"A Survey On Morphological Analysis And Segmentation Of Menisci From Magnetic Resonance Images"

Prof.Pavan D. Mahendrakar,
Assistant Professor,
Department of Computer Science and Engineering,
B.L.D.E.A's V.P.Dr. P.G.Halakatti College of Engineering & Technology, Vijayapur, Karnataka.

Abstract:

Nowadays, people around the globe are suffering from various types of musculoskeletal and articular disorders. In recent years, the disease is not only affecting the aging population but also to the younger generation who are lesser than 40 years of age. According to the report of the World Health Organization (WHO), muscular structure and articular disorders are the principal contributors to disability worldwide, with low back pain being the single foremost cause of disability globally [1]. According to the United Nations (UN), 20% of the global population will suffer from musculoskeletal problems by the year 2050[2]. So the Morphological Analysis and Segmentation of human body joints such as knee and spine etc. gain considerable importance in recent days. Some of the measure health problems in the knee joints are meniscal tear and osteoarthritis (OA) etc., which can lead to chronic disabilities. Researchers across the globe are using Manual, Semi-automated and automatic methods for detection of Menisci tears and degeneration in the menisci. This paper surveys the different techniques used for segmentation and detection of menisci tears using Magnetic Resonance Images (MRI).

Keywords: Menisci tear, Osteoarthritis (OA), Magnetic Resonance Image (MRI)

1. INTRODUCTION:

MR Imaging has been the best suitable to achieve the desired result in the imaging diagnosis of meniscal injuries and degeneration from several decades. The knee menisci are soft fiber kind of tissue present in between the femoral condyles and the tibial plateau as shown in Fig. 1[3]. The function and biomechanics of the knee entirely depend on menisci structure and healthy menisci structure plays a significant role in the biomechanics of the complete human body.

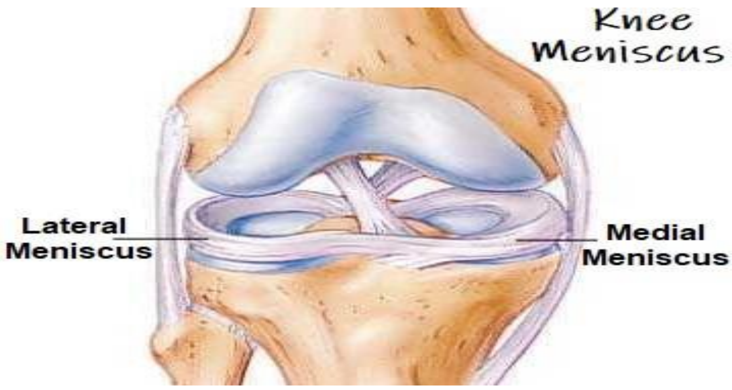

Fig 1. Knee Meniscus and Cartilage

MR imaging is commonly used as a diagnostic tool to study the meniscal pathology. The sensitivity and specificity for MR Imaging in the treatment of meniscal tears of patients without prior surgery differ depending on the observation. However, most researchers and radiologists agree that MR Imaging is precise in this patient group. Because meniscus plays a crucial role within the shape and characteristic of the knee and the abnormal meniscus can result in increased and irretrievable degenerative changes

Meniscal transplantation and its repair have become extremely normal [4]. Segmentation of meniscus from MR images has two important aspects in knee OA studies; 1) Because of its shock absorption and load distribution properties, the meniscus is considered a critical part of the healthy knee joint. 2) In MRI, Meniscal degeneration is a regular outcome of knee osteoarthritis (OA). Various researchers have proposed techniques to segment the meniscus, to fulfill the above-mentioned importance. Meniscus segmentation from MR Images is a complex task. Research shows that there is a strong correlation between abnormalities of the meniscus and the radiographic Osteoarthritis development [5], cartilage loss [6], and progression in cartilage loss [7]. 3D segmentation of the menisci is required for the Quantification of meniscal measures such as measuring meniscal volume and tibial coverage etc.

2. Literature Survey:

Several Researchers, Rheumatologist, and Clinicians worked on different techniques for the analysis of the morphological structure of Menisci, Segmentation and determining the menisci tear and degeneration using Knee MR Images. MR Imaging uses magnetic fields and radio frequencies to probe tissue structure. In contrast to X-ray and CT which require the exposure of ionizing radiation, MRI is a non-invasive imaging method. As such it has become an essential diagnostic imaging modality in the medical field [8].

John V. Crues III et.al. [9] Reported the effectiveness of MR Images in evaluating the structure in and around the knee. From the research, it became ostensible that MR Imaging was perhaps most sensitive in depicting meniscal abnormalities. In the study, the performance and efficiency of the grading system proposed by researchers were assessed in a larger perspective set of patients, by comparing the classification of MR Images with surgical findings. In the study, the researchers examined two hundred and seventy-seven menisci in one hundred forty- four knees with MR Imaging before surgery. The MR images had been evaluated via some of the radiologists who are expert in image analysis and skeletal radiology for grading. Duringoperation, 137 out of 154 menisci showing only grade 1 or grade 2 signs are determined to be consistent which nearly about 89% is. 116 of 123 had tears in the menisci showing intra-meniscal signal collaborating with a meniscal articular surface (grade 3 signal) which are about 94%. MR Imaging discoveries agreed with surgical findings in 91.3% of the menisci. There was also an outstanding connection between the spot of the damage found at the surgery and the location of the signal irregularity on the MR Image.

J M Le Minor [10] did the study on the morphology of lateral meniscus in primates by taking the X-Ray images of their knee joints. The study consist of 316 non-human primates such as Prosimii, Cebuscapucinus, Macacafascicularis, Hylobatesconcolor, young Pongopygmaeus. The researcher found numerous variations in the morphological characteristics of Human knee menisci compared with Primates. The lateral meniscus has a thin, c-shaped structure that's thicker in the center and tapers to thin points at each end in Prosimii, in PongopygmaeusandPlatyrrhinii (New World monkeys). The lateral meniscus is disc-shaped, with a central foramen, in Hylobates (Old World monkeys), in Catarrhinii in Gorilla and Pan troglodytes.

Joes G.Tamez-Penaa,et.al. [11] demonstrated a 4D-analysis approach to analyze the movement patterns of knee joints and evaluate correlation variations among soft tissue structures of the joints while in motion. This method significantly increases the understanding of musculoskeletal related disease development while in motion. The meniscus kinematics was especially observed at the time of the knee flexing by 3D MRI data. They aim to study knee flexibility during motion using 3D MRI data. They applied a “Motion estimation and tracking algorithm” to extract and analyze the major structures of musculoskeletal from a set of MRI images. From this research, an anatomic 3D kinematic model was developed for all musculoskeletal structures and patient-specific 3D motion mechanics and biomechanical prototypes can be developed and used in clinical practice.

R. Lee Cothran et.al. [12] Conducted the clinical study at the Department of Radiology, Duke University Medical Center the set of patients having an acute trauma history to the knee. The patients are subjected to preoperative evaluation of menisci before MR Imaging to study the intensity and specificity of the meniscal tears. Three categories have been made based on the abnormal meniscal signal described during MR Images. However, numerous cases with an abnormal signal in the menisci will not fall into these groups. Meniscal tears were not found in many of these cases and there were no causes and significance. The key difference between signal typically seen with a meniscal tear and abnormal signal was the lack of a definite linear component to the irregular signal. Sometimes abnormal signals can be misunderstood as a tear because of its connection with the articular surface. In the study, numerous cases of abnormal signals adjacent to the articular plane an arthroscopy were found not to show meniscal tears. Among the six patients, five of them had found with meniscus signal abnormality in the back, and on the inner or medial side of the knee and one patient had abnormal meniscal signal in the front portion of the lateral meniscus. In that 5 of the 6 patients have meniscal appearance had ACL injuries. No one out of these six patients was found tears on arthroscopy on the area of the meniscus.

VikasV.Patel et.al. [13] developed a new method for flat, biomechanical image analysis and weight-bearing MR scanning. The capability of MR Imaging to portray bony structures and soft tissues non-invasively has confirmed to be an excellent source for dynamic and static joint imaging. In addition to the relation between total knee arthroplasty and bones in the context of osteoarthritis, the understanding of the physiological process of degeneration, the contact area between cartilage interfaces and surgical outcomes is necessary. The locality of the contact areas and size will play an important role in predicting the success of treatment or providing predictive information. These physiological parameters can be calculated non-invasively and accurately with MRI. In this study, researchers have presented an approach in which results compared with earlier studies of knee kinematics and providing greater 3D detail. An outstanding non-invasive assessment of knee joint kinematics with weight-bearing can be done through MR Imaging. The knee kinematics in patients with knee pathology can be potentially assessed by this tool.

Thomas Magee et.al. [14], are the Musculoskeletal Radiologist from Finland developed a novel technique to detect and characterize the meniscal damages accurately by MR Images. The study did not separate the accuracy of the detection of meniscal tears in the sagittal plane rather than the coronal MRI plane. Studies indicating that for some specific findings, knee coronal MR images might be useful such as loss of articular cartilage, radial meniscal tears and collateral ligament injuries have been published. This study demonstrated on 200 sequential sets of knee MR Images, meniscal tears were shown in 114 samples out of 200. 93 tears of meniscus were exposed to sagittal proton density images only. The utilization of coronal images of knee results in the confident discovery of 21 extra meniscal tears not correctly seen on sagittal proton density images alone. The researchers found that knee coronal MR Images show better recognition and classification of some meniscal tears than sagittal images alone.

Thomas Magee et.al. [15] did the comparative study of sensitivity and specificity of arthroscopic images and MRI images were taken from the 3.0 Tesla machine. They made a retroactive evaluation of one hundred sequential MR images of the knee succeeded by arthroscopy to assess the affectability and specificity of the 3.0. Tesla MRI compared to arthroscopy in examining meniscal tears. Consensus retroactive review of the One hundred knee MR investigation revealed meniscal degeneration. The 4 meniscal damages which have been visible on arthroscopy weren't been visible on the MR examination. There has been 3 false-positive MR Image analysis of meniscal deterioration compared with arthroscopy. During this whole investigation, the sensitivity of MR Images within the recognition of meniscal damage was 96% and therefore the specificity was 97%.

Megan E. Bowersa et.al. [16] uses 3.0-T MR Images for the quantification of meniscal volume by segmentation. When the menisci are tore the mechanism of tibiofemoral joint is altered which again can affect the articular cartilage. For the meniscal tears, meniscectomy and meniscal transplantation were the 2 standard procedures to operate out of which meniscectomy was once considered as standard treatment. This procedure reduces the contact area by 50 to70% and the frictional capacity of articular cartilage also reduces. Hence researchers design a novel method to segment the menisci and then volumetric analysis was done by using the water volume technique. The MR-dependent methodology is exact and consistent for the following modifications in meniscal dimensions. This procedure may also be beneficial for determining the dimensions of meniscal allografts because the meniscal morphology and volume are often examined by the MR-dependent segmentation technique which ends up in the 3D model.

Michael G. Fox [17] professor of Radiology at the University of Virginia conducted a review on current trends and technology to extract and study the meniscus from knee MRI. In the study, the researcher concentrated on the anatomy of the menisci, Meniscal variations, and Meniscocapsular Separation. The affectability and accuracy of MR Imaging in discovering meniscal damages in patients without previous medical procedures differ subjected to the study. However, consent is that MR Imaging is accurate in these patients. Since in the well-maintained structure and function of the knee, the meniscus will play a very significant role and the abnormal meniscus can lead to faster and irretrievable deteriorating changes. The study showed that parallel imaging allegedly delivers a measurable performance to Fast Spin-Echo (FSE) proton density imaging using an Echo Train Length (ETL) of 5 for meniscal injuries with closely a 50% decrease scan time. No considerable variation in the sensitivity, specificity, and correctness in discovering meniscal damages using FSE techniques with and without parallel imaging.

L. Tielinen et.al. [18] discovered the new clinical technique to repair the meniscal tears by using Bio Absorbable Arrows. The bio-absorbable screw was created to overcome the danger of neurovascular injuries recognized with arthroscopically helped outside-in or back to the front fix system. The research was conducted to measure the clinical and MRI result of meniscal damages treated arthroscopically with bio-absorbable screws and differentiate the clinical outcomes and the MRI findings. The patient has been follow-up for 2-444 weeks postoperatively for further clinical examination. In six out of the 51 asymptomatic menisci, the MR Images indicated incomplete recovering. The general recovering degree in the gathering of 77 fixed menisci was 66% as controlled by the clinical assessment. No inflammatory outside body responses were recognized.

IoannisBoniatis et.al. [19] developed a computer-based system that successfully categorized the normal and degenerated menisci. Meniscal Myxoid Degeneration (MMD) is a kind of deteriorating injury that is associated with histological modifications in the meniscus. MMD must be reason for the degeneration of menisci, even in the person of the younger generation. MR Imaging will show a promising role in the recognition of meniscus injuries and degeneration during the clinical examination. The experimental sample of the present study contained 55 medial menisci matching to the one knee of 55 individuals. The age of the patients ranges from 12 to 78 years considering average age as 34 years. The MR images of all 55 individuals are extracted. The researchers utilized custom-developed algorithms in the Matlab software to extract texture features by using the co-occurrence matrix and Region of Interest (ROI). As a result, researchers have successfully discriminated against the normal and degenerated menisci with an accuracy of 89.1%.

Jeffrey W. Grossman et.al. [20] did the comparison study on Knee Magnetic Resonance Imaging in the treatment of Meniscal damages by using 3-Tesla and 1.5-Tesla MRI machines to check the accuracy rates. The research aimed to check whether the decreased slice thickness and higher resolution in 3-Tesla knee MRI protocol guide to a statistically substantial increase in incorrect detection of meniscal injuries compared with 1.5-Tesla imaging. During the research, the author identified 200 patients with different ages, sex, and history of previous knee injuries. The 100 patients had MR investigation on a 1.5-Tesla machine succeeded by arthroscopy and rest 100 patients undergone MR investigation on 3.0 Tesla machine followed by arthroscopy. The researcher found comparable accuracy of 1.5-Tesla and 3-Tesla MR Images of the knee in the treatment of meniscal damages.

JurgenFripp et.al. [21] designed a novel technique to segment the meniscus automatically from MR Images. MRI is the widely encouraging imaging modality to identify morphological variations in menisci tissue and cartilage. MRI is widely accepted for quantitative cartilage evaluation and is usually used clinically to evaluate meniscal pathology and injuries. In the study, the author collected 14 samples of knee MRI from healthy volunteers who do not have any medical history of knee pain and OA. The medial and lateral meniscus was semi-automatically outlined from the 2D sagittal section by one of the authors using a "live-wire algorithm implementation in MEVisLab". The Menisci is segmented from a shape-based algorithm. The outcome of segmentation after these approaches are properly visible, as are frequently seen by the segmentation outcomes obtained for the menisci. Even though these results aren't strongly associated in all cases, it provides a very good concept that a strong and particular automatic technique is feasible for the perfect segmentation of menisci.

Bharat Ramakrishna et.al. [22] programmed "Computer-Aided Detection System (CADS)" to detect meniscal tears from Magnetic Resonance Images (MRI). They found that if the tear of the meniscus is untreated then it will affect the whole mechanism ofknee and may lead to chronic diseases. Hence it is very essential to develop a computer-based system that will automatically detect the meniscal tears which help in treatment further. The framework helps the radiologist to identify the meniscal tears which earlier was done through manual intervention. The projected CAD framework contains three innovative stages. The first one is a programmed choice of areas of intrigue and cuts, another is tear signal identification and solo meniscus extraction which is practiced by the development of specially manufactured extraction and thresholding systems. The third is the structure and improvement of two novel methods for tear representation, fragility, and dependability that yields a scoring framework for the assessment of degree in created CAD framework.

Kunlei Zhang et.al. [23] presented an automatic knee segmentation scheme that works on multi-contrast MR images where a new classification model uniting an "Extreme Learning Machine (ELM)-based association potential and a Discriminative Random Field (DRF)-based interaction potential" is proposed. The DRF model introduces three-dimensional dependencies between neighboring voxels to the independent ELM classification. From these methods, it became clear that the MR Imaging is probably very sensitive at portraying meniscal abnormalities. In this research, the correctness of the grading system proposed by Lotyschet. al. was evaluated by comparing the MRI imaging classification with surgical findings. The study makes use of native image features including (normalized) depth values, the 1st and 2nd order differentiation, and the eigenvalues of the hessian images. The information on the calculation of the native image capabilities is provided in additional materials.

M. S. Holi et.al. [24] developed a technology based on image processing to detect menisci tears. The technique was based on intensity thresholding which is very useful in the segmentation of menisci from MRI sagittal, axial and coronal view. The detection of menisci tears is based on canny edge detection and thresholding approaches. Input MR Images are pre-processed for format change and type conversion. Grey level thresholding is implemented to make sure a superior vision of the structural boundaries in images is areas with high-intensity contrasts. The edge detecting an image expressively decreases the total number of data and filters off futile information while conserving the significant morphological properties in an image. The technique subdivides cartilage, femur, tibia, and menisci. The processing stages are extended for the detection of menisci injuries and the thickness of menisci is plotted.

F.Cengiz .Pitikakis et.al. [25] developed a semiautomatic procedure to segment the meniscus tissues from MRI datasets and restructuring menisci into a 3D model, using advanced segmentation software. The meniscus has an important role in the biomechanics and function of the knee. The research aimed to regenerate the meniscus tissue using tissue engineering and 3D Bio-printing technology. Advanced technology was presented to translate medical imaging information from a patient into a fabricated implant. The Meniscus tissue image is first Pre-processed and segmented manually for the correction. Later 3D image is constructed by using the marching cube algorithm. This was the major stage in the direction of a modified tissue engineering therapy model for meniscus.

AhmetSaygılı et.al. [26] developed a novel software-based approach for automatic knee meniscus segmentation using MRI. The proposed methodology consists of two important portions. The purpose of the one portion is to detect the tiniest areas surrounding the meniscus. Since the meniscus size is not consistent in MR slices, dissimilar patch sizes are used for patch determination. The second portion of the study concentrated on different alternatives of the histogram of oriented gradients and Gabor filters which can be used as a feature extraction technique will be used to improve the system's accuracy in the future.

Luke D. Jones et.al. [27] conducted a study on meniscal margin extending beyond the tibial margin on the same point over the period using MR Images. The target is investigating the meniscus part in the pathogenesis of knee osteoarthritis (OA). The important stage in osteoarthritis development is meniscus extends beyond the tibial joint margin. A more absolute and suitable measurement of extension length will be used to measure the vertical distance between the edge of the meniscus and edge of the tibia which is possible only on a tibial slice of meniscus segmentation not on coronal slices. In the study, twenty high-resolution knee MRI scans are taken from non-symptomatic patients. The medial meniscus and tibia were physically segmented. A custom-developed Matlab program was used to analyze the variation in the medial displacement of the body of the meniscus beyond the outmost boundary of the medial tibial plateau of the knee using the standard compared to other methods. The meniscus and tibia were divided into innermost and outermost portions using a coronal plane creating four distinct anatomical regions. The study suggested clinicians and radiologists consider meniscal extrusion of the knee to treat the patients over the period.

Tack et. al. [28] present a novel technique for automated knee menisci segmentation from MRIs. The technique of segmentation using convolutional neural networks has been developed in combination with statistical shape models. On 88 manual segmentation accuracy was measured. Differences between OA classes, joint space narrowing (JSN), and WOMAC pain were measured and checked for meniscal length, tibial coverage, and meniscal extrusion.

Several researchers proposed different approaches and techniques to study the morphology and anatomy of knee meniscus from the MR Images. Most of the semiautomatic and automatic methods were not performed well up to the expectation to segment the knee meniscus and examine the tears of meniscus. Hence the development of fully automated technology to discriminate against the normal and degenerated menisci is essential for the researcher and radiologists.

3. Methodology Used:

As per the literature survey, most of the researchers and radiologists were using the manual method or semi-automated method to segment the meniscus and check whether it is normal or degenerated. The result of these methods was not considered to develop it further because most of the methods were complex, time taking and prone to the error. This also depends on the quality of MR Images and relevant information present in the frame. Based on the drawback of manual and semiautomatic methods, researchers developed a computer-dependent approach to automatically segment the meniscus from MR Images using image processing [29]. Since image processing techniques were used for visualization and in the treatment of many of the biological structures. The following Fig. 2 illustrates the flow diagram of the methodology used in a computer-based approach to automatically segment the menisci and discrimination between normal or abnormal menisci.

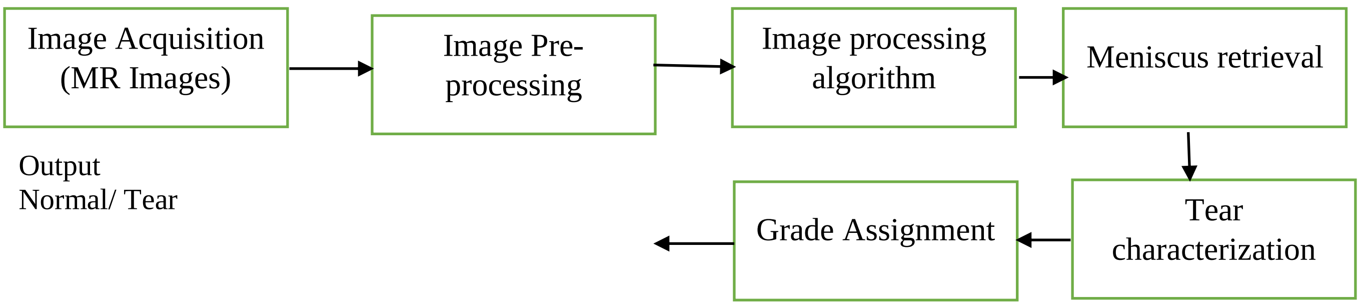

Fig 2. Flow diagram to detect Normal/Tore meniscus using Computer Based Approach

The Knee MR Images are provided as input to the system. The first step of the methodology is image pre-processing. The researchers specified the Region of Interest (ROI) and select the slice, which are critical steps towards extracting meniscus effectively. In the next step image, processing based algorithms were used to segment the meniscus from pre-processed images. Segmented meniscus then will be retrieved by using a shape-based retrieval algorithm, Gradient vector flow, and morphological operations. The tear characterization is implemented by separating the extracted meniscus into two main sections: The lateral and medial meniscus, further divided into the rear and anterior parts. In the next step, the tears will be graded as Type1, Type 2 and Type 3 based on certain constraints like the size of the tear, age of the patient, etc.

4. Future Scope:

Since most of the automatic menisci segmentation techniques were failed to discriminate between normal and degenerated meniscus efficiently, a Novel fully-automatic system must be developed for the discrimination between normal and degenerated menisci from Magnetic Resonance Images. Artificial Intelligence and Machine learning are emerging and most promising area in the world of computer technology. The technology can be used to solve the complex problems which have not yet solved by computer vision and image processing technique. Research shows that applying deep learning to complex problems will results in greater accuracy compared to image processing and computer vision techniques [29].

5. CONCLUSION:

In this paper, we have presented the different approaches used for segmentation and morphological assessment of meniscus from MR Images based on the survey. In future machine learning techniques can be used to enhance the efficiency of the segmentation and discriminating normal and degenerated menisci.

REFERENCES

[1] James SL, Abate D, Abate KH, et al. "Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990-2017: a systematic analysis for the Global Burden of Disease Study " 2017. Lancet 2018; 392: 1789-858.

[2] René Fejerand Alexander Ruhe"What is the prevalence of musculoskeletal problems in the elderly population in developed countries? A systematic critical literature review" Chiropr Man Therap. 2012; 20: 31. Published online 2012 Sep 24. doi: 10.1186/2045-709X-20-31,PMCID: PMC3507809 PMID: 23006836.

[3] F.CengizM.Pitikakis ,L.Cesario , P.Parascandolo , L.Vosilla , G.Viano , J.M. Oliveira, R.L.Reis "Building the basis for patient-specific meniscal scaffolds:From human knee MRI to fabrication of 3D printed scaffolds" www.elsevier.com/locate/bprint, 13 May 2016.

[4] Michael G.Fox,MD "MR Imaging of the Meniscus:Review,CurrentTrends,and Clinical Impications", Magnetic Resonance Imaging Clinics of North America 15:1,February 2007.

[5] Englund M, Guermazi A, Roemer FW, Aliabadi P, Yang M, Lewis CE, et al. Meniscal tear in knees without surgery and the development of radiographic osteoarthritis among middle-aged and elderly persons: The multicenter osteoarthritis study. Arthritis Rheum 2009;60(3):831-839.

[6] Hunter DJ, Zhang YQ, Niu JB, Tu X, Amin S, Clancy M, et al. The association of meniscal pathologic changes with cartilage loss in symptomatic knee osteoarthritis. Arthritis Rheum 2006;54(3):795-801.

[7] Sharma L, Eckstein F, Song J, Guermazi A, Prasad P, Kapoor D, et al. Relationship of meniscal damage, meniscal extrusion, malalignment, and joint laxity to subsequent cartilage loss in osteoarthritic knees. Arthritis Rheum 2008;58(6):1716-1726.

[8] Catherine Westbrook. MRI at A Glance. Wiley Blackwell, 3 edition, 2016.

[9] John V. Crues III, MD Jerrold Mink MD, Teresa L. Levy, BA S Matthew Lotysch, MD , David W. Stoller, MD "Meniscal tears of the knee: accuracy of MR Imaging" Radiology. 1987 Aug; 164(2):445-8.

[10] J. M. LE MINOR, "Comparative morphology of the lateral meniscus of the knee in primates", Journal of Anatomy . (1990), 170, pp. 161-171.

[11] Joes G.Tamez-Penaa, SaaraTotterman and Kevin J.Parker, "Kinematic analysis of musculoskeletal structures via volumetric MRI and unsupervised segmentation", Proceedings Volume 3660, Medical Imaging 1999: Physiology and Function from Multidimensional Images; (1999).

[12] R. Lee Cothran, Jr., Nancy M. Major, Clyde A. Helms, Laurence D. Higgins, "MR Imaging of Meniscal Contusion in the Knee", American Journal of Roentgenology: PP 177, November 2001.

[13]Vikas V. Patel, Katherine Hall , Michael Ries , Jeff Lotz , Eugene Ozhinsky , Colleen Lindsey, Ying Lu ', SharmilaMajumdar , "A three-dimensional MRI analysis of knee kinematics", Journal of Orthopaedic Research 22 (2004) 283-292, Elsevier Publication, 20 August 2003.

[14] Thomas Magee, David Willams, "Detection of Meniscal Tears and Marrow Lesions using Coronal MRI" , American Journal of Roentgenol. 2004 Nov;183(5):1469-73.

[15] Thomas Magee, David Willams, "3.0-T MRI of Meniscal Tears", AJR:187, August 2006.

[16] Megan E. Bowers,Glenn A Tung,Braden C. Fleming,Joseph J. Crisco, Jesus Rey, "Quantification Of Meniscal Volume By Segmentation Of 3t Magnetic Resonance Images", Journal of Biomechanics 40(12), March 2007:PP 2811-2815.

[17] Michael G. Fox, "MR Imaging of the Meniscus:Review,CurrentTrends,and Clinical Impications", Magnetic Resonance Imaging Clinics of North America 15:1, February 2007.

[18] L. Tielinen, J. Lindahl , S. Koskinen, E. Hirvensalo, "Clinical And Mri Evaluation Of Meniscal Tears Repaired With Bio absorbable Arrows" Scandinavian Journal of Surgery, Volume: 96 issue: 3, page(s): 252-255 Issue published: September 1, 2007.

[19] IoannisBoniatis,GeorgePanayiotakis, "A Computer-Based System for the Discrimination Between Normal and Degenerated Menisci From Magnetic Resonance Image" IEEE International Workshop on Imaging Systems and Techniques – IST 2008 Chania, Greece, September 10–12, 2008.

[20] Jeffrey W. Grossman, Arthur A. De Smet and Kazuhiko Shinki, "Comparison of the Accuracy Rates of 3-T and 1.5-T MRI of the Knee in the Diagnosis of Mensical Tear", American Journal of Roentgenology 2009: PP 509-5014.

[21] JurgenFripp, PierrickBourgeat, Craig Engstrom, SebastienOurselin , Stuart Crozier, Olivier Salvado, "Automated Segmentation of The Menisci From MR Images" , IEEE International Symposium on Biomedical Imaging: From Nano to Macro, 28 June-1 July 2009.

[22] Bharath Ramakrishna, Weimin Liu, Ganesh Saiprasad, NabileSafdar, Chein-I Chang, Khan Siddiqui, W. Kim , Eliot Siegel, "An Automatic Computer-Aided Detection System for Meniscal Tears on Magnetic Resonance Images" , IEEE Transactions On Medical Imaging, Vol. 28, No. 8, August 2009.

[23] Kunlei Zhang, Wenmiao Lu, PinaMarziliano, “The unified extreme learning machines and discriminative random fields for automatic knee cartilage and meniscus segmentation from multi-contrast MR images”, Machine Vision and Applications volume 24, pages1459–1472(2013).

[24] M. S. Holi, M. S. MallikarjunaSwamy, “Knee Joint Menisci Visualization and Detection of Tears by Image Processing”, International Conference on Computing, Communication and Applications 2012. DOI: 10.1109/ICCCA.2012.6179203.

[25] F.CengizM.Pitikakis ,L.Cesario , P.Parascandolo , L.Vosilla , G.Viano , J.M. Oliveira, R.L.Reis, “Building the basis for patient-specific meniscal scaffolds: From human knee MRI to fabrication of 3D printed scaffolds” Bioprinting, Volumes 1–2, March–June 2016, Pages 1-10.

[26] AhmetSaygılı ,SongülAlbayrak , “A new computer-based approach for fully automated segmentation of knee meniscus from magnetic resonance images”, Biocybernetics and Biomedical Engineering Volume 37, Issue 3, 2017, Pages 432-442.

[27] Luke D. Jones, Stephen J. Mellon, Neil Kruger, Andrew P. Monk, Andrew J. Price, David J. Beard, “Medial meniscal extrusion: a validation study comparing different methods of assessment“,Knee Surgery, Sports Traumatology, Arthroscopy volume 26, pages1152–1157(2018).

[28]A. Tack, A. Mukhopadhyay, and S. Zachow, "Knee menisci segmentation using convolutional neural networks: data from the Osteoarthritis Initiative," Osteoarthritis Cartilage, Mar 9 2018.

[29] PiotrKohut, Krzysztof Holak, RafałObuchowicz, “Image processing in detection of knee joints injuries based on MRI images”, Journal of Vibroengineering, Vol. 19, Issue 5, 2017, pp. 3822-3831.

[30] Niall O’ Mahony, Sean Campbell, Anderson Carvalho, SumanHarapanahalli, Gustavo Velasco Hernandez, LenkaKrpalkova, Daniel Riordan, Joseph Walsh, “Deep Learning vs. Traditional Computer Vision”, Advances in Computer Vision, PP 128-144, 24 April 2019.