Performance Comparison of Machine Learning Algorithms Clinical Diagnoses of the Risk of Knee Osteoarthritis (KOA)

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ABSTRACT

Knee Osteoarthritis (KOA) is a deteriorating sickness that affects human knee joints leading to impaired quality of life with no curative treatments. Early detection of Knee Osteoarthritis will ensure its proper management, prevent cartilage damage and slow down its progression. Machine Learning (ML) techniques have been used to learn and discover useful patterns from patient datasets to diagnose diseases and infections. This study models five diagnostic models using a dataset of patient information from the Federal Medical Centre, Ido-Ekiti, located in the South-Western part of Nigerian. The result from the study showed a diagnostic accuracy that ranges from 82.79% to 87.93% among the five diagnoses models. The evaluation of the models with the OAI dataset showed an improved diagnostic accuracy compared to existing similar research in the literature.

Keywords: Knee Osteoarthritis Detection, Machine Learning in Healthcare, Diagnostic Model Accuracy

1 Introduction

The invention of the computer as a tool for solving human problems has grown from solving simple to complex problems. The exponential nature of this growth has resulted in computers imitating man's intelligence to solve problems that require man's intelligence. Artificial intelligence (AI) is a branch of computer science that creates a computer machine or program that thinks and acts intelligently as human beings. AI has built and displayed intelligent behavior by analyzing and learning from its environment and taking action with some degree of autonomy to provide the solution to a specific problem. Indeed, AI is an umbrella term including a wide range of technologies and applications, one of which is machine learning. Machine learning focuses on the imitation of human learning capability to analyze, learn and improve learning accuracy from a given data with the aid of learning algorithms (Sarker 2021).

Knee Osteoarthritis (KOA) also known as "wear and tear" disease, is a form of arthritis of the knee that is deteriorating. This sickness causes bones in the knee joint to touch one another as a result of wearing away the slippery cartilage in the bone joints responsible for frictionless movement. It is one of the foremost causes of disability globally affecting 3.8% of the global population (Olase-hinde and Olayemi 2019). According to Murphy *et al.* (2008), the risk of KOA in men and women is put at 40% and 47% respectively. A study carried out in a Nigerian hospital shows a high prevalence of KOA with a high incidence in women with the knee joint being mostly affected with low involvement in the hand joints (Ogunlade *et al.* 2005). Akinpelu *et al.* (2009) reported a point prevalence of 19.6% in a study of Igbo-Ora, a countryside in South-Western Nigeria. The work of Ojoawo *et al.* (2016) shows the prevalence of symptomatic KOA at Odo-Ogbe community at Ile Ife in the western part of Nigerian where it shows that more female was affected and many of those affected have a family history of arthritis and it shows that it is higher than that of Northeast China reported by (Jiang *et al.* 2012).

The Centre for Disease Control has estimated that nearly one in every two people develop KOA symptoms

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by age 85 (Murphy *et al.* 2008). Symptoms of KOA are often developed slowly and worsen over time and this invariably leads to osteophyte formation, weakening of the periarticular muscles, slackness of ligaments, and synovial effusion (Dulay *et al.* 2015). Signs and symptoms of KOA include pains in the affected joints during or after movement, noticeable joint stiffness upon awakening or after being inactive, grating sensation, Bone spurs, and swelling (Tiulpin *et al.* 2018). According to Zhong *et al.* (2021), early diagnosis of KOA will ensure its proper management, prolong healthy patient-years, prevent cartilage from falling apart to slow down its progression, and reduce its effect on future disability.

A patient's health history and physical exam lock up a lot of hidden patterns that can be unlocked to provide diagnoses and treatment for the patient. Knowledge from medical records has been used to diagnose disorders or infections in patients.

Machine learning (ML) algorithms have been used to analyze and generate intelligence to discover hidden and potentially useful patterns from medical datasets for the correct prescription and treatment of diagnosed diseases Olase-Hinde and Olayemi 2019). Esteva *et al.* (2017) put the ability of ML intelligence to diagnose and classify skin cancer at par with the level of competence of a dermatologist. This research compared the diagnostic accuracy of five machine learning algorithms applied to build five diagnostic models of Logistic Regression (LR), Support Vector Machine (SVM), C4.5 Decision Tree (DT), Naïve Bayes (NB), and K-Nearest Neighbors (KNN) for clinical diagnosis of the risk of KOA.

2 Dataset Description

Datasets on the risk of KOA used for this research were obtained from the Federal Medical Centre, Ido in Ekiti State, southwestern Nigeria under the advice and supervision of orthopedic experts. A total number of two thousand, two hundred and thirty-seven (2237) cases of arthritis patients that visited the hospital during the period of October 2011 to October 2019 were extracted from their case files. Each record consists of fourteen independent variables (risk factors) and one dependent variable. All the four- teen independent risks factors were validated by a medical expert as one of or set of possible factors for identifying risks of Knee Osteoarthritis (dependent variable). The dataset was randomly split into training and testing datasets in the ratio of 6 to 4, as shown in Table 1. The training and testing dataset comprise 1130 and 782 patients with KOA respectively and 212 and 113 patients did not have KOA. These patients who were not having KOA were diagnosed with other forms of arthritis and bones disorder such as Rheumatoid Arthritis, Inflammatory arthritis, Psoriatic Arthritis, and Osteoporosis. The training dataset is an imbalanced dataset with a ratio of 6 to 1 of the infected patients to non-infected patients.

Table 1: *Distribution of KOA Dataset Splits*

	Training Dataset	Testing Dataset	Total
KOA Infected	1130	782	1912
Non KOA Infected	212	113	325
Total	1342 (60%)	895 (40%)	2237

All the attributes of the dataset were discretized to make it suitable for the ML model diagnosis building and evaluation, as reported in Table 2. All attributes with value "yes" were discretized as nominal value "one" (1), attributes with value "no" were discretized as nominal value "zero" (0). Ages more than 20 years were discretized as ratio value "one" (1) and ages less than 20 were discretized as ratio value "zero" (0). The low waist-hip ratio is discretized as ordinal values "one" (1), moderate and high waist-hip ratios were discretized as ordinal values "two" (2) and "three" (3) respectively. BMI values; underweight, normal, overweight, and obsessed were discretized as ordinal values, "one" (1), "two" (2), "three" (3), and "four" (4) respectively.

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Table 2: *Distribution of Identified Features in the Original Dataset*

	Attribute Values	**Attribute Type**	**Discretization of attribute values**
Gender	Male, Female	Nominal	1 = male, 2= female
Age (years)	Above 21 to 85 years	Ratio	1 = ages > 20 years, 0 = ages < 20 years
Family History	Yes, No	Nominal	1 =Yes, 0 = no
Waist Hip Ratio	Low, Moderate, High	Ordinal	1 = low, 2= moderate, 3 = high
BMI	Underweight, Normal, overweight, Obsessed	Ordinal	1=Underweight, 2 = Normal, 3 = overweight, 4 = Obsessed
HHD	Yes, No	Nominal	1 =Yes, 0 = No
Joint pains	Yes, No	Nominal	1=Yes, 0 = No
Cellulitis of Leg	Yes, No	Nominal	1=Yes, 0 = No
Seizure Disorder	Yes, No	Nominal	1 =Yes, 0 = No
Ulcer of L/R Limb	Yes, No	Nominal	1 =Yes, 0 = no
Septic Arthritis	Yes, No	Nominal	1=Yes, 0 = No
Repeated stress on Joint	Yes, No	Nominal	1=Yes, 0 = No
Bone Deformities	Yes, No	Nominal	1 =Yes, 0 = No
Joint Injuries	Yes, No	Nominal	1=Yes, 0 = No
Class Label	Yes, No	Nominal	1 =Yes, 0 = No

3 Dataset Modelling

Modeling a successful diagnosis model depends on the ma- chine learning algorithm used in the model building and its eminence. The Five (5) Machine Learning Algorithms, LR, SVM, C4.5 DT, NB, and KNN, were adapted to build the diagnostic models. The training dataset was used to train the five machine learning algorithms to build the diagnostic models. Also, the testing dataset was then used to evaluate the strength and accuracy of the diagnostic models in terms of diagnostic accuracy. The system was implemented using Python programming language on a Corel i3, 64bits, 2.4 GHz processor, 16MB Cache, 512GB SDD, Ms. Windows 7 operating system.

3.1 Logistic Regression

Logistic Regression (LR) is a simple supervised ML algorithm that models a relationship between independent features and the dependent response feature. It uses the logit function to predict the probability occurrences of binary classification of an event. LR assumes and treats all features (risk factors of KOA) as independent of one another.

3.2 K-Nearest Neighbors (KNN)

KNN is a distance-based classification model capable of handling both binary and multi-class label classification. It is an instance-based learner that does less work during the training and more work during classification and prediction. Model evaluation with KNN is very computational and expensive. A new instance of a patient to be classified is compared against all instances in the KOA training dataset based on their Euclidean distance.

3.3 Support Vector Machine

A support vector machine (SVM) is a powerful supervised learning algorithm used for analyzing data and pattern recognition. It is suitable for classification and regression problems based on a principle similar to KNN in that it represents the training set as points in an N-dimensional space and then attempts to

construct a hyperplane that will divide the space into particular class labels with a clear margin of error. SVM constructs a separating optimal hyperplane with the largest margin between the dataset. It splits the dataset into two vector sets to identify two different classes in 'n-dimensional space vector, such that the margin between the classes is maximized and the distance between the hyperplane points is minimized.

3.4 C4.5 Decision Tree (DT)

(C4.5) Classification model consists of nodes that attribute names of KOA dataset and arcs that attribute values connected to other nodes to the leaves, which are the class label. A Decision Tree (DT) builds a classification tree, uses for the diagnosis, and predicts a new patient (either having KOA or not) in the KOA test dataset.

3.5 Naive Bayes

Naïve Bayes is a probabilistic classifiers. It assumes that the attributes of the KOA dataset are independent of each other, it calculates the probability for each symptom in the risk factor given a class label to obtain a joint conditional probability for each patient's risk factors and then uses the Bayes rule to derive conditional probability for each class label. A given risk factor is diagnosed as the class label with the highest probability value.

4 Results and Discussion

Table 3 and Figure 1 reported the diagnosis accuracy and diagnosis Error rate recorded by each of the diagnostic models. SVM model recorded the lowest diagnostic error rate of 12.07% and the highest true positive rate of 89.64%. It shows that the SVM model performs better than all the other base models. The lowest true positive value of 85.42% and the highest diagnostic error rate of 17.21% recorded by the NB model implies that the NB model recorded the least diagnosis performance.

Table 3: *Confusion Matrix and Diagnosis Performances of the Diagnostic Models*

Diagnosis Models	TP	FN	TN	FP	Diagnosis Accuracy	Diagnosis Error Rate	Model Precision	True Positive Rate Model Sensitivity	False Positive Rate	F1 Score
SVM	701	81	86	27	87.93%	12.07%	96.29%	89.64%	23.89%	0.9285
LR	685	97	82	31	85.70%	14.30%	95.67%	87.60%	27.43%	0.9146
C4.5 DT	682	100	80	33	85.14%	14.86%	95.38%	87.21%	29.20%	0.9111
KNN	681	101	75	38	84.47%	15.53%	94.71%	87.08%	33.63%	0.9073
NB	668	114	73	40	82.79%	17.21%	94.35%	85.42%	35.40%	0.8966

Out of the 895 patients who presented for diagnosis, SVM achieved the highest correct diagnosis of 786 patients with a misdiagnosis of 109 patients. LR achieved the correct diagnosis of 767 patients with a misdiagnosis of 128 patients. NB recorded the highest misdiagnosis of 155 patients.

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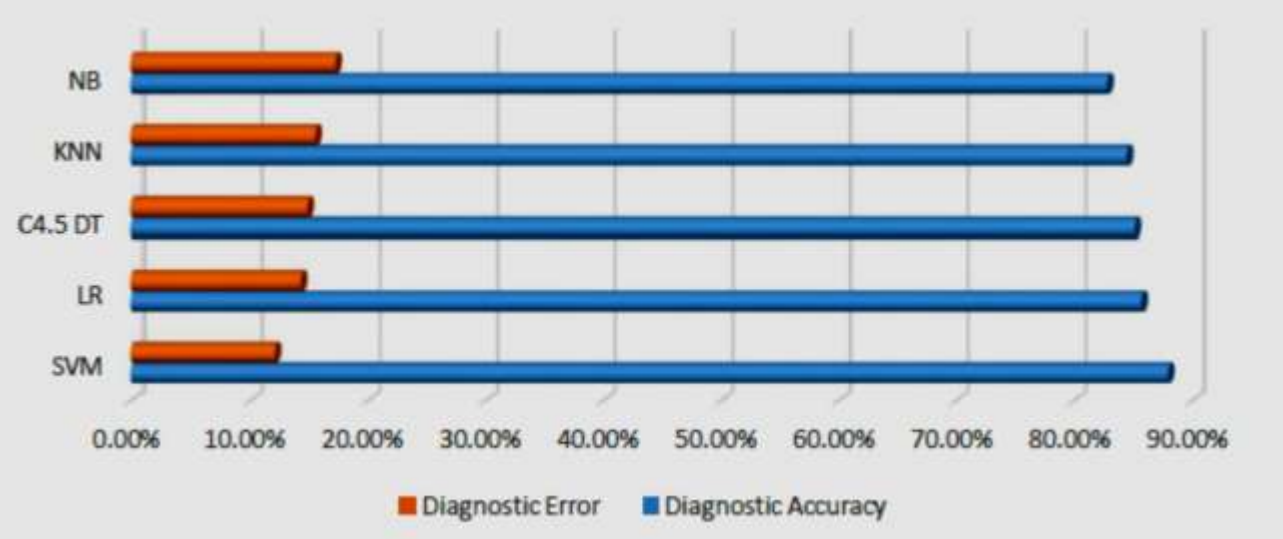

Figure 1: *Diagnosis Accuracy and Error Rate of the Five Diagnostic Models*

4.1 Performance Evaluation

Kokkotis *et al.*, (2020) applied seven ML algorithms to implement seven KOA diagnostic models with the osteoarthritis initiative (OAI) database. OAI database is a nationwide research study, sponsored by the National Institutes of Health to established and maintains a natural history database for osteoarthritis that include clinical evaluation data, radiological (x-ray and magnetic resonance) images, and a biospecimen repository from 4796 men and women between 45-79, enrolled between February 2004 and May 2006.

Table 4: *Performance Evaluation of the Five Diagnostic Models*

Proposed Models Evaluation with OAI Database		**Kokkotis *et al.* 2020 Evaluation of OAI Database**	
Machine Learning Models	**Diagnostic Accuracy**	**Machine Learning Models**	**Diagnostic Accuracy**
SVM	83.18%	SVM	74.07%
LR	82.23%	LR	72.84%
C4.5 DT	81.92%	DT	61.73%
KNN	78.53%	KNN	71.60%
NB	76.93%	NB	68.52%
		Random Forest	67.11%

Table 4 shows the evaluation of the five diagnostic models and it compares in terms of diagnostic accuracy with the work in Kokkotis *et al.* (2020). Figure 2 shows the evaluation of five models in comparison with the result in Kokkotis *et al.* (2020). In each of the works under comparison, SVM models achieved the best diagnostic accuracy. LR achieved the second best accuracy in both compared models. C4.5 DT achieved the third-best accuracy in the proposed model and the least diagnostic accuracy in Kokkotis *et al.* (2020); the rea- son for this disparity could be attributed to the strength of different DT algorithms, while the proposed model implemented C4.5 DT, the type of DT model implemented in Kokkotis *et al.* (2020), was not mentioned. The performance of NB is closely higher than that of KNN in both research works. All the five developed diagnostic models recorded higher diagnostic accuracy than their corresponding models in Kokkotis *et al.* (2020).

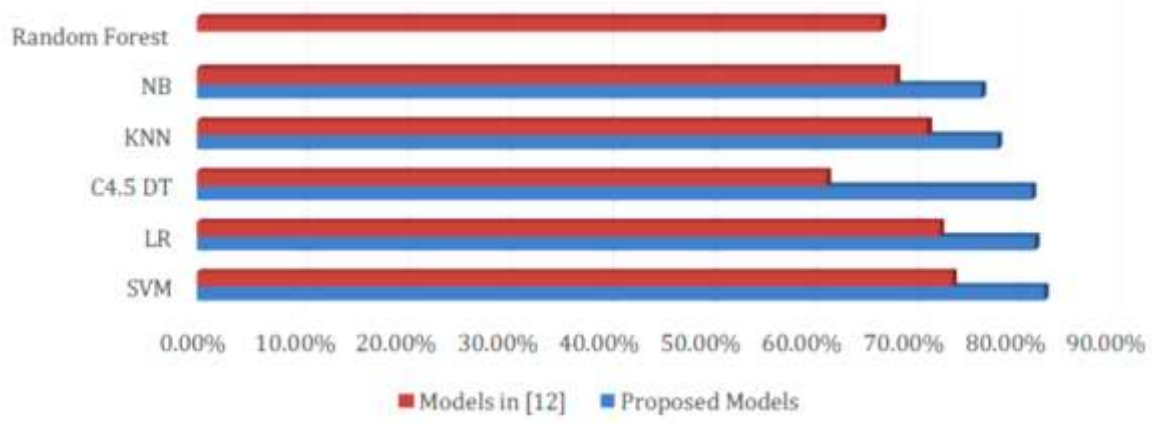

Figure 2: *Evaluation and of the Five Diagnostic Models with the OAI Database*

5 Conclusion

KOA is the most common form of arthritis and one of the leading causes of disability globally, affecting 3.8% of the global population. Early diagnosis of KOA has proven to ensure its proper management, prolong healthy patient- years, prevent cartilage from falling apart to slow down its progression, and reduce the effect of its future disability. Machine learning has been applied to clinical diagnoses of diseases and infections. This study's results have established the possibility for early clinical diagnosis of the risk of KOA using artificial intelligence. The five diagnostic models developed recorded a good accuracy with the dataset obtained from FMC Hospital and the AOI database.

6 Declarations

6.1 Acknowledgments

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6.2 Publisher's Note

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