Potential studies on Knee Osteoarthritis Segmentation and Classification

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ABSTRACT

In recent days automatic grading of Knee Osteoarthritis (KOA) is mainly helping to diagnose the severity of the disease. This illness is now diagnosed by a clinical examination and radiographic evaluation. However, these diagnostic tools have low sensitivity and specificity. Several methods have been developed that can automatically identify the KL grade from the radiographs. The Kellgren-Lawrence (KL) grading system is the golden standard that uses five categories to assess the severity of osteoarthritis. Many researchers have been developed models and evaluated on publically available dataset like Osteoarthritis Initiative dataset (OAI), Multicenter Osteoarthritis Study (MOST) dataset, KOACAD (OAI derived dataset). Data must be considered an important thing, since it is one of the most valuable assets in the healthcare area. Several data sources were used as inputs in KOA study, resulting in strong multidimensional training and testing data sets. To extract meaningful information from accessible data, a variety of feature selection methods were utilized. The segmentation algorithms such as canny edge detector, Graph cut algorithm, PCA and GLCM were used to extract the features or to reduce the space dimensionality. In an X-ray based investigations, Machine Learning models such as SVMs were most commonly chosen to drive the decision-making process. This paper discusses all the ideas on automatic grading of KOA published by each researcher.

KEY WORDS: AUTOMATIC GRADING, CONVOLUTION NEURAL NETWORK, CLASSIFICATION, KNEE OSTEOARTHRITIS, MACHINE LEARNING, SEGMENTATION.

INTRODUCTION

Arthritis is an inflammatory condition that affects one or more joints. Arthritis may be classified into over a hundred distinct kinds. Osteoarthritis (OA) and Rheumatoid arthritis (RA) are the two most prevalent kinds. The most prevalent musculoskeletal condition is osteoarthritis, commonly referred to as Wear and Tear arthritis or Degenerative Joint Disease. This disease generally influences the elderly people. Joint space narrowing (JSN), the development of osteophytes, and sclerosis are the main clinical

characteristics of KOA (Antony et al., 2017; Górriz et al., 2019; Kondal et al., 2020).

There is a tissue called cartilage which connects the bones and it cushions the ends of the bones to provide the frictionless joint motion. If the cartilage is damaged or unhealthy, the bones are rubs each other which causes pain, swelling and stiffness. The space between the bones narrows in KOA-affected knees, which is termed as Joint Space Narrowing (JSN). The common risk factors associated with osteoarthritis are Obesity, bone density, trauma, gender, lack of exercise, genetic predisposition (Wahyuningrum et al., 2019; Kondal et al., 2020). Early diagnosis is the only option to reduce its impact and lead the healthy life, because the joint replacement surgery can be done only at early stage of OA. According to the survey, there were 303 million cases of hip and Knee osteoarthritis worldwide as of 2017. The purpose of this article was to offer a quick overview of research work done by a number of researchers on the identification and classification of KOA and its severity

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using simple radiographs (Wang et al., 2019; Kondal et al., 2020).

Figure 1: Healthy and KOA affected Knee image (Gornale et al., 2019)

Figure 2: KL Grade Scale

Sample Images				
KL Grade 0	KL Grade 1	KL Grade 2	KL Grade 3	KL Grade 4
No features of OA Healthy Knees	Doubtful OA Presence of unclear osteophytes, doubtful JSN	Mild (Early) OA Presence of definite osteophytes, Possible JSN	Moderate OA multiple osteophytes, definite JSN, sclerosis	Severe OA Large osteophytes, Loss of JS, bone deformity

Table 1. Osteoarthritis Cartilage Histopathology Assessment System

Grade	Explanation
Grade-0	surface intact, cartilage intact
Grade-1	Uneven but intact Possible features: superficial fibrillation, cell death and proliferation.
Grade-2	surface discontinuity
Grade-3	vertical fissures
Grade-4	Erosion
Grade-5	Denudation

Table 2. Stage Assessment OA Cartilage Histopathology

Stages	% Involvement (Surface)
Stage-0	No OA activity seen
Stage-1	Less than 10%
Stage-2	Between 10 to 25%
Stage-3	Between 25 to 50%
Stage-4	4 > 50%

The medical imaging methods such as MRI, CT scan, Ultrasound, and plain radiography (X-rays) are used to

detect the early signs of OA. Among these techniques, X-rays is the cheap, readily available and this will be less hazardous technique. Clinicians generally analyze the plain radiographic images of OA/ Non OA knees to grade the severity of OA with the help of Kellgren-Lawrence (KL) grades. The normal and affected knee cartilage image is shown in the above Figure 1 (Pedioia et al., 2019).

KL Grading scale: KL grades have been accepted globally for measuring the severity of knee Osteoarthritis. This grading system has five (0-4) stages shown in figure 2. Grade 0 represents the healthy knees and subsequent grades (1-4) represent the increasing severity of OA (Roemer et al., 2018). **OARSI Grading System:** An Osteoarthritis cartilage histopathology assessment system (OARSI system) is first introduced by the Osteoarthritis Research Society International (OARSI) in the year of 2006. This system composed of a grading and Staging component. This method is made up of two parts: Grading and Staging. The capacity to distinguish between early and moderate OA is the system's key feature. OARSI grades and stages are listed in table 1&2.

Available Datasets for KOA: Researchers have worked on a variety of data sets, either publicly available or gathered by own. The well-known publicly available data sets are OAI, MOST, BLSA, and OAI derived data set (KOACAD). Most of the researcher has used OAI data set. Some researchers used more than one data set for their work. According to the requirement, few authors collect the data with their own interest. Table 3 shows most commonly used dataset and their description (Dey et al., 2018; Kondal et al., 2020).

Machine Learning in Knee Osteoarthritis: The goal of this section is to give an overview of Machine Learning (ML) in medical applications, with a focus on Knee Osteoarthritis. Machine learning approach has been widely applied in a variety of applications, including medical imaging, segmentation, classification and image identification (Raj et al., 2018; Juras et al., 2020).

Machine Learning is a field of Artificial Intelligence that allows computers to learn from their experiences and solve problems. The mathematical model must first be constructed, after which it must be trained to generate the results. Machine learning models are trained through the use of training data, which is subsequently fine-tuned using optimization approach to provide accurate predictions. The tuned models are to be able to generalize their expertise and bring the correct prediction for new data. Machine Learning provides intelligent solutions in medical applications, improving clinical diagnostic accuracy. There are various machine learning algorithms available such as Support vector machines, kNN, Logistic regression and so. The researcher can be selecting the algorithm with respect to the nature of problem (Saini et al., 2021; Revathy et al., 2021).

The machine learning system has two parts (i) Training Part (ii) Testing Part shown in figure 3. Initially data to be used for training is undergoes preprocessing such as data cleaning, data integration, data transformation including

discretization and normalization. Next step is Feature extraction which is used to identify the relevant feature and subsequently mathematical model will be applied in training part Gan et al., (2021). The feature extraction portion and

the pre-processing unit are adjusted via a feedback loop, which improves the model's performance. During testing part the models are taking proper decision based on the feature present in each sample.

Table 3. Dataset available for KOA

Dataset	Number of Participants	Description
OAI-Osteoarthritis Initiative	4796	i) Sponsored by the National Institutes of Health ii) Multi-centre iii) Ten-year observational study of men and women
MOST-Multicenter Osteoarthritis Study	3026	i) Sponsored by the National Institutes of Health / National Institute on Aging ii) Lateral knee assessment for 84 months.
BLSA-Baltimore Longitudinal Study of Aging	More than 3200	i) It began in 1958 ii) Longitudinal normative aging study iii) Radiographs were obtained in all participants, irrespective of symptoms or functional limitations.

Figure 3: Block of Machine Learning System (Tack et al., 2021)

Segmentation: Whenever the patient comes to the orthopedic he/she is advised to take MRI or X-ray for further evaluation. An image contains more information and this information can be extracted automatically by the process called segmentation. This process is a fundamental step in image analysis (Wang et al., 2021; Yifan et al., 2021). The manual evaluation may take some time to reach conclusion and it is not error-free. Generally in the segmentation process, a digital image can be divided into multiple segments which gives a better understanding of the further processing. Many segmentation methods have been developed analyzing medical data of the patients such as MRI (Magnetic Resonance Imaging), X-Rays, CT (Computerized Tomography) scans, ECG (Electro Cardio Gram), and are stored in DICOM format (Tiulpin et al., 2019; Felfeliyan et al., 2021).

There are three types of classical segmentation methods. The first one is Manual segmentation which is necessary to precisely delineate the boundaries of damaged cartilage by placing seeds over specific anatomic regions. Despite this, the treatments are notorious for being time-consuming. It

fully depends on the doctor's experience and knowledge of anatomy. The second method is automated segmentation and is used to segment the cartilage automatically (Rosenberger et al., 2006; Mahmood et al., 2015; Dalia et al., 2021). Some of the methods are active shape model, watershed and kNN classification. Another method is interactive segmentation; it combines features from both manual and automated segmentation methods such as graph cuts and random walks. The various segmentation methods have been reviewed for detection of knee osteoarthritis in early states. The simple method and robust method is nobel edge detection that highlights the region of high spatial frequency (Mahmood et. al., 2015; Gornale et al., 2019; Von et al., 2021; Sarvamangala et al., 2021).

There are many algorithms for gray scale image segmentation. But the threshold segmentation algorithm is used commonly because of its simplicity and efficiency. An OTSU threshold segmentation technique has been applied to ROI of joint space area of the knee to get the clear joint gap but its computation time is high when the number of threshold increases. Table.4 gives the comparative study of various algorithms have been used for segmentation process (Chan et al., 2020; Palacios and Laura, 2021; Chai et al., 2021). Classification: The research on Knee OA can be carried out in two ways. One is automatically classifying the images into KOA and non-KOA cases. Another one is classification of KOA severity by quantifying pathological features. The most common pathological features of Knee OA are osteophytes formation, joint space narrowing (JSN), and subchondral sclerosis. All these pathological features are playing a major role in identifying the grading of KOA like KL and OARSI grading system. The researchers have been classified the KOA severity by quantifying any one pathological features and some researchers have used composite grading systems (Kokkotis et al., 2020).

Table 4. Comparative study of various segmentation techniques used in KOA

Ref	Number of Images Used	Algorithm	Result
Anifah et al., 2013	-	3D Statistical Shape models (SSM) as well as 2D and 3D CNN	i) Total Score 74.0 ± 7.7 ii) For base line 89.4% DCS for FC and 89.1% for 12m. iii) Base line DCS is 86.1% and 90.4% for MTC and LTC respectively. iv) DCS for 12m is 85.8% and 90.0% for MTC and LTC respectively
Anifah et al., 2018	532 X-ray Images: 301-female and 231-male	Otsu's segmentation, KNN, Texture based segmentation	Obtained accuracy of 94.92%, 91.16%, 96.80%, and 97.55% for texture method, Sobel method, Otsu's method, and Prewitt method respectively.
Bien et al., 2018	OAI: 748, Dataset A: 161(Own dataset), Dataset B: 209 (Own Dataset)	Hourglass Network	Precision 93.48 ± 0.44
Dey et al., 2008	10	Flexible seeds labelling method	For observer1, the average Dice coefficient- 0.80 ± 0.060 , sensitivity 0.86 ± 0.044 and specificity 0.994 ± 0.0019 . For observer 2, the average Dice coefficient- 0.82 ± 0.043 , sensitivity 0.85 ± 0.049 and specificity 0.995 ± 0.0010 .
Górriz et al., 2019	Dataset A: 88 Dataset B: 600 Dataset C: 184 Dataset D: 184 Dataset E: 184	3D Convolution Neural Network	Accuracy: Medial tibial cartilage- 88.02 ± 4.62 lateral tibial cartilage - 91.27 ± 2.33
Kokkotis et al., 2020	4130 images	Single short Detector	94.03% of images having $J > 0.75$

Gornale et al., (2016) have considered the following features: Texture features, Haralick, First four movements, statistical feature set, and region properties. These features were classified using Random Forest Classifier. In this work, the miss classified rate is little high in individual feature set whereas the proposed algorithm provides a better result for the combined feature sets. One of the procedure of examine the knee osteoarthritis is analyzing the joint space width (Kondal et al., (2020). The multidisciplinary data from OAI were used in Ntakolia et al., (2021) to predict the progression of JSN where the proposed methodology employs clustering process, Feature selection process and

decision making process. They concluded that LR model produced significantly good accuracy while combining data of both legs. Recent research works have been focused particularly on patellofemoral Osteoarthritis Bayramoglu et al., (2021).

The automatic JSW measurement is more accurate than manual measurement method. For the comparison purpose an author has done the manual measurement by using ruler to join the outermost of each femur and tibia. As a result, the lateral Joint space width is narrower than medial joint space width where as in automatic method the medial

JSW is narrower than the lateral JSW. In table 5 it has been analyzed that the various classification techniques such as

SVM, Random Forest Classifier and various CNN networks have been used by the researchers for classification of knee Osteoarthritis (Sugiyanto et al., 2020).

Table 5. Comparative survey of various classification techniques used in KOA

Reference	Year	Dataset	Data	Number of Images Used	Algorithm	Result
Yang et al., (2021)	2017	Own dataset	X-ray	616	Multiclass SVM	Accuracy for KL Grade-0: 97.96%, Grade-1:92.85%, Grade-2:86.20% Grade-3&4: 100%
Gornale et al., 2021	2016	Own dataset	X-ray	128 images: 62 of normal condition and 66 of OA images	Random Forest Classifier	Accuracy of 87.92%
Oei et al., 2021	2017	Own dataset	MRI	There are 213 images in total: 147 for training and 66 for testing.	SVM classifier	95.45% for SVM with RBF kernel, 87.8% for SVM with linear kernel.
Edwin et al., 2021	2018	Own dataset	MRI	1370 knee images	CNN-MRNet,	AUC values: Detecting
						abnormalities- 0.937, ACL tears- 0.965, Meniscal tears- 0.847.
Ebrahimkhani et al 2021	2019	OAI	MRI	4384 subjects	CNN-DenseNet	For RF model, Sensitivity- 67.01%, Specificity- 71.79% For DenseNet, Sensitivity-76.99%, Specificity-77.94%
Cicuttini, 2021	2016	Own dataset	MRI	15 subjects	SVM Classifier	Accuracy 86.66% Specificity 100% Sensitivity 75%
Wahyuningrum et al., 2021	2013	OAI	X-ray	303 unimpaired images	SOM- Self Organizing Maps	Accuracy for KL Grade-0: 93.8%, Grade-1:70%, Grade-2:4% Grade-3: 10% and Grade-4: 88.9%
Tack., et al., 2021	2018	OAI	X-ray	303 unimpaired images	SOM	Accuracy for KL Grade-0: 36.21% Grade-1: 40.52% Grade-2:15.52% Grade-3:25.86% Not able to classify KL Grade 4
Wang et al., 2021	2020	OAI and MOST	X-ray	19704 knees from the OAI dataset were used as a training set. 11743 knees from the MOST dataset were used in the testing.	Transfer Learning from Image Net	Cohen's Kappa coefficient for KL is 0.82 and 0.79, 0.84 for femoral osteophytes (lateral and medial compartment), for tibial osteophytes 0.94 and 0.83 (lateral and medial compartment). 0.84 and 0.90 for Joint
Dalia et al., 2021	2021	OAI	X-rays	4130 images	DenseNets	Space Narrowing. Average Multi class accuracy is 71.08%
Yong et al., 2021	2020	OAI, data set from private hospital in India.	X-rays	4447 knee images from OAI and 1043 from private hospital.	CNN	The mean absolute error from 1.09 to 0.28

CONCLUSION

The several machine learning approaches for KOA diagnostic and prediction have been discussed in above literature review. The development of disease can be avoided by diagnosing it earlier and can be treated appropriately. Data must be considered an important thing, since it is one of the most valuable assets in the healthcare area. Several data sources were used as inputs in KOA study, resulting in strong multidimensional training and testing data sets.

To extract meaningful information from accessible data, a variety of feature selection methods were utilized. The segmentation algorithms such as canny edge detector, Graph cut algorithm, PCA and GLCM were used to extract the features or to reduce the space dimensionality. In an X-ray based investigations, Machine Learning models such as SVMs were most commonly chosen to drive the decision-making process. In the future, the research work can be extended to formulate more efficient segmentation and classification algorithms to automatic grading of KOA where Deep learning approach such as VGG-19, VGG-16, DenseNet, ResNet-34, and LSTM will be the best choice because of its automatic methodology though it requires large data, high power GPU and better performance graphics processing units. Since it will be useful for earlier diagnosis and it might be possible to slow down its progression.

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