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A Survey on Computer Aided Methods for Diagnosis and Assessment of Knee Osteoarthritis

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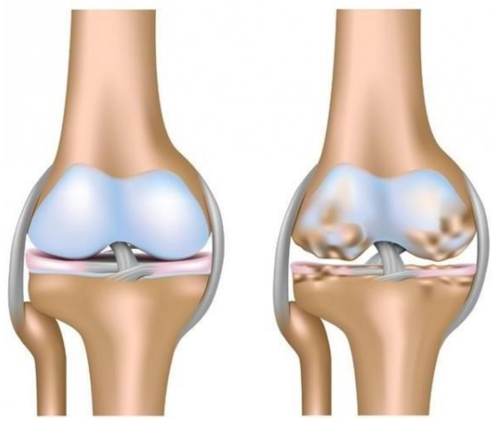
ABSTRACT

Knee Osteoarthritis (OA) is the most common joint disorder that mainly occurs due to wear down of cartilage. An early diagnosis has a pivotal role in treating osteoarthritis and in attenuating further effects. The analysis of medical images is done manually by the medical expert, which is time consuming, subjective and sometimes unpredictable. The complexities related to the medical images make it hard to examine them in an effective way. Thus, to overcome these difficulties several computer-aided methods are being adopted. This paper provides study and analysis of recently developed computer aided methods for diagnosis of knee osteoarthritis and assessment of its severity.

Keywords : Knee Osteoarthritis, Classification, Computer Aided Diagnosis, Grading of OA, Neural Networks.

I. INTRODUCTION

Knee Osteoarthritis is a chronic disease caused by degeneration of cartilage, which leads to sclerosis and osteophytes. Pictorial representation of healthy knee and osteoarthritic knee joint [1] is shown in Fig.1. Cartilage helps the easy glide of bones and prevents them from rubbing each other. In addition to the knee, OA can also occur in various joints such as toes, fingers, pelvis and even the spine [2]. This disease affects 250 million people or about 4% of the world's population. The major risk factors of osteoarthritis are ageing, obesity and injury. In primary stages, treating osteoarthritis includes medications and physiotherapy.



(a) (b)

Fig.1. (a) Healthy knee, (b) Osteoarthritic knee

In this paper, Section II highlights the comparison of different imaging modalities used for diagnosing osteoarthritis by clinicians. Section III discusses the recently developed methods of diagnosing osteoarthritis based on Magnetic

Resonance (MR) images, radiographic images and statistical data. The conclusions are presented in Section IV.

II. IMAGING MODALITIES

Osteoarthritis can be diagnosed radiographically or clinically. Although pathological changes may be evident in all structures within an OA joint, articular cartilage abnormalities are always present. Because of the ease of standardization and acquisition, radiography is the gold standard for diagnosing OA. Magnetic Resonance Imaging (MRI) can provide the most comprehensive assessment of knee joint as it provides excellent soft tissue contrast. However, MRI is expensive, time consuming procedure. Other imaging modalities used in diagnosing knee OA are Computed tomography (CT) and CT Arthrography (CTA), thermography. Musculoskeletal ultrasound has advantages in depicting effusion and the grey scale features can identify inflammation in OA. However, X-ray and MRI has been frequently used in diagnosing knee osteoarthritis [3]. Detection and classification of osteoarthritis from medical images is one of the active fields in computer vision due to availability of datasets such as Osteoarthritis Initiative (OAI) and Multicenter Osteoarthritis Study (MOST) dataset.

III. OA DIAGNOSIS METHODS

A. Based on Magnetic resonance images

Over the past decade, researchers have developed different approaches to detect and classify knee osteoarthritis from MR images. Ashinsky et al., [4] applied cartilage mask to segment the cartilage from T2 maps. OA prediction was done using the machine learning tool, Weighted Neighbor Distance using Compound Hierarchy of algorithms representing morphology (WND-CHRM) with 75% accuracy. Kumar et al., [5] applied pixel based segmentation technique to segment cartilage from 2D coronal view of MRI. These images are subjected to contrast enhancement and histogram equalization for better view of boundaries. Canny edge detection method is adopted for detection of boundaries. Features such as area, energy, entropy, correlation, homogeneity, sum variance, sum entropy, difference entropy, Information measure of correlation, Inverse difference normalized, Inverse difference moment normalized and total articular cartilage thickness are used for training the Support Vector Machine (SVM) classifier. The subjects were differentiated into normal and OA with an accuracy of 86.66%.

Aprilliani et al., [6] proposed the classification of OA disease based on biochemical and morphological changes. MR images of T2 Map and density weighted proton sequence along with age and sex was used. Dodin et al., [7] applied Random Forest algorithm to classify into 3 classes of severity and results with accuracy of 86% were obtained. An automatic segmentation algorithm for human knee cartilage volume quantification from MRI was based on a Bayesian decision criterion. This system allows the quantification, not only of the global knee cartilage volume, but also of the femur and tibia independently. The advent of deep learning has enabled the development of intelligent medical diagnostics. Liu et al., [8] trained 3D Convolutional Neural Network (CNN) using automatically computed segmentation masks for volumetric analysis of knee cartilage. Such a process supports the diagnosis and assessment of knee OA progression. But over estimation of cartilage volume is a limitation in this method. Raj et al., [9] developed a knee cartilage segmentation algorithm from a high resolution MR volume using a novel 3D-fully CNN, called ‘μ-Net’ coupled with a multi-class loss function. Dice score measure varied from 78.5%

to 85.7% for various cartilage surfaces that will enable automatic quantitative evaluation of knee cartilage morphology for the adoption of the quantitative MRI techniques for OA in routine clinical practice.

B. Based on radiographic images

Much of the literature has proposed image classification-based solutions to detect knee OA and assess its severity. OA classification is most commonly done using Kellegren Lawrence (KL) grading system as shown in the table1.

Grade Description
0 No joint space narrowing
1. Doubtful joint space narrowing, possible osteophytic lipping
2. Definite osteophyte, definite joint space narrowing
3. Multiple osteophytes, definite joint space narrowing, sclerosis, possible bony deformity
4. Large osteophytes, marked narrowing of joint space, severe sclerosis, definite bone deformity.

Table.1. KL grading system

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0	No joint space narrowing
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Accurately segmenting knee contours from X-ray images is a challenging problem. Mu et al. [10] presents an algorithm to extract knee bone contours from X-rays based on bone sweep using decomposition and graph search. Horizontal sweep lines and rotary sweep rays were used to segment tibia and femur. Circles were used for segmenting patella instead of sweep lines as patella contains many irregular curves. The final segmentation was performed using graph search to refine the results. This approach proved to extract the contours of overlapped bones in a best way.

A strong relationship between severity of radiographic knee osteoarthritis and knee pain was established by Neogi et al., [11]. The pain measures taken into consideration are, frequency consistency and severity of pain experienced by participants in MOST and Framinghan Osteoarthritis studies. The outcomes stated that the radiographic features accurately reflect the presence of painful pathology. Hegadi et al., [12] presents a simple Artificial Neural Network (ANN) based classification system to diagnose knee osteoarthritis from X-ray images. The boundaries of synovial cavity were extracted using global threshold based segmentation. Image features such as mean standard deviation, range, skewness and edge curvature were given to a two-layer feed forward network to classify into normal or affected knee.

Yoo et al., [13] presented a convenient scoring system and ANN to identify the risk for knee osteoarthritis. The predictors of scoring system were selected as inputs of ANN. The neural network was trained to provide output variables with a five graded scale of radiographic severity. It was established that the performance of scoring system was improved significantly by ANN. Vijayakumari et al., [14] presented the use of Particle Swarm Optimization

(PSO) algorithm along with inertia weight to segment the cartilage which cushions the bones. Applying PSO gives a low contrast grey image and thresholding is done to extract cartilage from background. Cartilage thickness value was set to 1.65 mm and below standard value is notified as presence of OA. Yousuf et al., [15] applied Otsu segmentation method to acquire the region of interest. Feature extraction techniques include Discrete wavelet transform (DWT) followed by Histogram of gradients (HoG). SVM classifier was developed to classify the features into normal and abnormal cases. The outcomes of SVM classifier was compared with ANN and proved to be superior in time effectiveness and iterative learning with an accuracy rate of 85.33%. Brahim et al., [16] applied circular fourier filtering to keep necessary information related to tibial trabecular bone structure. Independent Component Analysis (ICA) was adopted for feature extraction and first ten discriminant components were used for classification in Naive Bayes and Random Forest classifier. This method classified radiographic images with an accuracy of 82.98%, sensitivity of 87.15%, and up to 80.65% for specificity.

The intrinsic nature of Kellegren-Lawrence grade prediction in an ordinal regression problem was put forward by Chen et al., [17]. The proposed ordinal loss model satisfies for a particular grade only if its probability distribution function is close to 1.0 and for other grades it is even smaller than the particular grade. Although the cross entropy loss does not consider the closeness between grades, it satisfies only first property stated in ordinal loss classification. . Lilik et al.

[18] employed Gabor kernel, template matching, row sum graph and grey level center of mass method for segmentation. A classic Self Organizing Map algorithm was trained with Grey Level Co-occurrence Matrix (GLCM) features. The

experimental results proved excellent classification accuracy for grade 0,1 and 4, whereas the grade 2 and 3 were failures. Wahyuningrum et al., [19] applied Structural 2-Dimensional Principal Component Analysis (S2DPCA) for feature extraction and Support Vector Machine (SVM) for classification. The maximum average classification accuracy was compared with Gaussian kernel and Polynomial Kernel. The experimental results proved that the hybrid of S2DPCA and SVM could differentiate KL grade 0 from the other grades with accuracy up to 94.33%. Mahima et al., [20] calculated the joint space width from segmented X-ray image to detect the presence of osteoarthritis. This approach provided better results when compared with Ahlback grading.

Tiulpin et al., [21] proposed a more robust model of deep Siamese neural network using random seeds. It consisted two branches, each with convolution layers followed by batch normalization, ReLU layer and a max pooling layer. The outputs from two branches were concatenated using a softmax layer. Instead of comparing image pairs, it used the symmetry in the image to learn identical weights. This method yielded a quadratic kappa coefficient of 0.83 and an average multiclass accuracy of 66.71%. Wahyuningrum et al., [22] proposed Convolutional Neural Network that combines pre-processing and feature extraction process, followed by Long Short-Term Memory (LSTM) as a classification process. LSTM is an improved model of recurrent neural network. The experimental results have shown that CNN architectures have performed well in extracting high level features, thus enabling the LSTM to effectively discriminate between KL grade 0 – 4 with a mean accuracy of 75.28 %.

C. Based on statistical data

Kumar et al., [23] proposed the application of fuzzy logic interference system to automate diagnosis of osteoarthritis from medical data of patients such as pain, morning stiffness, warmth on joints, bony tenderness, and C - Reactive Protein (CRP) test and so on. A rule base consisting of 33 rules was constructed and the fuzzy outputs were aggregated to one fuzzy set. Centroid defuzzification method was addressed to obtain crisp detection with an accuracy of 91%. Lim et al., [24] adopted medical utilization and health behavior information of subjects aged 50 years and older as statistical data. To avoid over fitting issues, dropout and batch normalization techniques were adopted. Deep neural network (DNN) was experimented with four different combinations of Principle Component Analysis (PCA) techniques. Comparatively DNN and PCA with quantile transformer showed best performance.

As an alternative, Zhang et al., [25] and Losina et al., [26] headed towards developing a risk calculator for OA based on family history, ethnicity, obesity, physical activity, knee injury and occupational risk. In the prior researches, the prediction was based on logistic regression model and the later reported a personalized risk calculator. Risk prediction models are currently recommended by clinicians to predict the risk of osteoarthritis. OA risk calculators has provided new insight in predicting the disease.

IV. CONCLUSION

Computer-aided diagnosis systems have immense potential in clinical diagnosis, as well as in scientific research. This investigation finds that pre-processing and feature extraction techniques play a major role in determining the classifier accuracy. This paper also interprets that SVM classifiers performed well with classifying radiographic images of knee with better accuracy. On comparing deep learning algorithms, CNN out performs several methods discussed in the literature. Currently, the detection of knee joints, feature extraction, and classification or regression are separate steps in most of the researches. Future work must focus on developing end-to-end deep learning system by combining these steps.

Early and accurate identification of significant risk factors in clinical data is of vital importance in diagnosing knee OA. Different machine intelligence approaches enable automated, non-invasive identification of risk factors from self-reported clinical data about joint symptoms, disability, function and general health but the search for more sensitive and specific indicator continues.

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