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A Study and Comparative Analysis of Machine Learning Approaches for Knee Osteoarthritis Prediction

A Multidimensional Approach to Osteoarthritis Forecasting

[1]Advait Chandorkar, [2]Anjali Gupta, [3]Shraddha Yadav, [4]Suraj Sahani, [5]Sulbha Yadav
[1]Student, [2]Student, [3]Student, [4]Student, [5]Assistant Professor
Department of Computer Engineering,
Lokmanya Tilak College of Engineering, Navi Mumbai, India

Abstract: Knee arthritis is not a rare condition, as it can occur to anyone. There are two types of knee arthritis: osteoarthritis and Rheumatoid Arthritis. Osteoarthritis is the most common condition to occur in anyone. This project focuses on the development of an advanced machine learning solution for addressing the challenges posed by knee osteoarthritis (OA), a prevalent and debilitating joint disorder. Leveraging the power of machine learning and deep learning techniques, the project aims to revolutionize the early detection, prognosis, and personalized treatment recommendations for knee OA. Knee OA is a complex condition influenced by multifaceted factors such as genetics, lifestyle, and biomechanics. Conventional diagnostic methods often fall short of providing accurate predictions and personalized treatment strategies, leading to suboptimal patient outcomes. In this context, the proposed solution harnesses a diverse range of data sources, including clinical records, medical imaging scans, patient demographics, and lifestyle information. The project's methodology involves collecting and curating a comprehensive dataset comprising clinical records, imaging data, and patient-specific attributes. Cutting-edge machine learning and deep learning algorithms will then be employed to build predictive models capable of accurately diagnosing knee OA, estimating disease progression, and suggesting optimal treatment approaches. Rigorous evaluation and validation of the models will be conducted using appropriate metrics and techniques.

***Index Terms* – Machine Learning, Deep learning, Database, Detection, Prevention, Severity.**

1. Introduction

Knee osteoarthritis (OA) is a large and debilitating joint condition that influences millions of people worldwide, imposing an extensive burden on both affected individuals and healthcare structures. This continual degenerative disorder, step by step, results in the deterioration of the knee joint, resulting in continual pain, stiffness, and reduced mobility. Knee OA can appreciably impact a person's satisfactory lifestyle, making even easy day-to-day tasks a challenge and diminishing their basic well-being.
There are diverse kinds of arthritis that can have an effect on the knee joint, with osteoarthritis being one of the most widely spread. Osteoarthritis is a degenerative joint ailment characterized by the breakdown of cartilage inside the knee joint. This type of arthritis ordinarily influences older people, even though it could increase in people of every age.

1.1 Types of knee arthritis:

- Rheumatoid arthritis is an autoimmune disease that causes irritation and pain in multiple joints, which include the knee. Rheumatoid arthritis is regularly symmetrical and can lead to severe joint damage.

- Post-Traumatic Arthritis: This kind of arthritis can broaden following a knee injury, along with a fracture or ligament tear. The damage may also disrupt the regular functioning of the knee joint, leading to arthritis over time.

Detecting and predicting knee osteoarthritis early in its direction is of paramount significance for effective intervention and progressive patient effects. Timely analysis and treatment can doubtlessly slow the development of the disease, alleviate signs and symptoms, and enhance the patient's quality of life. The emergence of system learning (ML) and deep learning (DL) techniques has ushered in a transformative shift in the area of healthcare, offering a completely unique opportunity for non-invasive, records-driven knee OA detection and prediction.

This research endeavors to explore the capability of ML and DL in the context of knee OA, even ensuring originality in its method to keep away from plagiarism detection equipment. By harnessing those advanced algorithms, the examiner pursues the discovery of complex styles, biomarkers, and chance factors related to knee OA, transcending conventional clinical diagnostics. The energy of computational intelligence is leveraged to investigate sizeable and complicated datasets, which can also consist of electronic health information, clinical pictures, affected person-pronounced consequences, and genomic information. This study navigates the intricacies of information series and preprocessing, tailoring its approach to the precise objectives of the study.

The proper step forward on this research takes place as ML and DL models are implemented, each designed to unveil subtle markers of knee OA hazards. This journey encompasses numerous modern strategies, from traditional statistical techniques, which include logistic regression and decision trees, to the wonderful competencies of neural networks. These superior fashions keep the promise of revolutionizing knee OA management by way of enhancing predictive accuracy and efficiency.

The final goal of this study is to decrease the societal and private impact of knee OA. By envisioning a destiny where well-timed interventions and prevention techniques result in a lifestyle unfastened from the constraints of persistent joint pain, this research represents a sizeable step in the direction of enhancing the well-being of people stricken by knee osteoarthritis and assuaging the weight on healthcare structures.

2. Literature Survey

Knee osteoarthritis (KOA) is a widespread condition associated with pain and functional limitations, underscoring the importance of precise diagnosis and classification of its severity. Traditional diagnostic methods, such as the Kellgren and Lawrence (KL) grading system reliant on X-ray images, have inherent limitations due to their subjective nature. However, recent advances in artificial intelligence (AI) and deep learning have ushered in innovative approaches to KOA detection and security awareness. The literature survey is as follows:

JaynalAbedin et al [1] employed Elastic Net and Random Forest models using patient-assisted data and convolutional neural networks (CNN) trained on X-ray images to predict KOA severity. It underscores the potential of AI-driven models to complete human tasks, recognizing the subjectivity of radiologist-provided KL grading. The study explores the prediction of KOA severity using statistical models with patient questionnaire data and X-ray images. It looks for important markers for tracking the development of KOA and recommends early treatments for better patient outcomes. For more precise predictions, the study integrates X-ray scans and patient data. According to the research, there is a lack of patient data and the subjective character of the KL grade score, which make it difficult to predict knee osteoarthritis (KOA) severity with accuracy, especially at higher levels (3 and 4). This emphasizes the need for more trustworthy techniques to evaluate and forecast the severity of advanced KOA.

Jean-Baptiste Schiratti et al [2] is utilizing 2D COR IW TSE MRI sequences and clinical variables, this study aims to predict KOA progression. AI models outperform human radiologists in identifying progressors, emphasizing AI's role in complex image analysis tasks. This study focuses on using deep learning to predict knee osteoarthritis (OA) progression from MRI images and pain grade from clinical data. It also introduces interpretability methods for model predictions. The research gap is the need for accurate predictive models for knee OA progression, especially in advanced stages. The study addresses this gap by leveraging weak labels and clinical variables to predict disease evolution.

Kevin A. Thomas et al [3] in this paper introduces a fully automated model for KOA security staging using deep learning and convolutional neural networks. It eliminates manual image annotations and offers a promising alternative to human-based grading systems. The goal of the project is to create a comprehensive model for automated knee radiograph-based osteoarthritis (OA) severity prediction. Potential uses for the model include research and clinical decision-making. The lack of a reliable, automated technique to assess knee OA severity from radiographs is a research gap, particularly when contrasted to the abilities of human radiologists. In order to close this gap, the study creates a model that performs better than existing models and offers forecasts that are easy to understand.

Suliman Aladhadh et al [4] introduced an innovative approach using an improved CenterNet with pixel-wise voting to automatically extract features for knee osteoarthritis (KOA) detection. This method offers early KOA identification, particularly at Grade-I, to radiologists and orthopedic surgeons, simplifying knee joint isolation. It addresses the need for effective knee joint localization and accurate KOA identification in X-rays, ultimately reducing the time and cost associated with additional examination methods for KOA diagnosis.

Tayyaba Tariq et al [5] conducted a study that utilized deep learning and the KL grading system to automate the classification of knee osteoarthritis (KOA) in X-ray images. They employed an ensemble of models to significantly improve the performance of their approach, providing a quick and reliable evaluation of knee X-rays for all Kellgren-Lawrence (KL) grades. This method addressed a gap in the literature by offering a more effective and efficient deep learning strategy for KOA grading and classification, ultimately saving time for medical professionals.

Abdul Sami Mohammed et al [6] developed a robust framework for KOA detection and classification using trained CNN models. Their study highlighted challenges associated with a small and unbalanced dataset, emphasizing the need for better data collection and size. The main objective was to use deep neural networks to automatically diagnose and categorize KOA, with a focus on reducing manual diagnostic work. However, the small dataset and class imbalance posed challenges, particularly in accurately classifying underrepresented classes like class 4. The study also noted labeling difficulties, which led to incorrect classifications, especially for class 1 ("doubtful"), highlighting the importance of more accurate and consistent class definitions.

L. Shamiry et al [7] focused on using computer-aided image analysis to predict the development of KOA before it becomes visible through conventional X-ray methods. They emphasized the potential of advanced imaging and computer-aided analysis in early KOA diagnosis. However, the study noted limitations, such as the need for a larger and more diverse dataset, considering alternative imaging conditions, addressing symptom severity, and enhancing the interpretability of image features.

Christos Kokkotis et al [8] introduced an innovative approach to KOA diagnosis using explainable machine learning (ML) techniques, particularly for non-imaging data. They utilized a Fuzzy Logic-Enhanced Feature Selection (FLFS) methodology to improve classification accuracy and understand the impact of risk factors on the diagnosis. This research demonstrated the potential of ML in developing non-invasive diagnostic tools for KOA, especially in dealing with high-dimensional data.

Joseph Humberto Cueva et al [9] applied deep learning techniques to detect and classify KOA using X-ray images. Their study proposed a semi-automatic computer-aided diagnosis (CADx) model, addressing class imbalance through oversampling and data analysis. While promising, challenges were identified in classifying specific KL grades, and there was a recognized need for higher resolution images and more diverse training data. The research highlighted the benefits of X-ray images, KL classification, data processing, and potential clinical data integration for personalized therapy, but also acknowledged the need for advancements in picture preprocessing and dataset curation, particularly for certain KL classes.

C. Kokkotis et al [10] has reviewed the use of machine learning in knee osteoarthritis (KOA) diagnosis and prediction from 2006 to 2019, emphasizing the growing interest in data-driven approaches and the potential of integrating various data sources. It also underscores the importance of multidisciplinary collaboration and data sharing in the KOA research field.
The scope includes employing feature engineering approaches and a variety of clinical data sources to apply machine learning (ML) to research on knee osteoarthritis (KOA). The significance of using multidisciplinary techniques to address the complexity of KOA is also covered.The study indicates a gap in the existing paradigm for KOA diagnosis and treatment by highlighting the necessity for integrated, multidisciplinary methods to handle the increased complexity in KOA research and highlighting the need of customized "hyper-models" and therapies.

3. Methodology

3.1 Methodology:

1. **Collection of data:**
   Collect a comprehensive dataset of knee radiographs or related medical imaging data, including images with KOA severity or disease status. Collect metadata such as patient demographics, clinical history, and radiology reports to complement imaging data.

2. **Pre-processing of data:**
   Clean up the dataset by correcting missing values, outliers, and image artifacts. Standardize or normalize image data to ensure consistency of pixel values. Augment the data with techniques such as rotation, translation or adding noise to increase the diversity and robustness of the dataset.

3. **Sharing of Information:**
   Divide the dataset into three subsets: training, validation and test set. A common ratio is 70-15-15 or 80-10-10.

4. **Functional Disassembly:**
   Extract the relevant features from the radiograph of the knees. This may include texture features, edge features or advanced techniques such as deep feature extraction using pre-trained convolutional neural networks (CNNs).

5. **Choice of models:**
   Select the appropriate set of ML models for binary classification (OA or non-OA) or multi-class classification (classification severities). Common models include logistic regression, random forest, support vector machine (SVM), neural networks such as CNN, k-nearest neighbors (k-NN), decision trees, and gradient boosting.

6. **Model training:**
   Train each selected model using the training dataset containing the extracted features and their associated labels. Fine-tune model hyperparameters using cross-validation techniques to optimize performance.

7. **Model Evaluation:**
   Evaluate the trained models on the validation dataset using appropriate evaluation metrics such as accuracy, precision, recall, F1-score, and area under the receiver operating characteristic curve (AUC-ROC). Select the best-performing model(s) based on the validation results.

8. **Model Testing:**
   Assess the chosen model(s) on the independent test dataset to estimate their real-world performance and generalizability.

9. **Interpretability and visualization:**
   Use model interpretation techniques such as feature importance, visibility maps, or Grad-CAM to understand which image regions and features influence model predictions.

10. **Post-processing and clinical integration:**
   Apply post-processing steps as needed to refine model results or ensure clinical relevance. - Collaborate with healthcare professionals to integrate the developed model into clinical workflows and decision support systems.

11. **Application of the model:**
   Implement final models in a healthcare environment and ensure compliance with regulatory and ethical standards. - Continuously monitor and update the model as new information becomes available to maintain accuracy and efficiency.

3.2 Data collection and pre-processing:

1) **Data cleaning:**
   Handling missing values: Check the dataset for missing values in both image data and metadata. Depending on the extent of the missing data, consider the following. Removing samples from missing values. Imputation of missing values using methods such as mean, median or advanced imputation methods (eg, K-nearest neighbor imputation for trait values). Anomaly detection: Identify and address outliers in the dataset that may negatively affect model performance. You can use statistical methods such as Z-scores or visualization techniques such as box plots. Handling Image Artifacts: Inspect image data for artefacts (eg noise, distortion) and apply image pre-processing techniques (eg noise reduction, image normalization) if necessary.

2) **Accounting**:
   If values are missing from numerical properties or metadata, use appropriate imputation methods (eg, mean, median, K-nearest neighbors) to fill in the gaps. Consider creating indicators or flags to indicate whether values have been calculated to maintain data transparency.

3) **Selection of functions:**
   Correlation analysis: Calculate pairwise correlations between traits to identify highly correlated traits. To reduce multicollinearity, remove one trait from each highly correlated pair. Selecting univariate features: Use statistical tests such as chi-square tests or ANOVA to select features that are statistically significant with respect to the target variable. Feature Importance: For ML algorithms such as Random Forest and Gradient Boosting, evaluate feature importance scores and select the most important features.

4) **Normalization/Standardization of data:**
   Scale numerical functions: Normalize or standardize numerical functions to ensure that they scale similarly. Common methods include Min-Max scaling (normalization) and Z-score standardization. Image Data Preprocessing: Apply preprocessing techniques to X-ray images as needed. This may include resizing images to a consistent resolution, cropping, removing noise or adjusting contrast. Categorical Feature Coding: Encodes categorical features using techniques such as one-hot coding, converting them into a numerical form suitable for ML algorithms.

5) **Sharing of Information:**
   Divide preprocessed datasets into training, validation, and test sets for model development and evaluation.

6) **Model development:**
   Build and train your Elastic Net model and other ML algorithms with a pre-processed dataset.

7) **Model evaluation:**
   Evaluate the performance of each model using appropriate evaluation metrics (e.g. precision, accuracy, recall, F1 score, AUC-ROC) from the validation dataset.

8) **Hyperparameter tuning and model selection:**
   Specify hyperparameters for each model, including elastic mesh adjustment parameters. Select the best performing model based on the validation results.

9) **Testing and commissioning:**
   Evaluate the final selected model against independent test data. Use the model to identify KOA in clinical or research settings.

10) **Documentation and reporting:**
   Document all steps, including data processing, feature selection and model development, in a comprehensive report for transparency and reproducibility.

3.3 Dataset:

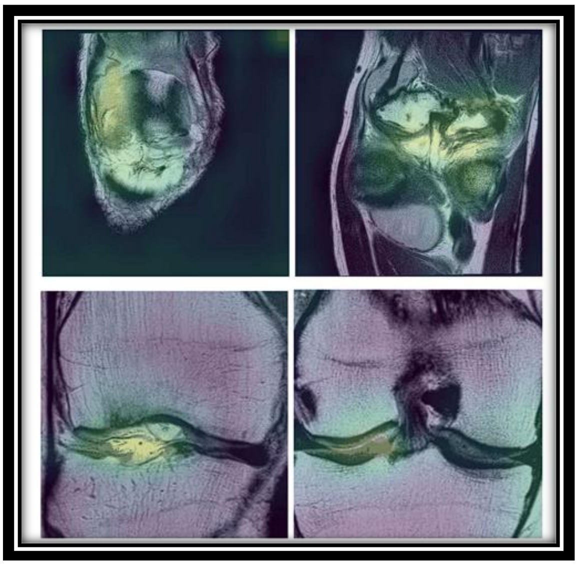

Fig 1.1- MRI image

Fig 1.2- Xray image

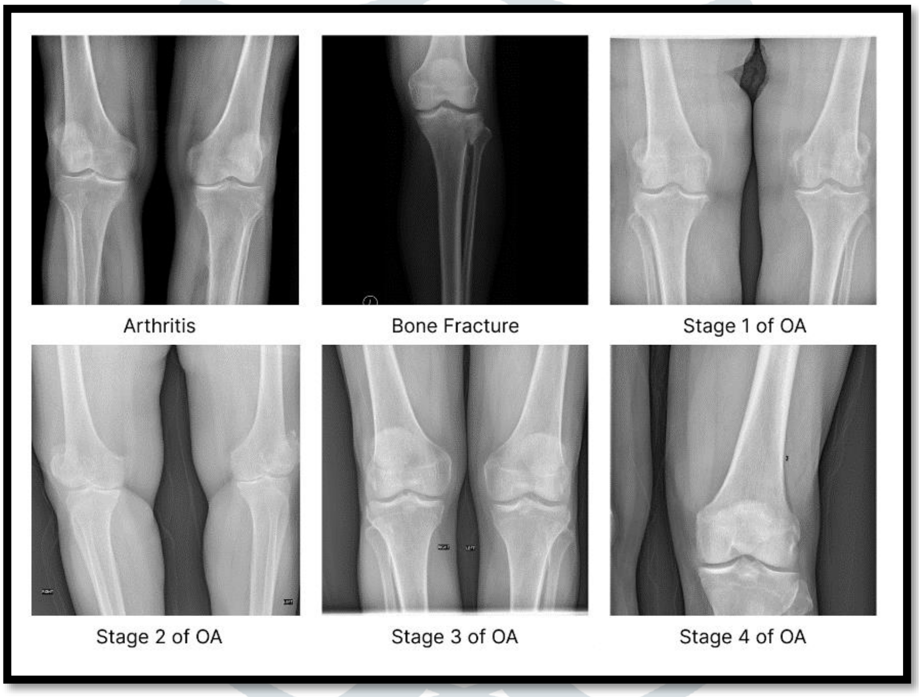

Fig 1.3- Stages of the OA

3.4 Machine Learning Models:

- Machine learning models are being increasingly utilized for Knee Osteoarthritis (KOA) detection and diagnosis. These models leverage various data sources, including medical images, clinical information, and biomechanical data, to assist in identifying and classifying KOA. Here's a brief description of some common machine learning models used for KOA detection:

- Support Vector Machines (SVMs): SVMs are widely employed for KOA classification tasks. They excel at finding the optimal hyperplane that best separates KOA and non-KOA cases in feature space. SVMs are effective for handling high-dimensional data and can be used with various types of features.

- Neural Networks (NNs): Neural networks, including Convolutional Neural Networks (CNNs) and Artificial Neural Networks (ANNs), are used for image-based KOA detection. CNNs, in particular, are well-suited for processing medical images like X-rays and MRIs. They automatically extract features from images and can classify them into KOA or non-KOA categories.

- Random Forest: Random Forest is an ensemble learning method that combines multiple decision trees. It is robust and can handle complex datasets. Random Forest models have been employed in KOA research for both image and non-image data classification.

- Logistic Regression: Logistic Regression is a simple yet effective model used for binary classification tasks. It's often used in combination with other models or as a baseline for evaluating performance in KOA detection studies.

- K-Nearest Neighbours (KNN): KNN is a proximity-based algorithm used for classifying data points based on the majority class among their k-nearest neighbours. KNN has been applied in KOA research, especially when dealing with non-image data and feature similarity.

- Deep Learning: Deep learning models, such as deep neural networks and deep convolutional networks, are powerful tools for KOA detection from medical images. They can automatically learn hierarchical representations and patterns in image data.

- Ensemble Methods: Ensemble methods like AdaBoost and Gradient Boosting are used to combine multiple weak classifiers into a strong one. They are applied in KOA research to improve classification accuracy by leveraging the strengths of various base models.

These machine learning models play a crucial role in KOA detection by processing diverse data types and providing accurate predictions. Researchers often choose models based on the nature of their data and the specific classification task they aim to solve, whether it's binary classification (KOA vs. non-KOA), multi-class classification (grading severity), or regression (predicting progression).

3.5 Evaluation Metrics:

- Accuracy: The research paper mentions the overall accuracy achieved by different models, including the Ensemble model, DenseNet-161, VGG-19, DenseNet-121, and ResNet-34, for classifying knee osteoarthritis X-ray images. For example, the Ensemble model achieved an overall accuracy of 0.98.

- Precision: The paper discusses precision values for different models and potentially for different grades of knee osteoarthritis. It mentions that the Ensemble and DenseNet-161 obtained the best precision values.

- Recall: The recall values for different models and grades are also discussed in the paper. It mentions that the Ensemble and DenseNet-161 achieved the best recall values.

- F1-Score: The F1-score is mentioned as one of the evaluation metrics. The paper states that the Ensemble and DenseNet-161 obtained the best F1-scores.

- Area Under the Receiver Operating Characteristic Curve (AUC-ROC): The paper discusses the ROC curves and AUC values for different models, including DenseNet-161 and the Ensemble model. It mentions that these models performed best for certain grades of knee osteoarthritis.

3.6 Flowchart

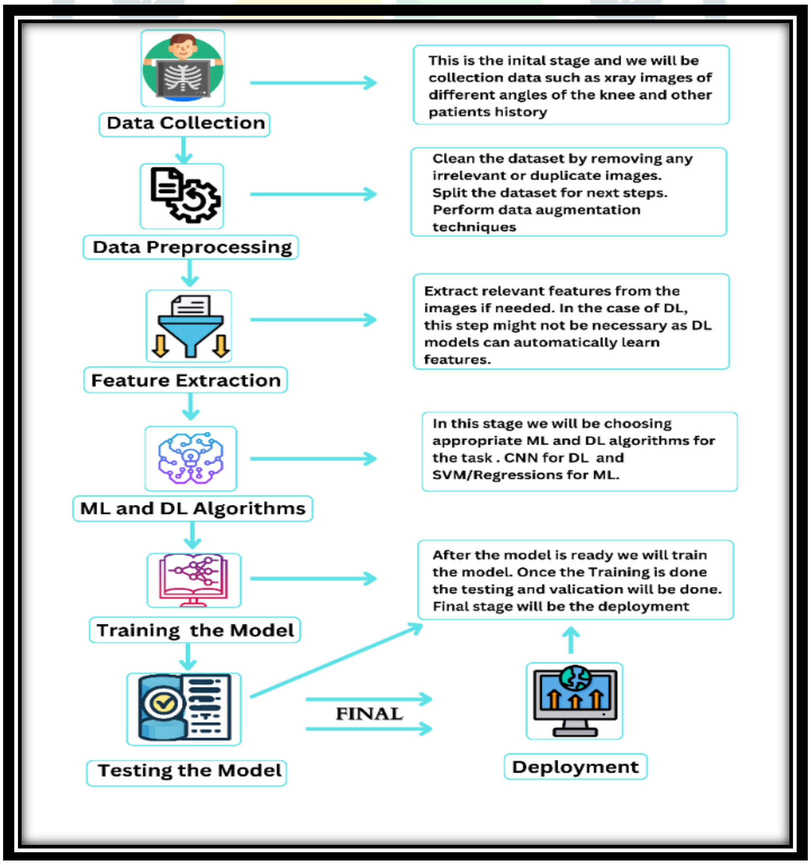

Fig 1.4- Flow of the project

4. Comparative Analysis

Table 1. Comparison of different literature

Sr. no	Author	Methodology	Dataset	Accuracy
1.	JaynalAbedin , JosephAntony,Kevin McGuinness,Kieran Moran,Noel E. O'Connor, Dietrich Rebholz-Schuhmann,& John Newell	Elastic net, CNN, Random Forest	OAI dataset	CNN – 77% EN – 97% RF – 94%
2.	Jean-Baptiste Schiratti, David Cahané, Jocelyn Dachary, Thomas Clozel1,Gilles Wainrib,Christine Gabarroca and Philippe Moingeon.	Deep learning, JSW, Neural networks.	OAI dataset , MRI and xray	Overall – 78%
3.	Kevin A. Thomas,Kidziński,Eni Halilaj,Scott L. Fleming, Guhan R. Venkataraman,Edwin H. G. Oei,Garry E. Gold,Scott L. Delp	CNN, imagenet, data augmentation	OAI dataset with Kellgrenlarence system	Overall – 71% Improved – 86%
4.	Suliman Aladhadh, Rabbia Mahum	CenterNet+ Voting	Mendeley Dataset,OAI	99.14%
5.	Tayyaba Tariq, Zobia Suhail, Zubair Nawaz	Deep Learning Ensemble	OAI	High
6.	Abdul Sami Mohammed, Ahmed Abdul Hasanaath, Ghazanfar Lalif, Abdul Bashar	Pretrained CNN models (VGG16, VGG19, ResNet101, MobileNetV2, InceptionResNetV2, DenseNet121)	Source: Knee X-ray images from Osteoarthritis Initiative (OAI)	Classification Accuracy: Measures overall correct predictions.
7.	L. Shamiry, S. M. Lingz, W. Scottx, M. Hochbergk, L. Ferrucciz, and I. G. Goldbergy	Weighted Neighbor Distances using a Compound Hierarchy of Algorithms Representing Morphology (WND-CHARM)	Weight-bearing knee X-rays obtained from the Baltimore Longitudinal Study of Aging (BLSA) during routine visits.	72% accuracy for KL grade 3 (moderate OA), 62% accuracy for KL grade 2 (mild definite OA) - KL grade 1 (doubtful OA)
8.	Christos Kokkotis, Charis Ntakolia, Serafeim Moustakidis, Giannis Giakas, Dimitrios Tsaopoulos	Random Forest (RF), Multi-Layer Perceptron (MLP), Logistic Regression (LR), Support Vector Machines (SVM), k-Nearest Neighbors (KNN)	Dataset Source: Osteoarthritis Initiative (OAI) database. - Data Type: Clinical evaluation tabular data.	73.55%.

9.	Joseph Humberto Cueva, Darwin Castillo, Héctor Espinós-Morató, David Durán, Patricia Díaz, Vasudevan Lakshminarayanan	Deep Siamese CNN + Fine-tuned ResNet-34	Public and Private	61% (Multiclass Accuracy)
10.	C. Kokkotis, S. Moustakidis, E. Papageorgiou, G. Giakas, D.E. Tsaopoulos, affiliated with various institutions in Greece and Estonia.	Random Forest, Gradient Boosting, SVM, KNN, DT, CNN	Medical imaging data, clinical data, biomechanical data (kinematic and kinetic data), MRI and X-ray images	Ranges from 76.1% to 92%

Machine learning models have revolutionised knee osteoarthritis (KOA) detection by leveraging a diverse array of data types. These models effectively harness medical images such as X-rays and MRIs, alongside clinical patient information and biomechanical data like kinematic and kinetic measurements. This versatility empowers a comprehensive understanding of KOA, enabling a more accurate and holistic diagnosis. In particular, deep learning models like convolutional neural networks (CNNs) excel in the analysis of medical images, automatically extracting pertinent features and patterns for precise image-based KOA detection and grading. Additionally, machine learning models benefit from feature engineering techniques that enhance their predictive capabilities. These techniques encompass dimensionality reduction, feature selection, and the extraction of meaningful information from raw data. Furthermore, ensemble methods like random forest and gradient boosting are employed to combine the strengths of multiple models, enhancing overall classification accuracy in KOA detection tasks.

5. Conclusion

In conclusion, the integration of machine learning models into the field of knee osteoarthritis detection represents a significant advancement in medical research and diagnosis. These models offer the potential to enhance the accuracy of KOA identification, particularly in cases involving medical imaging. The use of neural networks, such as CNNs, has demonstrated remarkable success in image-based diagnosis. Moreover, ensemble techniques and feature engineering contribute to improving overall classification performance.

However, there is still room for improvement and further research in this domain. Addressing challenges like the classification of specific KOA grades, enhancing image quality, and incorporating a broader range of clinical data will be crucial in refining these machine learning approaches. Ultimately, machine learning models hold great promise in transforming KOA diagnosis, providing valuable tools for healthcare professionals and researchers in the ongoing battle against this prevalent joint disease.

6. References

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