



CARTILAGE DEGENERATION IN OSTEOARTHRITIS USING AI

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Abstract: Osteoarthritis (OA), also known as degenerative joint disease, is a chronic condition characterized by the gradual deterioration of cartilage within the joints. This degeneration leads to pain, stiffness, and reduced joint function, significantly impacting the quality of life of those affected. OA is closely associated with aging, as its symptoms tend to worsen over time, causing long-term discomfort and structural changes to the affected joints. As the disease progresses, it can lead to severe pain, disability, and a significant loss of mobility, making it one of the leading causes of disability worldwide. OA primarily affects weight-bearing joints such as the knees, hips, and spine, but can also involve smaller joints in the hands and feet. Despite the widespread prevalence of osteoarthritis, the best available treatments primarily focus on pain management and improving joint function but do not offer a cure for the degenerative process. Current treatment options include medications, physical therapy, and in severe cases, joint replacement surgery. However, these therapies only address the symptoms, and they cannot stop or reverse the progression of the disease. As the global population ages, OA is expected to become an even more significant public health issue, with an increasing number of individuals experiencing its debilitating effects. In recent years, significant advancements in Artificial Intelligence (AI), especially Machine Learning (ML) and Deep Learning (DL), have shown promise in improving the accuracy and efficiency of osteoarthritis detection and diagnosis. AI techniques, when applied to medical imaging, clinical data analysis, and predictive modeling, offer a powerful tool to detect early signs of OA, potentially before the onset of symptoms. By analyzing complex datasets from medical images (such as X-rays, MRIs, and CT scans) and patient-specific clinical data, AI can identify subtle patterns and predict the risk of progression. This early detection could enable clinicians to intervene sooner, potentially preventing or slowing down the disease's progression. This review paper aims to explore the state-of-the-art AI techniques applied to the detection and diagnosis of degenerative joint disease, focusing on the most innovative image-based detection methods, clinical data analysis, and predictive modeling techniques. It will provide an overview of how AI is enhancing the diagnostic accuracy of OA, examining both established and emerging approaches. The paper also identifies key open problems and research gaps, including the need for better data quality, model generalizability, and integration of AI tools into clinical workflows. Furthermore, it discusses the challenges associated with incorporating AI into osteoarthritis diagnostics, such as data privacy concerns, regulatory hurdles, and the need for interpretability of AI models to ensure trust and adoption by healthcare professionals. Finally, this paper will look at the future prospects of AI in osteoarthritis diagnosis and management, including the potential for personalized medicine, more effective treatment strategies, and improved patient outcomes. As AI technologies continue to evolve, they hold the potential to revolutionize the way osteoarthritis is detected, treated, and managed, offering hope for better care and quality of life for millions of people worldwide.

Keywords - Osteoarthritis detection, X-ray Images, Segmentation, Machine learning Classifier, deep learning classifier.

1. INTRODUCTION

Knee osteoarthritis is a chronic & progressive disease with symptoms caused due to age, obesity overweight people. It is a common form of arthritis. It occurs structural changes in all soft tissues surrounding the knee joint Osteoarthritis (OA) [1]. Osteoarthritis (OA) is a joint disease that mostly affects the cartilage. Cartilage is the protective connective tissue that covers the end of bones in a joint. The normal or healthy cartilage allows easy glide of bone in the joint and prevents them from rubbing each other. It is painful and disabling disease that affects millions of patients. [2]Medical imaging is the process of creating visual representations of the internal structures hidden by the skin and bones. It is the technique where the interior parts of the body for clinical diagnosis and medical intervention are revealed. Medical imaging is a part of biological imaging that incorporates various imaging technologies like X-ray is the most common form of arthritis and a leading cause of joint pain and disability worldwide.[3] .The rate of knee cartilage is measured in Kellgren Lawrence[KL]. The KL scale is divided into five grades which are ranging from 0 to 4.

Early detection and accurate diagnosis are critical for effective treatment and management of OA, which can significantly improve patient quality of life and reduce healthcare costs.It affects millions of people globally. In this symptoms are like pain, swelling, stiffness and disability. For detection process we are using Artificial Intelligence (AI). [4]

Degenerative joint disease (DJD), or osteoarthritis (OA), affects millions of people globally. Characterized by the gradual degeneration of joint cartilage and bone, OA leads to symptoms like pain, swelling, stiffness, and disability. Traditional methods for diagnosing DJD rely heavily on clinical assessments and imaging techniques, such as X-rays, magnetic resonance imaging (MRI), and ultrasound, which can be time-consuming and prone to variability between observers [5].

2. Background of Osteoarthritis

Osteoarthritis is a chronic disease caused by various factors, including age, genetics, obesity, joint injuries, and mechanical stress. It primarily affects weight-bearing joints such as the knees, hips, and spine. The key pathological feature of OA is the breakdown of joint cartilage, leading to changes in the surrounding bones and tissues. As the disease progresses, patients experience pain, decreased range of motion, and joint deformities.

Early detection is crucial to managing the disease and slowing its progression. However, current diagnostic methods rely heavily on radiological imaging and clinical scoring systems, such as the Kellgren-Lawrence (KL) grading system, which can be subjective and inconsistent. AI-driven approaches offer a promising alternative, with the potential to provide more objective, accurate, and efficient diagnostic tools.[6]

This involves acquiring images of knee osteoarthritis from hospitals and employing various processing techniques such as re-processing, segmentation and feature extraction, machine learning classifier and deep learning classifiers. Subsequently, these processed images are categorized into five groups: normal, doubtful, mild, moderate, and severe to assess and compare the accuracy of different methods. Our goal is to detect the Knee Osteoarthritis using machine learning and deep learning algorithms.



Figure 1. Structure of human knee.

3. Literature Review

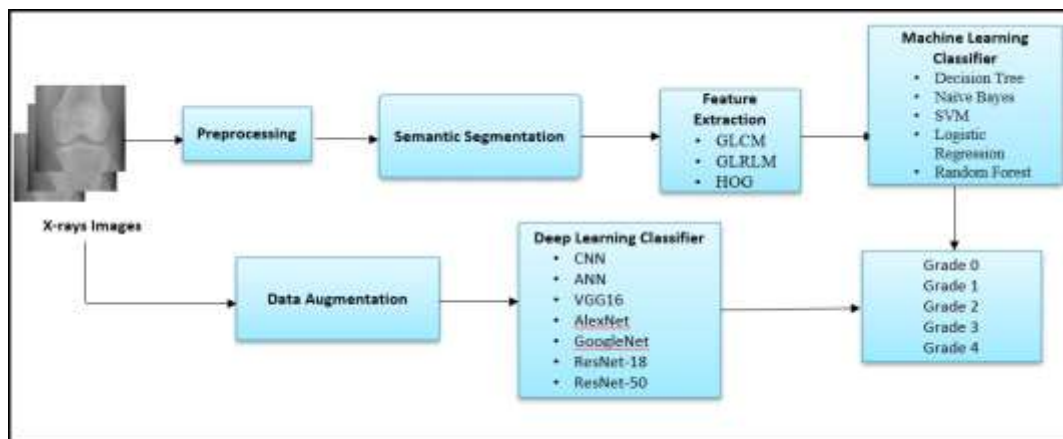
Shivanand S. Gornale proposed [1], Osteoarthritis cartilage is breaker due to which bones start kneading each other leading to a severe pain. The scenario for the evaluation of Osteoarthritis includes clinical examination & various medical imaging techniques. Authors have used Active contour segmentation technique to segment the part of the knee X-ray image to diagnosis the disease. The features like Haralick, Statistical, First four moments, Texture and Shape are computed and classified using Random Forest classifier. The used method gives more competitive and promising outcome with the existing algorithms.

A Novel Hybrid Approach Based on Deep CNN Features to Detect Knee Osteoarthritis presented for early-stage prediction of Knee Osteoarthritis. The multi-class classifiers SVM, RF, and KNN, are used to classify Knee Osteoarthritis. The input X-ray images are preprocessed, and then the Region of Interest (ROI) is extracted through segmentation. Secondly, features are extracted from preprocessed X-ray images containing knee joint space width using hybrid feature [4] descriptors such as Convolutional Neural Network (CNN) through Local Binary Patterns (LBP) and CNN using Histogram of oriented gradient (HOG).

Article[5] Identifying Severity Grading of Knee Osteoarthritis from X-ray Images Using an Efficient Mixture of Deep Learning and Machine Learning Models proposed models which are divided into two frameworks based on applying pre-trained convolutional neural networks (CNN) for feature extraction as well as fine-tuning the pre-trained CNN using the transfer learning. In the first framework five classes-based models using a proposed pre-trained CNN for feature extraction, principal component analysis (PCA) for dimensionality reduction, and support vector machine (SVM) for classification. While in the second framework, a few changes were made to the steps in the first framework, the concept of TL was used to fine-tune the proposed pre-trained CNN from the first framework to fit the two classes, three classes, and four classes-based models.

Kumar and Goswami [9] tackled the limitations of traditional machine learning and deep learning approaches by incorporating image sharpening techniques in their CNN-based model for knee osteoarthritis classification. They noted that inadequate preprocessing of knee X-ray images had previously hampered feature extraction, leading to suboptimal model accuracy. By applying image sharpening, they improved the clarity of the X-rays, which in turn enhanced the model's ability to identify key features related to OA severity. Their study, which utilized the Kellgren–Lawrence (KL) grading system on images from the Osteoarthritis Initiative (OAI), demonstrated a significant improvement in classification accuracy—from 72% with unprocessed images to 91.03% after sharpening.

3. AI Techniques in Osteoarthritis Detection



Block Diagram of Proposed System.

(Feature Extraction + Machine Learning Classification) Feature Extraction:-

1. Gray-Level Co-Occurrence Matrix (GLCM)

- GLCM contains information about the position of pixels having similar Gray-levels. Key features of GLCM known as Harlick features are listed below. Other features are also extracted. RGB channels are extracted, and then, for each channel, 22 GLCM features are extracted. So, for each image, 66 features are considered for classification.
- The basic idea behind GLCM is texture, and it can be categorized as randomized patterns. GLCM uses a co-occurrence matrix. The spatial relationship between the pixel and its neighboring pixel is considered.

2. Gray-Level Run Length Matrix (GLRLM)

GLRLM is a method for extracting texture features from images. In GLRLM, RGB channels for each colposcopy image are extracted, and the features mentioned below are extracted from each channel. These feature vectors are used for classification by machine learning classifiers. Thus, in total, 21 features are extracted for an image.

Long-run emphasis	$LRE = \sum_{i=1}^{N_g} \sum_{j=1}^{N_r} P(i, j \Theta) / j^2 / N_r(\Theta)$
Short-run emphasis	$SRE = \sum_{i=1}^{N_g} \sum_{j=1}^{N_r} \frac{P(i, j \Theta)}{j^2} / N_r(\Theta)$
Gray-level nonuniformity	$GLN = \sum_{i=1}^{N_g} \left(\sum_{j=1}^{N_r} P(i, j \Theta) \right)^2 / N_r(\Theta)$
Run length nonuniformity	$RLN = \sum_{j=1}^{N_r} \left(\sum_{i=1}^{N_g} P(i, j \Theta) \right)^2 / N_r(\Theta)$
Run percentage	$RP = N_r(\Theta) / N_p$
Short-run low-Gray-level emphasis	$SRLGLE = \sum_{i=1}^{N_g} \sum_{j=1}^{N_r} \frac{P(i, j \Theta)}{i^2 j^2} / N_r(\Theta)$
Long-run low-Gray-level emphasis	$LRLGLE = \sum_{i=1}^{N_g} \sum_{j=1}^{N_r} \frac{P(i, j \Theta) j^2}{i^2} / N_r(\Theta)$
Long-run high-Gray-level emphasis	$LRHLGLE = \sum_{i=1}^{N_g} \sum_{j=1}^{N_r} P(i, j \Theta) i^2 j^2 / N_r(\Theta)$

3. Histogram of Gradients (HOG)

- HOG features measure the average gradient in the cell of an image concerning direction. In this, for each image, 26,112 features are extracted, and PCA with 20 components is applied for feature reduction.
- The main idea behind HOG is local object or shape in the image can be described by the distributions of intensity gradients and edge directions. The image is divided into small connected regions known as cells, and for pixels within cells, the histogram is compiled. The image gradient vector captures the changes in the magnitude of pixel colors. Steps for the calculation of HOG are shown as follows:

- Pre-processing.*

An image is cropped to size 100×200 and resized to 64×128 .

- Image gradients calculation.*

To calculate the gradient of the image, both directions, that are horizontal direction and vertical direction, are considered, i.e., the image derivative is calculated from both directions. The magnitude and direction of the gradient can be calculated as

$$g = \sqrt{g_x^2 + g_y^2} \quad \theta = \arctan \frac{g_y}{g_x}$$

where g is the magnitude of the gradient and θ is the direction of the gradient.

- *Histogram of gradients.*

The image is divided into cells of 8×8 . For each cell gradient magnitude and gradient, the direction is calculated. Histograms of magnitude and direction are made and used for the classification.

Machine Learning Classification:-

1. **Logistic Regression:-** In logistic regression, the probabilities are modeled by discrete outcomes given the input variables. It uses the sigmoid function to predict the class based on the aggregated input values. Logistic regression is a supervised ML algorithm; it predicts the probability of an output variable. The output of the target variable varies between 0 and 1.
2. **Naïve Bayes:-** The Naïve Bayes algorithm is derived from Bayes' theorem. Each feature pair is ranked independently of each other. The two assumptions of the characteristics of Naïve Bayes are independent, and all the characteristics are treated in the same way. The three types of Naïve Bayes classifiers: Gaussian, Bernoulli, and Multinomial. Gaussian Naïve Bayes is used for continuous data; Bernoulli Naïve Bayes is used for binary data; and Polynomial Naïve Bayes is used for count data.
3. **Decision Tree:-** A random forest is a supervised learning algorithm. A forest is a collection of decision trees and a supervised algorithm. The basic logic of the random forest algorithm is the decision tree. Decision trees essentially learn a hierarchy of if-then-else type problems that ultimately lead to classification. A decision tree asks the top node a series of questions with the highest priority. Then, several decision trees are run from the forest, and a majority vote is to give the final classification decision.
4. **Support Vector Machine:-** Support Vector Machine (SVM) is a supervised machine learning algorithm used for both classification and regression. Though we say regression problems as well, it's best suited for classification. The main objective of the SVM algorithm is to find the optimal hyperplane in an N-dimensional space that can separate the data points in different classes in the feature space.
5. **5.Random Forest:-** A random forest is a supervised learning algorithm. A forest is a collection of decision trees and a supervised algorithm. The basic logic of the random forest algorithm is the decision tree. Decision trees essentially learn a hierarchy of if-then-else type problems that ultimately lead to classification. A decision tree asks the top node a series of questions with the highest priority. Then, several decision trees are run from the forest, and a majority vote is to give the final classification decision.

Machine learning (ML) and Deep learning (DL) techniques are used in osteoarthritis detection. These technologies utilize extensive datasets, such as medical images and clinical data, to recognize patterns and forecast disease outcomes.

The primary motivation of this study is to build up a strategy that mixes ML and DL methods to develop an efficient DHL to classify knee OA severity based on KL grades in different categories [7]

The method used for this faster R-CNN and Google net which classifies into grades. For the performance we are using Matlab. The coding is stored in dataset.

The following steps are involved in this process

Machine Learning in Osteoarthritis Detection

Machine learning algorithms, particularly supervised learning models, have been extensively applied to osteoarthritis diagnostics. Common ML techniques include image based approach decision trees, MRI & CT imaging, support vector machines (SVM), random forests, and logistic regression. ML technologies can significantly enhance patient outcomes. Continued advancements in data integration, model validation, and ethical practices will be essential for the successful adoption of machine learning in clinical settings. [7] These models are trained on labeled datasets, where features such as age, body mass index (BMI), and joint movement data are used to predict the presence and severity of DJD [8].

Predictive Modeling: ML models are capable of analyzing patient-specific data (e.g., demographic, clinical, and genetic factors) to predict the likelihood of developing OA. These models can aid clinicians in identifying high-risk individuals for early intervention.

Feature Selection: ML models can identify the most relevant clinical and imaging features that correlate with disease progression. This is particularly useful for enhancing the interpretability of medical data.

Deep Learning in Image-Based Detection[9]

Deep learning, a subset of ML, has revolutionized medical image analysis by enabling automatic feature extraction and image classification. Convolutional Neural Networks (CNNs) have been particularly effective in detecting and grading osteoarthritis in X-rays and MRI scans. Unlike traditional ML models, CNNs do not require manual feature selection, as they learn relevant features from raw image data.[10]

- **X-ray Analysis:** Deep learning models have been applied to automate the classification of radiographic images according to the Kellgren-Lawrence grading scale. CNNs have demonstrated high accuracy in detecting osteophytes, joint space narrowing, and other radiographic signs of OA.
- **MRI Analysis:** MRI provides a more detailed view of joint structures than X-rays, allowing for the assessment of cartilage thickness, bone marrow lesions, and synovitis. DL models, particularly CNNs, have been trained to segment and quantify these features, improving diagnostic precision.

Integration of Clinical Data with Imaging

Integrating clinical data (e.g., patient demographics, medical history, and symptomatology) with imaging data (e.g., X-ray, MRI) can enhance diagnostic accuracy and facilitate personalized treatment strategies. A growing trend in AI-based osteoarthritis detection is the integration of clinical data (e.g., patient history, symptoms, and biomarkers) with imaging data to create comprehensive diagnostic models. These hybrid models leverage the strengths of both data types, allowing for more accurate predictions of disease progression and treatment outcomes.[11]

5. Challenges and Limitations

Artificial intelligence (AI) has the potential to transform the detection and management of osteoarthritis (OA)

- **Data Quality and Availability:** The success of ML and DL models heavily depends on the availability of large, high-quality datasets. Inconsistent labeling, image resolution, and demographic biases can impact model performance.[12]
- **Interpretability:** Many AI models, especially deep learning algorithms, function as "black boxes," making it difficult for clinicians to interpret the results. Developing models with greater transparency and explainability is critical for clinical adoption.[13]
- **Generalizability:** Models trained on specific datasets may not perform well when applied to different patient populations or imaging modalities. Ensuring that AI models generalize well across diverse populations is essential for widespread implementation.
- **Clinical Acceptance and Adoption:** Clinicians may be resistant to adopting AI solutions due to concerns about reliability, the need for training, and potential disruption to established practices.[14]

6. Future Directions and Conclusion

The system is a responsive web application named 'AI Dietitian' which contains the knowledge and data regarding the fitness of a person. The basic information related to the fitness such as how to maintain a good health by doing some workouts and eating some food products which includes calories, proteins and carbohydrates etc. Also contains user login such as Admin and User. The online artificial dietitian predicts the health of a person whether he is fit or unfit by using collected user data and Machine Learning prediction model. [15]

On the basis of this, the result contains the diet plan according to the predicted value. The system also contains the Chat bot which solves the different queries of user regarding the health and diet. The chat bot on backend uses a Deep Learning and Machine Learning Model which makes bot an intelligence bot and we have named it as AI Bot.

It acts as a diet consultant similar to a real dietitian. Dietitians are educated with nutrient value of foods. It also calculates BMI and other body necessary check which needs to be done for every individual.

REFERENCES

- [1] Liu, X., Virk, S., Fedorova, T., Oo, W. M., & Hunter, D. J. (2023). The effect of pentosan polysulfate sodium for improving dyslipidaemia and knee pain in people with knee osteoarthritis: A pilot study. *Osteoarthritis and Cartilage Open*, 5(2), 100343. <https://doi.org/10.1016/j.ocarto.2023.100343>
- [2] Gornale, Shivanand, "Detection of Osteoarthritis using Knee X -Ray Image Analyses: A Machine Vision based Approach ", *International Journal of Computer Applications* (0975 – 8887) Volume 145 No.1, July 2016.
- [3] Bhagyashri L. Wagaj, M.M.Patil "Osteoarthritis Disease Detection with the help of Image processing technique", *International Journal of Computer Applications* (0975- 8887), Conference on Emerging Applications
- [4] Bindushree R, Sanjeev Kubakaddi, Nataraj Urs " Detection of Knee Osteoarthritis by Measuring the Joint Space Width in Knee X ray Images", *International Journal of Electronics & Communication*, ISSN 2321- 5984, Volume 3, Issue 4, pp:18-21, April 2015
- [5] Loeser, R. F., Goldring, S. R., Scanzello, C. R., & Goldring, M. B. (2012). Osteoarthritis: A disease of the joint as an organ. *Arthritis & Rheumatism*, 64(6), 1697-1707. <https://doi.org/10.1002/art.34453>
- [6] Park, H. J., Kim, S. S., Lee, S. Y., Park, N. H., & Park, J. Y. (2013). A practical MRI grading system for osteoarthritis of the knee: association with Kellgren–Lawrence radiographic scores. *European Journal of Radiology*, 82(12), 2258-2263. doi:10.1016/j.ejrad.2013.08.016.
- [7] Ahmed, S.M.; Mstafa, R.J. Identifying Severity Grading of Knee Osteoarthritis from X-ray Images Using an Efficient Mixture of Deep Learning and Machine Learning Models. *Diagnostics* 2022, 12, 2939. <https://doi.org/10.3390/diagnostics12122939>

- [8] A. Zebari, S. S. Sadiq and D. M. Sulaiman, "Knee Osteoarthritis Detection Using Deep Feature Based on Convolutional Neural Network," 2022 International Conference on Computer Science and Software Engineering (CSASE), Duhok, Iraq, 2022, pp. 259-264, doi: 10.1109/CSASE51777.2022.9759799.
- [9] Zhang, Y., Xu, C., & Li, J. (2020). A decision support tool for early detection of knee osteoarthritis using X-ray imaging and machine learning: Data from the Osteoarthritis Initiative. *Medical Image Analysis*, 60, 101623. doi:10.1016/j.media.2019.101623.
- [10] Khalid, A.; Senan, E.M.; Al-Wagih, K.; Ali Al-Azzam, M.M.; Alkhraisha, Z.M. Hybrid Techniques of X-ray Analysis to Predict Knee Osteoarthritis Grades Based on Fusion Features of CNN and Handcrafted. *Diagnostics* 2023, 13, 1609. <https://doi.org/10.3390/diagnostics13091609>
- [11] M, G.K.; Goswami, A.D. Automatic Classification of the Severity of Knee Osteoarthritis Using Enhanced Image Sharpening and CNN. *Appl. Sci.* 2023, 13, 1658. <https://doi.org/10.3390/app13031658>
- [12] Hema Rajini, N., Anton Smith, A. (2023), "Osteoarthritis Detection and Classification in Knee X-Ray Images Using Particle Swarm Optimization with Deep Neural Network", In: Kose, U., Gupta, D., Khanna, A., Rodrigues, J.J.P.C. (eds) *Interpretable Cognitive Internet of Things for Healthcare. Internet of Things*. Springer, Cham. https://doi.org/10.1007/978-3-031-08637-3_5
- [13] T. Tariq, Z. Suhail and Z. Nawaz, "Machine Learning Approaches for the Classification of Knee Osteoarthritis," 2023 3rd International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME), Tenerife, Canary Islands, Spain, 2023, pp. 1-6, doi: 10.1109/ICECCME57830.2023.10252236.
- [14] S. Aladhadh and R. Mahum, "Knee Osteoarthritis Detection Using an Improved CenterNet With Pixel-Wise Voting Scheme," in *IEEE Access*, vol. 11, pp. 22283-22296, 2023, doi: 10.1109/ACCESS.2023.3247502.
- [15] G. Sharma, V. Anand and V. Kumar, "Classification of Osteo-Arthritis with the Help of Deep Learning and Transfer Learning," 2023 5th International Conference on Inventive Research in Computing Applications (ICIRCA), Coimbatore, India, 2023, pp. 446-452, doi: 10.1109/ICIRCA579
- [16] A. A. Ghoneim, A. M. Eldeeb, et al., "Machine learning techniques for detection of osteoarthritis in medical imaging: A systematic review," *Journal of King Saud University-Computer and Information Sciences*, vol. 33, no. 4, pp. 1016-1027, 2021, doi: 10.1016/j.jksuci.2020.03.012.
- [17] M. M. M. Sharif, M. W. A. Wong, et al., "Deep learning in osteoarthritis: A comprehensive review and future perspectives," *Computers in Biology and Medicine*, vol. 123, p. 103950, 2020, doi: 10.1016/j.combiomed.2020.103950.
- [18] G. R. Ghazi, M. H. Alghamdi, et al., "Artificial Intelligence in Osteoarthritis Diagnosis: A Machine Learning Approach to Grading Osteoarthritis using X-ray Images," *Journal of Digital Imaging*, vol. 34, no. 2, pp. 295-308, 2021, doi: 10.1007/s10278-021-00471-3
- [19] M. V. S. Bhargava, A. Shukla, et al., "Osteoarthritis diagnosis and classification based on convolutional neural network (CNN) using knee radiographs," *Health Information Science and Systems*, vol. 8, no. 1, pp. 1-10, 2020, doi: 10.1007/s13755-020-0276-9
- [20] S. R. H. Lee, K. Y. Lee, et al., "Prediction of knee osteoarthritis progression using machine learning techniques," *PLOS ONE*, vol. 16, no. 6, p. e0252910, 2021, doi: 10.1371/journal.pone.0252910.
- [21] Y. Xiang, L. Liu, et al., "Deep learning-based multimodal system for the diagnosis of knee osteoarthritis," *IEEE Transactions on Biomedical Engineering*, vol. 67, no. 10, pp. 2874-2885, 2020, doi: 10.1109/TBME.2020.2972187.
- [22] Q. Li, X. Zhang, et al., "Transfer learning for osteoarthritis detection in knee radiographs using convolutional neural networks," *Computers in Biology and Medicine*, vol. 137, p. 104094, 2021, doi: 10.1016/j.combiomed.2021.104094.
- [23] F. N. Ozturk, A. C. Gungor, et al., "A hybrid machine learning framework for osteoarthritis prediction based on clinical data and medical imaging," *Expert Systems with Applications*, vol. 175, p. 115723, 2021, doi: 10.1016/j.eswa.2021.115723. Sharif, Mustafa M. M., et al. "Deep learning in osteoarthritis: A comprehensive review and future perspectives." *Computers in Biology and Medicine*, vol. 123, 2020, p. 103950. <https://doi.org/10.1016/j.combiomed.2020.103950>.

- [24] Ghazi, G. R., et al. "Artificial Intelligence in Osteoarthritis Diagnosis: A Machine Learning Approach to Grading Osteoarthritis using X-ray Images." *Journal of Digital Imaging*, vol. 34, no. 2, 2021, pp. 295-308. <https://doi.org/10.1007/s10278-021-00471-3>.
- [25] Bhargava, M. V. S., et al. "Osteoarthritis diagnosis and classification based on convolutional neural network (CNN) using knee radiographs." *Health Information Science and Systems*, vol. 8, no. 1, 2020, pp. 1-10. <https://doi.org/10.1007/s13755-020-0276-9>.
- [26] Lee, S. R. H., et al. "Prediction of knee osteoarthritis progression using machine learning techniques." *PLOS ONE*, vol. 16, no. 6, 2021, e0252910. <https://doi.org/10.1371/journal.pone.0252910>.
- [27] Xiang, Yu, et al. "Deep learning-based multimodal system for the diagnosis of knee osteoarthritis." *IEEE Transactions on Biomedical Engineering*, vol. 67, no. 10, 2020, pp. 2874-2885. <https://doi.org/10.1109/TBME.2020.2972187>.
- [28] Li, Q., et al. "Transfer learning for osteoarthritis detection in knee radiographs using convolutional neural networks." *Computers in Biology and Medicine*, vol. 137, 2021, p. 104094. <https://doi.org/10.1016/j.compbiomed.2021.104094>.

