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MINIREVIEWS

Machine learning and deep neural network-based learning in osteoarthritis knee

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Abstract

Osteoarthritis (OA) of the knee joint is considered the commonest musculoskeletal condition leading to marked disability for patients residing in various regions around the globe. Application of machine learning (ML) in doing research regarding OA has brought about various clinical advances viz, OA being diagnosed at preliminary stages, prediction of chances of development of OA among the population, discovering various phenotypes of OA, calculating the severity in OA structure and also discovering people with slow and fast progression of disease pathology, *etc.* Various publications are available regarding machine

learning methods for the early detection of osteoarthritis. The key features are detected by morphology, molecular architecture, and electrical and mechanical functions. In addition, this particular technique was utilized to assess non-interfering, non-ionizing, and in-vivo techniques using magnetic resonance imaging. ML is being utilized in OA, chiefly with the formulation of large cohorts viz, the OA Initiative, a cohort observational study, the Multi-centre Osteoarthritis Study, an observational, prospective longitudinal study and the Cohort Hip & Cohort Knee, an observational cohort prospective study of both hip and knee OA. Though ML has various contributions and enhancing applications, it remains an imminent field with high potential, also with its limitations. Many more studies are to be carried out to find more about the link between machine learning and knee osteoarthritis, which would help in the improvement of making decisions clinically, and expedite the necessary interventions.

Key Words: Osteoarthritis; Knee; Artificial intelligence; Machine learning; Deep neural network

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Core Tip: Application of machine learning in research has various clinical advances viz, osteoarthritis (OA) knee being diagnosed at preliminary stages, prediction of development of OA, discovering various phenotypes. Large cohorts have been formulated viz, the OA Initiative, the Multi-centre Osteoarthritis Study and the Cohort Hip & Cohort Knee. Many studies are awaited to find about the link between ML and knee OA, which would improve making decisions clinically, and expedite the necessary interventions.

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INTRODUCTION

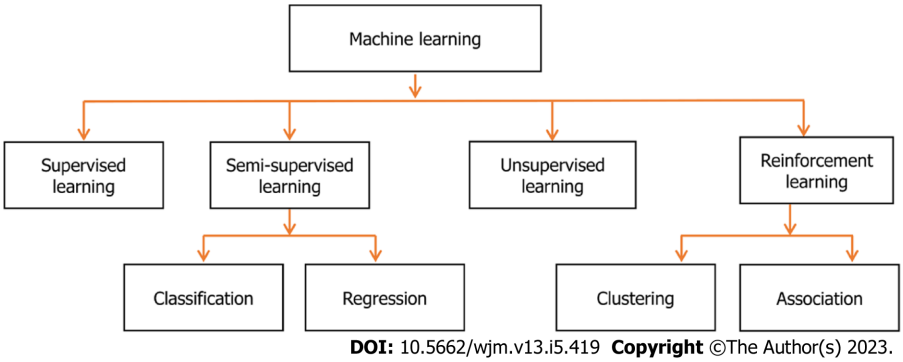
Osteoarthritis (OA) of the knee joint is considered the commonest musculoskeletal condition leading to marked disability for patients residing in various regions around the globe[1,2]. OA is a degenerative disease, still, there is no clear knowledge regarding the factors that are responsible for the progression of the disease pathology. In the late stages of the disease, the only option for treatment is total knee arthroplasty, which is not affordable by many, is very much invasive, and highly degrades the individuals' quality of living.

A breakthrough was brought about by artificial intelligence (AI), specifically by machine learning (ML) in the field of medical care, mainly in subspecialties like rheumatology, mainly OA[3-6]. Machine learning includes Supervised, Semi-supervised, Unsupervised, and Reinforcement learning[7]. Deep learning is a subtype of ML that depends on various layers of a network consisting of a neuron architecture, that allows a model to improvise itself and train on its own, which in turn will lead to great accuracy levels by extracting greater level features from the given data[8-10].

Application of ML in doing research regarding OA has brought about various clinical advances viz, OA being diagnosed at preliminary stages, prediction of chances of development of OA among the population, discovering various phenotypes of OA, calculating the severity in OA structure and also discovering people with slow and fast progression of disease pathology, *etc*. The present models for the prediction of the progression of OA have been based on the collaboration of texture descriptors separated from the trabecular bone, Kellgren Lawrence (KL) grade, and clinical and anthropometric data[11-14]. Methods of Machine learning are divided into supervised and unsupervised (Figure 1). In supervised analysis, the results are established and the data are tagged. Whereas, in unsupervised analysis, the results are not established and the data are not tagged. In addition to these, two new categories were added viz, semi-supervised & reinforcement learning, in which the outcomes are only partially established[7].

Models of semi-supervised learning comprise a mixture of data that are tagged & untagged and are predicated on weak monitoring, with limited tagged data that are used to gain information and for the monitoring of untagged data. On the other hand, reinforcement learning is an ML prototype in which learning happens collectively by a sequence of hit-and-miss trials to increase the result achieved after every hit and thereby increase the learning behavior. Amongst the above-mentioned methods, supervised ML methods are most frequently utilized in the health care systems and medical field[15].

ML is being utilized in OA, chiefly with the formulation of large cohorts viz, the OA Initiative (OAI)[16], a cohort observational study, the Multi-centre Osteoarthritis Study[17], an observational, prospective longitudinal study, and the Cohort Hip & Cohort Knee[18], an observational cohort prospective study of both hip and knee OA. Though ML has various contributions and enhancing applications, it remains an imminent field with high potential, also with its limitations.



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Figure 1 Various algorithms used in machine learning.

LITERATURE REVIEW

Various publications are available regarding machine learning methods for the early detection of osteoarthritis. The detection of osteoarthritis of the knee in its early stages and the exact & persistent assessment needed to detect changes in cartilage were discussed by Mohd Hani *et al*[19]. The key features are detected by morphology, molecular architecture, and electrical and mechanical functions. In addition, this particular technique was utilized to assess non-interfering, non-ionizing, and in-vivo techniques using magnetic resonance imaging (MRI).

Nelson *et al*[20] elaborated on the various causative factors of Osteoarthritis of the knee viz age, mass, and problems to the joint because of the flexing and kneeling activities. The data was attained by the authors from the OAI to assess the advancement of the knee. Dual Echo Steady State MRI was utilized to scrutinize the various images that are available and to choose the part of comparison and later on, perform a computerized differentiation from the data that is available. The modus operandi and design utilized is the Active Appearance Model. The CDI values that are acquired, are fed into machine learning methods like support vector machines (SVM), artificial neural network (ANN) & Random Forest to achieve precise results.

In a study conducted by Kwon *et al*[21], the radiographic maps were used & applied the model of SVM grouping was to authorize the deep learning model. For the multi-classification system, the deep learning network that was used was the Inceptio-ResNet-v2. Calculations of various parameters viz sensitivity, precision, gait analysis, X-ray findings, and F1-values were separated and skilled with property extraction and depth learning features extraction respectively and the training & conditioning of the SVM model was done by utilizing the training set and the compiled data was utilized in the diagnosis of OA. They found an ambiguous learning technique based on radiographic findings, blue-print-dependent scrutiny of data & analysis of functions. Following the inferences of this study improved the accuracy of the diagnosis of OA of the knee.

Wahyuningrum *et al*[22] utilized Long Short-Term Memory (LSTM) for extraction of the features to inquire about the pre-processing through a convolution neural network (CNN). Their main concerns were on the process of cross-validation, of which 2/3 and 1/3 were taken as training and testing data respectively. They performed the analysis by cropping the data of knee images into 400 × 100 pixels which were then arranged as piled augmented images and in turn were introduced in the manner of sequences, as input into the CNN, because LSTM should be performed sequentially. Three convolution filters followed the stride of Max pooling, and 1000 softmax channels into the LSTM processed the entire data from CNN. They have proposed that the LSTM technique is based on the KL grade and is more precise than deep learning.

An analysis of the cases was performed by Galván-Tejada *et al*[23] on the grounds of the data available from the OAI analysis. In this study they utilized two kinds of radiological grades, the first one being a quantitative analysis score and the second being a semi-quantitative analysis score, with the results of radiological images analyzed by two different sets of radiologists. To measure the variables related to pain in the future, A single variable logistic regression test was conducted. They found that the formation of bone osteophytes acts as the predictor of joint pain in the early stages and there's no correlation between pain in the subsequent period and a decrease in joint space. By the findings of the study, they have found that by using plain radiographs the reasons for potential OA knee can be predicted early. They have demonstrated the correlation between the discriminant X-ray of retrogression and the knee pain that developed.

Due to the difficulties faced in diagnosing knee Osteoarthritis, Christodoulou *et al*[24] brought about the concept of deep neural networks for the categorization of issues faced in diagnosis. In this study, to solve the problems in diagnosing osteoarthritis, taking into consideration the variable health factors that cause osteoarthritis, they have introduced a deep learning network to solve the problems faced in classifying knee OA, as a new and efficient machine learning method. The efficiency of the new method was proven by making discrete subgroups of the treated patients, from the data available and by designing a category for the diagnosis of OA knee. Deep neural networks serve as a successful technique in tackling the several problems of machine learning technique viz classification of images, predilection and disease prognosis, *etc*.

Magnetic resonance imaging was utilized by Du *et al*[25] to find the biomedical information concealed in it to diagnose osteoarthritis. Four techniques of machine learning were utilized to assess the osteoarthritis progression and to figure out the transformation in grades according to Kellgren and Lawrence's (KL) classification system, narrowing of joint space in

both medial or lateral compartments. The 36-dimensional elements were divided into two separate 18-dimensional elements with each 18-dimensional element to be individually examined by a four-graded technique for analyzing the various changes of both lateral and medial compartments. In an attempt to narrow down the regions and increase the performance, the analysis by PCA was utilized. By this technique, the machine learning methods for analysis were used to project the increase in KL grades, and medial and lateral compartment joint space reduction, and helped in delineating the pathological progression of knee OA. For the analysis purpose of PCA, the CDI information was compiled from one of the 36-dimensional elements on the 3D knee model of the MR tibiofemoral compartment.

In another study conducted by Kawathekar *et al*[26], they used geometrical parameters from the radiographs of the knee (anteroposterior view), by calculating the distance between the femur and tibia in active form models. Other approaches like local binary arrangement, which is being utilized in most of the pattern recognition tools are also used in the diagnosis of OA knee.

MACHINE LEARNING TECHNIQUES

The typical programming consists of an Algorithm, that includes a couple of rules that require pre-processing data (input) that is utilized to calculate a form of processed data (output) (Figure 2).

The algorithms of machine learning (Figure 3) can learn from the available data and are utilized for the automatic calculation of the set of rules. To perform such approaches, three components[27,28] are essential viz, pre-processed input data, Output data that the algorithm is supposed to predict, and A comparative tool to verify the predicted output performance.

The working mechanism includes entering both the data into the pipeline, which in turn will learn on its own to transform one data into the other data form. Machine learning techniques can be utilized effectively when there is no feasibility or possibility for defining an algorithm by manual techniques and when there's adequate data that applies to the training method.

Various subtypes of machine learning are available like supervised and unsupervised methods. Supervised methods can be utilized when there is a definite idea about the output data and Unsupervised methods can be utilized to discover anonymous data patterns. For instance, Supervised-learning methods encompass linear array regression, gradient boosting and ANN, *etc*.

ARTIFICIAL NEURAL NETWORKS

In the recent past, AI has been used graciously in the field of medicine. AI is nothing but a division of software engineering that includes algorithm training to reflect the human learning process. The design of the human brain has been the basis of various machine learning methods like the ANN. The ANN consists of a congruence of neurons that are interrelated. The ground structure of the neurons, can transform their inner structure or initiate a process, based on the information that is being fed to them and in turn results in a yield that depends upon both the input provides and the present execution.

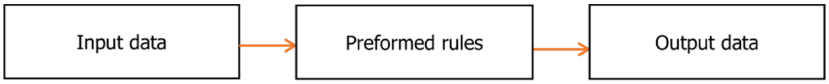
CONVOLUTION NEURAL NETWORKS (CNN)

CNN is utilized widely in various modalities like an assertion of images and videos, recommendation systems, and handling of basic languages. Convolutions are vastly used in processing images[29,30], this being one of the reasons behind its introduction to deep learning methods to perform visual tasks. CNN facilitates the advantage of knowing about the local patterns that are concealed in the data given unlike the other systems, which treat the input data variables globally. CNN belong to a special subgroup of ANN, which uses a system known as a convolution in a minimum of at most one of their steps. Yann LeCunn introduced CNN first in 1990 though it was not that popular at that time[31].

Convolutions involve the mathematical assessment of two different functions that are assertions of real values. In imaging modalities, various terminologies are used to describe the input and kernel, which indicates the first and second functions respectively. The output data that is attained is termed the feature map. CNN models date back to one among the historical deep neural network models, which have various layers that are hidden between the general ones, and this, in turn, helps in knowing more information regarding the features that are concealed in the images that are provided as the input. A second type of layer that is often utilized in CNN models conducts pooling undertaking. Due to this pooling, there is a reduction in spatial resolution and the most appropriate features are only retained, which is solely necessary for maintaining a feasible network size.

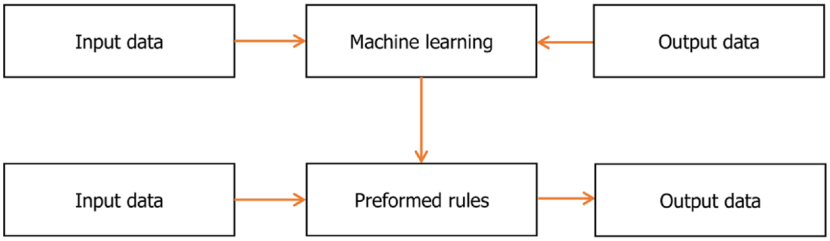
OBJECT CLASS DETECTION

In today's treatment modalities, technologies of machine vision are utilized mostly for the identification of surgical materials among the available objects. The features of medical image inquiry have helped doctors in various ways viz



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Figure 2 Typical programming algorithm.



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Figure 3 Machine learning algorithm.

enhancing the diagnostic capabilities of pediatricians, outcomes which are object-guided, treatment-oriented, and extensive evaluation of various body organs like evaluation of clinical images of those in a state of vulnerability. The availability of advanced technological systems enhances the necessity for identifying and diagnosing various diseases like osteoarthritis, but there are various hurdles to the analysis of its probable location.

Nowadays various algorithms are available which are being used in health care to solve these hurdles. Numerous numbers of various technological advancements are happening in the day-to-day period, which focuses on the diagnosis and recognition of many other disease conditions. The traditional object analyzing methods can be utilized in a broad spectrum of imaging methods viz Radiography, Ultrasonography, Computed Tomographic images, and MRI.

There is no standard method of ML which is acceptable in order to apply them for real-time application[32]. Future research should concentrate on making algorithms that can detect OA in the stages of less severity. The lacunae in the real-time application can be fulfilled by utilizing data in larger numbers and multimodality data to make the ML models more accurate and increase the credibility simultaneously[9].

CONCLUSION

The future of medical science relies upon developing new methods of detecting osteoarthritis in its early stages, which would help in providing joint-preserving treatment modalities to patients. Machine learning techniques would develop a new revolution of augmented radiological methods. Machine learning can explore a wide range of designs, to identify the interaction and multiresolution models, which can easily predict the dynamics of the system to find the predisposing factors. Many more studies are to be carried out to find more about the link between machine learning and knee osteoarthritis, which would help in the improvement of making decisions clinically, and expedite the necessary interventions.

FOOTNOTES

Author contributions: Jeyaraman M contributed to conceptualization; Ratna HVK, Jeyaraman N, and Nallakumarasamy A contributed to initial draft; Ratna HVK and Jeyaraman M contributed to final draft; Sharma S, Khanna M, and Gupta A contributed to supervision; All authors accepted to publish the current version of the manuscript.

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