International Journal of Business and Technology Management
e-ISSN: 2682-7646 | Vol.6, No. 2, 224-229, 2024
http://myjms.mohe.gov.my/index.php/ijbtm

The Development of Artificial Intelligence in Knee Joint MRI Detection

Chen Xu[1*], Nor Alina Ismail[1], Gan Hong Seng[1]

[1] Faculty of Data Science and Computing, University Malaysia Kelantan, Kota Bharu, Malaysia

*Corresponding Author: alina.i@umk.edu.my

Received: 30 March 2024 | Accepted: 17 May 2024 | Published: 1 June 2024

DOI: https://doi.org/10.55057/ijbtm.2024.6.2.21

Abstract: *The application of artificial intelligence in the diagnosis and analysis of knee joint MRI has significantly advanced, leveraging technologies like machine learning and deep learning to enhance both accuracy and efficiency. AI models are adept at identifying, classifying, and predicting various pathologies such as osteoarthritis and ligament tears by analyzing complex imaging data. This facilitates more accurate diagnoses by assisting radiologists. Key developments include automation of image segmentation, image resolution enhancement, and noise reduction in MRI scans. Despite these advances, integrating AI into clinical workflows, managing data variability, and ensuring extensive validation pose ongoing challenges. Nonetheless, AI's potential to transform diagnostic processes, improve patient outcomes, and reduce healthcare costs by streamlining workflows remains promising.*

Keywords: Artificial Intelligence, Knee Joint, Application

---

1. Introduction

Due to its complex and delicate anatomical structure, the knee joint is one of the body parts most susceptible to severe injuries. Knee joint diseases have a high incidence rate and carry the risks of disability and deformation, significantly affecting patients' quality of life and imposing a substantial burden on society and the economy. Accurately assessing the progression and status of knee joint diseases can help in providing precise, staged, and personalized treatment plans. Currently, Magnetic Resonance Imaging (MRI) is the standard clinical method for assessing and diagnosing such diseases. Quantitative analysis of joint structures like cartilage, bone, synovium, and menisci helps in understanding morphological and structural changes, such as cartilage degradation and meniscal injuries, and in assessing the severity of the disease. With improvements in computer capabilities, algorithms, and other hardware and software levels, along with the advent of big data in medical imaging and biological samples, the application of artificial intelligence, especially deep learning methods, has achieved remarkable results in the field of medical imaging. AI technologies provide new approaches for conducting intelligent research on knee joint imaging and smart assessment of osteoarthritis, with many studies focusing on improving image quality to aid diagnosis through deep learning.

2. Basic Overview

2.1 Concept of Radiomics

Lembin first proposed the concept of radiomics in 2012. Radiomics is a research field that involves quantitative analysis and pattern recognition using medical imaging data. By extracting and analyzing features from medical images and combining machine learning and statistical methods, radiomics aims to study and predict information related to disease development, treatment effects, prognosis, and more. Radiomics assists doctors in making more accurate diagnoses, evaluating disease severity, predicting treatment responses, and supporting personalized medicine.

2.2 Concept of Machine Learning

Machine learning is a branch of artificial intelligence. Artificial intelligence was first proposed by McCarthy at the Dartmouth Conference in 1956. It is a new technical science that studies, develops, and applies theoretical methods, techniques, and application systems for simulating, extending, and expanding human intelligence. Machine learning is a method that enables computers to learn and extract patterns from data, thereby achieving autonomous learning and prediction capabilities. By constructing and training models, machine learning allows computers to automatically recognize and understand patterns and rules in the data, and make decisions or predictions based on these patterns and rules. Machine learning is widely used in various fields such as image recognition, speech recognition, natural language processing, recommendation systems, etc., providing people with more intelligent and efficient solutions. However, machine learning is not inherently intelligent, as this process requires humans to provide features.

2.3 Concept of Deep Learning

Deep learning is a branch method within machine learning that avoids the need for manual feature extraction, as required by traditional methods. It eliminates the necessity for region annotations and is typically proficient in localization tasks as well. By simultaneously extracting, selecting, and classifying features during the training process, deep learning summarizes the most significant and appropriate features from countless possible patterns to complete predictions.

2.4 Convolutional Neural Networks (CNNs)

CNN, Convolutional Neural Network, is a type of deep learning model primarily used for processing and analyzing data with grid-like structures. It's one of the most widely used deep learning algorithms, with increasingly widespread applications in the field of medical imaging. CNN achieves this by employing components such as convolutional layers, pooling layers, and fully connected layers to extract and learn features from images. Techniques like parameter sharing through convolutional kernels and downsampling significantly reduce the number of parameters in the entire network, thereby enhancing its performance and efficiency.

3. Research and Application of Deep Learning in the Analysis and Processing of Knee Joint MRI

In recent years, research on deep learning in the field of radiomics has been increasing, with significant progress made in the diagnosis of MRI images. This paper collects and selects relevant literature on MRI and deep learning from the PubMed platform of the National Institutes of Health (NIH) between 2021 and 2023, focusing on studies related to knee joints and excluding some review articles. By summarizing these papers, we can gain insights into the latest research directions of deep learning in knee joint MRI images. The research directions can be broadly categorized into the following aspects.

3.1 Research on Intelligent Tissue Segmentation Based on MRI Images

Such studies aim to develop algorithms that can accurately and rapidly segment different tissue structures in MRI images, thereby improving the accuracy and efficiency of medical image diagnosis. By utilizing deep learning techniques, researchers can train models to learn the features of different tissues in MRI images and automatically perform segmentation. Research on knee joints mainly involves distinguishing structures such as cartilage tissue, bone tissue, and meniscal ligaments.

(Hong et al.) constructed an artificial intelligence image-assisted model for accurate segmentation and image reconstruction of knee ligaments and femoral nerves using a multi-path CNN with multiple convolutional and fully connected layers. The area under the ROC curve (AUC) was 0.838, with a sensitivity of 0.800 and specificity of 0.836. (Si et al.), (Szoldán et al), (Zhang et al), and Chadoulos et al. utilized artificial intelligence models based on the U-Net deep learning model, deep convolutional neural networks, and two-stage multi-atlas methods under the semi-supervised learning (SSL) framework, respectively, for segmenting knee joint cartilage in MRI images, achieving satisfactory results in evaluation metrics such as the Dice similarity coefficient (DSC).

In further research, Khan et al. [9] attempted, for the first time, to model semantic segmentation of knee joint MRI in a fully automatic manner using multi-path CNN and image matting algorithms. Techniques such as low-rank tensor decomposition and reconstruction, automatic static image matting, and alpha matting algorithms were employed to address the lack of image-specific adaptability of the CNN model, such as low tissue contrast and structural heterogeneity, achieving better results in terms of boundary and shape consistency.

3.2 Intelligent Image Denoising and Scan Sequence Optimization Based on MRI Images

Traditional scan sequences may require a longer time to obtain high-quality images. By employing artificial intelligence (AI) technology, AI techniques in post-image processing can enhance image quality through image reconstruction and denoising algorithms. Additionally, AI can optimize the parameters of scan sequences to improve scanning efficiency, reduce scan time, and mitigate motion artifacts. (Fayad et al.) used a modified CNN-based U-Net to create synthetic fat-suppressed MRI images (AFSMRI) by synthesizing fat-suppressed MR images from a single non-fat-suppressed PD sequence. AFSMRI showed a similar detection rate to traditional 3D MR sequences in diagnosing common knee joint abnormalities but reduced the scan time by 54.5%. (Kaniewska et al.) employed a combination sequence of PROPELLER acquisition technique and CNN-based reconstruction to image the knee joint. This sequence effectively reduced motion artifacts, image noise, and scan time. It decreased the average acquisition time of standard sequences by 60%, showing advantages in evaluating knee joint pathologies, especially in assessing defects and chondral injuries. (Wang et al.) and (Kim et al.) respectively optimized knee joint MRI imaging using artificial intelligence-assisted compressed sensing (ACS) technology. They utilized deep learning-enhanced and traditional reconstruction techniques, studying various combinations of parallel imaging (PI) and simultaneous multi-slice (SMS) acceleration imaging. Both teams' research demonstrated the superior image quality of the novel ACS protocol and achieved equivalent detection of structural abnormalities while reducing half of the acquisition time (56% reduction by Wang et al., 47% reduction by Kim et al.). (Iuga et al) based their research on standard fat-saturated 2D proton density (PD) sequences and developed a novel algorithm combining compressed sensing (CS) and convolutional neural network-based deep learning (CS-AI) to accelerate two-dimensional diagnostic MRI imaging of the knee joint. The results showed superior imaging quality in both qualitative and quantitative aspects with CS-AI-accelerated images. (Akai et al) conducted AI-assisted compressed sensing research, using compressed sensing with parallel imaging technology, random under sampling in phase encoding, and wavelet transform to remove artifacts. After optimization through deep learning reconstruction (DLR), the optimized images with a scan time of 100s exhibited better visualization of noise, ligaments, and menisci, and overall image quality compared to pre-optimized images with a scan time of 390s.

3.3 Research on Disease-Assisted Diagnosis Based on Knee Joint MRI Images

Through the analysis and interpretation of knee joint MRI images, doctors can determine the type, extent, and location of knee joint lesions, thereby guiding clinical treatment and surgical decisions. Research involves various knee joint diseases such as meniscal injuries, ligament injuries, and synovitis. Through quantitative and qualitative analysis of knee joint MRI images, the degree, extent, and severity of lesions can be evaluated, providing doctors with more accurate diagnosis and treatment recommendations.

(Awan et al) utilized the ResNet-14 convolutional neural network model, combined with real-time data augmentation techniques, for detecting three types of ACL lesions (healthy, partially torn, and completely torn). Researchers employed a hybrid category balance and real-time data augmentation strategy to address the scarcity of MRI data and class imbalance issues. According to experimental results, verified extensively by sensitivity, specificity, accuracy, recall, F1 score, receiver operating characteristic (ROC) curve, and other metrics, the average accuracy, sensitivity, and precision reached 92%, 91%, and 91%, respectively.

(Dunnhofer et a) utilized MRPNet for knee joint MRI imaging-assisted diagnosis. The module consisted of a feature pyramid network with a pyramid of details pool, advantageous for inserting into any existing CNN-based diagnostic pipeline. Through inserting different modules such as enhancing CNN intermediate features and capturing detailed information, it exhibited high accuracy and sensitivity in diagnosing ACL tears and meniscal tears, ranging from 0.87 to 0.97. It better captured features related to these injuries, thereby improving diagnostic accuracy.

(Zheng et al) employed a multi-modal MRI imaging algorithm based on low-rank decomposition denoising for diagnosing knee joint osteoarthritis and cartilage lesions. The sensitivity, specificity, and accuracy were all high, exceeding 0.85, with slightly lower consistency (0.73).

(Cui et al) used deep learning algorithms to automatically assess the severity of knee joint osteoarthritis on portable devices, offering new possibilities for automated assessment on portable devices.

(Zhuang et al) designed a CSNet model that jointly performs graph convolution and graph convolution to evaluate cartilage defects. Compared to other methods, the CSNet model considers the surface shape of cartilage and the defect correlation between adjacent cartilages, thus performing better in terms of performance. The accuracy (ACC) of CSNet was 87.4%, and the recall rate (REC) was 79.5%, achieving 94.7%.

4. Conclusion

Using deep learning on knee joint MRI images to perform tasks such as image classification, object detection, image segmentation, and accelerated data collection has shown promising preliminary results, with various evaluation metrics showing improvement. However, there are still many challenges: Insufficient Data: Due to the high cost of data acquisition and annotation, it is difficult to obtain a sufficiently diverse and representative dataset. Some models have a limited number of samples for research, leading to potential overfitting issues where the model performs well on the training set but poorly on the test set. Additionally, deep learning models require real-time access to the latest data for training and inference, preferably integrating with hospital systems for real-time data updates. Model Generalization: Knee joint MRI images exhibit significant variability and complexity, including different scan sequences, lesion types, and anatomical structures. Insufficient generalization capability of models may lead to decreased performance when facing new, unseen data in practical applications. Lack of Accurate Data Annotation Standards: Annotating knee joint MRI images typically requires expertise and experience from medical professionals, and the annotation process is time-consuming and labor-intensive. Manual annotation may introduce subjectivity and annotation errors, and annotating a large number of images manually requires substantial human resources.

Future research will focus on intelligent segmentation, image denoising and scan sequence optimization, disease-assisted diagnosis, and other directions. Exploring more deep learning models and algorithms in aspects such as data augmentation, transfer learning, adversarial training, model ensemble, reinforcement learning, interpreting model decision processes, and key features, aiming to pursue real-time data, enhance the robustness of AI images, and make models more universal, thereby improving diagnostic accuracy and efficiency.

References

Lambin, P., Rios-Velazquez, E., Leijenaar, R., et al. (2012). Radiomics: extracting more information from medical images using advanced feature analysis. Eur J Cancer, 48(4), 441-446.

Szegedy, C., Vanhoucke, V., Ioffe, S., et al. (2016). Rethinking the inception architecture for computer vision. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (pp. 2818-2826).

Hong, G., Zhang, L., Kong, X., et al. (2021). Artificial Intelligence Image-Assisted Knee Ligament Trauma Repair Efficacy Analysis and Postoperative Femoral Nerve Block Analgesia Effect Research. World Neurosurg, 149, 492-501.

Sil, X., Xu, K., Zhong, J., et al. (2021). Knee Cartilage Thickness Differs Alongside Ages: A 3-T Magnetic Resonance Research Upon 2,481 Subjects via Deep Learning. Front Med (Lausanne), 7, 600049.

Szoldan, P., Egyed, Z., Szabo, E., et al. (2021). Segmentation of knee cartilages in MR images with artificial intelligence. Orv Hetil, 162(9), 352-360.

Zhang, Y., Lian, H., Liu, Y. (2022). Deconstruction of Knee Cartilage Injury in Athletes Using MR Images Based on Artificial Intelligence Segmentation Algorithm. Contrast Media Mol Imaging, 2022, 4165232.

Chadoulos, C. G., Tsaopoulos, D. E., Moustakidis, S., et al. (2022). A novel multi-atlas segmentation approach under the semi-supervised learning framework: Application to knee cartilage segmentation. Comput Methods Programs Biomed, 227, 107208.

Khans, A., Azam, B., Yao, Y., et al. (2022). Deep collaborative network with alpha matte for precise knee tissue segmentation from MRI. Comput Methods Programs Biomed, 222, 106963.

Fayad, L. M., Parekh, V. S., De Castro Lunar, L., et al. (2021). A Deep Learning System for Synthetic Knee Magnetic Resonance Imaging: Is Artificial Intelligence-Based Fat-Suppressed Imaging Feasible? Invest Radiol, 56(6), 357-368.

Kaniewska, M., Deininger-Czermak, M., Lohezic, M., et al. (2023). Deep Learning Convolutional Neural Network Reconstruction and Radial k-Space Acquisition MR Technique for Enhanced Detection of Retropatellar Cartilage Lesions of the Knee Joint. Diagnostics (Basel), 13(14), 2438.

Wang, Q., Zhao, W., Xing, X., et al. (2023). Feasibility of AI-assisted compressed sensing protocols in knee MR imaging: a prospective multi-reader study. Eur Radiol, 33(12), 8585-8596.

Kim, M., Lee, S. M., Park, C., et al. (2022). Deep Learning-Enhanced Parallel Imaging and Simultaneous Multislice Acceleration Reconstruction in Knee MRI. Invest Radiol, 57(12), 826-833.

Iuga, A. I., Rauen, P. S., Siedek, F., et al. (2023). A deep learning-based reconstruction approach for accelerated magnetic resonance image of the knee with compressed sense: evaluation in healthy volunteers. Br J Radiol, 96(1146), 20220074.

Akai, H., Yasaka, K., Sugawara, H., et al. (2023). Acceleration of knee magnetic resonance imaging using a combination of compressed sensing and commercially available deep learning reconstruction: a preliminary study. BMC Med Imaging, 23(1), 5.

Awan, M. J., Rahim, M. S., Salim, N., et al. (2021). Efficient Detection of Knee Anterior Cruciate Ligament from Magnetic Resonance Imaging Using Deep Learning Approach. Diagnostics, 11(1), 105.

Dunnhofer, M., Martinel, N., Micheloni, C. (2021). Improving MRI-based Knee Disorder Diagnosis with Pyramidal Feature Details. In Medical Imaging with Deep Learning (MIDL) 2021, 2021.

Zheng, Z., He, R., Lin, C., et al. (2022). Multimodal Magnetic Resonance Imaging to Diagnose Knee Osteoarthritis under Artificial Intelligence. Comput Intell Neurosci, 2022, 6488889.

Cui, T., Liu, R., Jing, Y., et al. (2023). Development of machine learning models aiming at knee osteoarthritis diagnosing: an MRI radiomics analysis. J Orthop Surg Res, 18(1), 375

Zhuang, Z., Si, L., Wang, S., et al. (2023). Knee Cartilage Defect Assessment by Graph Representation and Surface Convolution. IEEE Trans Med Imaging, 42(2), 368-379.

Jamshidi, A., Pelletier, J. P., Labbé, A., et al. (2021). Machine Learning Based Individualized Survival Prediction Model for Total Knee Replacement in Osteoarthritis: Data From the Osteoarthritis Initiative. Arthritis Care Res, 73(10), 1518-1527.

Ramkumar, P. N., Karnuta, J. M., Haeberle, H. S., et al. (2021). Effect of Preoperative Imaging and Patient Factors on Clinically Meaningful Outcomes and Quality of Life After Osteochondral Allograft Transplantation: A Machine Learning Analysis of Cartilage Defects of the Knee. Am J Sports Med, 49(8), 2177-2186.

Zech, J. R., Carotenuto, G., Jaramillo, D. (2022). Inferring pediatric knee skeletal maturity from MRI using deep learning. Skeletal Radiol, 51(8), 1671-1677.