrest. the majority of the research deals with heart failure.

5.Conclusion

Heart disease is one of the global health challenges in recent years. At present, many research works were carried out to predict and diagnose the heart diseases. In this study, a systematic effort was made to identify, and review machine learning, data mining and deep learning approaches applied on HD research. EHR's in health care producing huge amount of data with the development of technology also give rise to in-depth exploration towards accurate disease prediction, diagnosis, and treatment. The potential benefits of applying Machine learning and deep learning methods with the suitable algorithm will reduce the disease rates and death failures of the global population. In this regard, in future state of the art performances from ML and DL applications not only in disease prediction and diagnosis but also in the other field of bioinformatics.

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