Shape characterization of the gonarthrosis in the X-ray images

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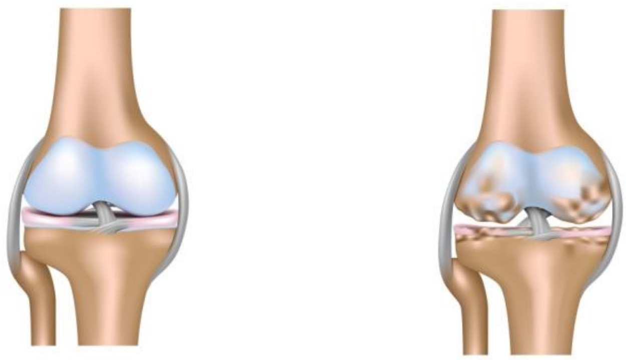
Abstract

Gonarthrosis is a degenerative disease of the knee joint that involves damage of the articular cartilage, formation of the osteophytes and reactive changes in the synovial membrane and in the synovial liquid. Location of the initial change in the knee joint is unknown, i. e. initial change can occur anywhere. Diagnosis of the gonarthrosis is based on the use of the clinical and radiological methods. In this study, X – ray images were used. Resolution and dimensions of the X – ray images can vary and influence precision in their reading and analysis. Taking into account a possible complexity of images, it is necessary to perform a few processing steps in order to obtain measurable information. In order to eliminate imperfections of images, a non-linear median filter is used for image filtering. The segmentation of the characteristic regions in the image is done by using active contour segmentation which is based on the curve flow, curvature and contour of the desired region. Therefore, the quantification of the obtained information is necessary in order to perform precise classification of the gonarthrosis grade. Quantification of the segmented regions was carried out by measuring space between femur and tibia and by comparing it with measured space between femur and tibia in healthy persons. The precise diagnosis of this disease is of great importance to preserve objectivity during decision making, for further treatment and to facilitate the performance of everyday activities of the patients.

Keywords: Gonarthrosis, Shape, Characterization**,** Segmentation

1. Introduction

Gonarthrosis is degenerative disease of the knee joint. Occurrence of the gonarthrosis is related to the functioning of the complex mechanism of the knee joint with its complex geometry. In other words, the knee joint is the most complex in the human body and it is exposed to the greatest load which can lead to overload and to faster wear/deficiency of the cartilage tissue that covers a bone surface, even in the static disorder cases of the human body (Taşkin G et al 2018, Haviv et al 2013, Hinman RS et al 2006).
Cartilage layer has a significant role in the wear prevention between contact surfaces and provides smooth movement inside the knee joint. Any changes lead to the irreversible degenerative process. Beginning of this process is characterized by joint cartilage fraying. However, degenerative disease progression leads to the destruction of the joint cartilage and to the abnormal growing of the bone tissue which results in elasticity loss, in joint cartilage deficiency occurrence, and in the knee joint swelling (Fig.1 (Taşkin G et al 2018, Haviv et al 2013).



a) b)

Figure 1. Healthy knee joint and degenerative deficient knee joint: a) Healthy knee joint, and b) Osteoarthritis (https://joints-health.co.uk/gonarthrosis-knee-joint-degeneration)

Initial deficiency of the knee joint is accompanied by discomfort which, later, grows into pain. In that case, patients reduce their movements (decrease in step length and load of the deficient knee is significantly shorter) to avoid pain. With degenerative disease progression, the sensation of pain also occurs at rest. The most common sites for pain occurring are in the front part or in the medial part of the knee (Nikolova V et al 2018, Haviv et al 2013).
Disease emergence can be associated with many causes, but the most common are impairment of the knee joint function caused by age, physical effort or trauma, weight excess, acute and chronic inflammatory processes of the knee joint, foot deformation (which leads to the non-adequate distribution of the loads in the joint), professional sportsman diseases (if it is developed at an early age) (Güvenc K et al 2019, Nikolova V et al 2018).

Clinical indicators of the gonarthrosis occurrence are a pain in the knee joint, reduced range of the motion in the knee joint, radiographic images with the clear indicators of the degenerative changes in the knee joint, and decreased patients' quality of life (Fryzowicz A et al 2018).
Since there is no medicament for gonarthrosis, current strategy in the disease treatment is to spot on time and to slow disease progression. It is necessary to interpret radiograph images in the objective, accurate, precise and quick manner. For that purpose, implementation of the automatic images segmentation methods could help (Kohut P et al 2017, Mahmood N et al 2015).
Aim of this study is to develop a segmentation model of the knee joint in the radiographic images, and to determine gonarthrosis category in order to facilitate the patient's daily life activities.

2. Gonarthrosis classification methods

Gonarthrosis classification is based on analysis of the X-ray images by clinicians, although new techniques may be encountered today (Elbaz A et al 2014). X-ray images could be useful before and during surgery. In the literature and in the practice could be found different classification methods of gonarthosis. Some of them are listed in Table (Kohn MD et al 2016, Wright RW et al 2014).

Table 1. Gonarthrosis classification methods

Kellgren – Lawrence Method			
Category	0	Space narrowing of the knee joint does not exist nor any reactive changes	Characteristic
	1	Interrogative knee joint space narrowing, osteophyte edges occurrence	
	2	Possible knee joint space narrowing, definitely osteophyte occurrence	
	3	Definite knee joint space narrowing, moderate osteophyte, possible sclerosis, possible bones deformities	
	4	Definite knee joint space narrowing, severe sclerosis, definite bones deformities	
IKDC Method			
Category	A	There is no narrowing of the knee joint space	Characteristic
	B	Knee joint space is greater than 4mm, small osteophytes, slight sclerosis or alignment of the femoral condyles	
	C	Knee joint space between 2mm and 4mm	
	D	Knee joint space is less than 2mm	

Table 1. Gonarthrosis classification methods

Ahlbäck Method			
Category	0	Normal	Characteristic
	1	Knee joint space narrowing is less than 3 mm or less than 50% of the other compartment (with or without subchondral sclerosis)	
	2	Obliteration of knee joint space	
	3	Bone defect/loss less than 5 mm	
	4	Bone defect and/or loss between 5mm and 10 mm	
Brandt et al. Method			
Category	0	Knee joint space is less than 25% without secondary phenomena (subchondral sclerosis, geodes or osteophytes)	Characteristic
	1	Knee joint space is less than 25% with secondary phenomena or between 25% and 50% without secondary phenomena	
	2	Knee joint space is between 25% and 50% with secondary phenomena or between 50% and 75% without secondary phenomena	
	3	Knee joint space is between 50% or 75% with secondary phenomena or greater than75% without secondary phenomena	
	4	Knee joint space is greater than 75% with secondary phenomena	
Fairbank Method			
Category	0	Normal	Characteristic
	1	Tibial margin becomes square in shape	
	2	Alignment of the femoral condyles, tibial margin becomes square in shape, sclerosis	
	3	Narrowing of the knee joint space, hypertonic changes	
	4	Alignment of the femoral condyles, tibial margin becomes square in shape, Narrowing of the knee joint space, hypertonic changes	
Jäger-Wirth Method			
Category	0	No arthrosis	Characteristic
	1	Initial arthrosis, small osteophytes, minimal narrowing of the knee joint space	
	2	Moderate arthrosis, about 50% narrowing of the knee joint space	
	3	Medium-grade arthrosis	
	4	Heavy arthrosis	

3. Data acquisition and processing

Acquisition of the X-ray images was done in the Clinical center Kragujevac according to the rules of the Helsinki declaration and good clinical practice with the approval of the local Ethical Committee. Resolution of the collected X-ray images was 2928x2328x8 bits per pixel.

An independent analysis of the X-ray images was performed by two clinicians according to Kellgren – Lawrence classification. This method is one of the first established radiographic criteria. It was suggested in 1957. and was accepted by the World Health Organization in 1961 (Kohn MD et al 2016).

Further processing and analysis were performed by using programmable environment MATLAB (www.mathworks.com) based on the algorithm showed in Fig.2.

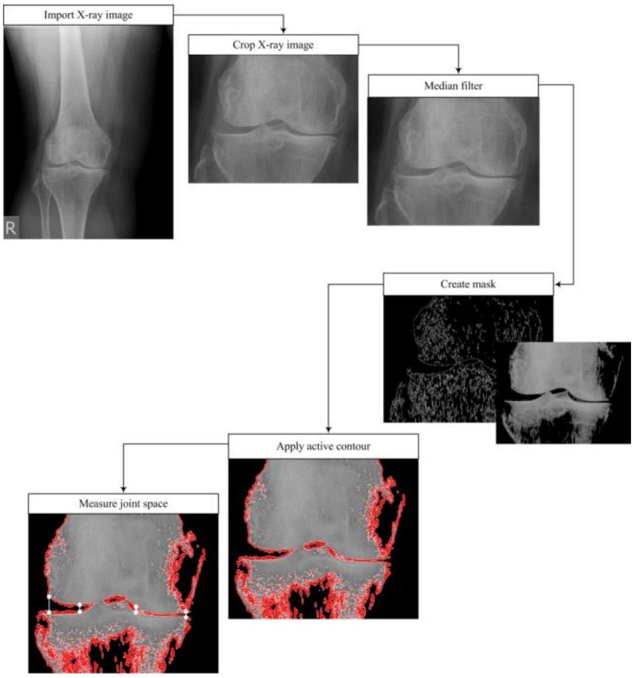


Figure 2. Algorithm for the X-ray image segmentation and determining the space in the knee joint

After importing desired X-ray image, a region of interest is cropped to make visible important details typical for gonarthrosis. Given the quality of X-ray image does not have to be constant always (because making an X-ray image is done by different operators), it is necessary to perform image filtering. In our case, median

filtering was done. This filtering method is one characteristic image processing step after which image is improved and prepared for further processing, such as contour detection.
After filtering, X-ray image becomes clearer. Considering the precise determination of the observed object contours by using active contours method, e.g. snakes, it is necessary to create initial state of the active contours by forming a binary mask.
Although there is enough contrast in the image between the observed object (knee joint) and background, for binary mask creation it is desirable to adjust the contrast by using operators which calculate the image gradient. By forming initial contours, conditions for applying snake algorithm are created. It can be seen as a special case of the generic techniques for adjustment to the deformable objects by minimizing energy. Also, this algorithm belongs to the category of the active models because of its iterative energy minimization characteristic, which results in their dynamic behavior – their shape changes in each iteration.
By using this algorithm for segmentation, gonarthrosis regions can be clearly seen, respectively deficient/healthy space in the knee joint. Also, any region of the interest can be measured, such as joint space.

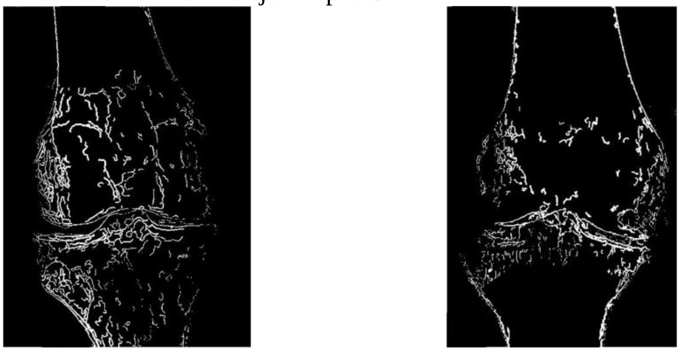
4. Results

The suggested segmentation method was tested on X-ray images which were manually classified according to Kellgren – Lawrence classification criteria. Each category of gonarthrosis had 10 images. Segmented regions of the knee joint are shown in Fig.3 and in Fig. 4.

a) b)

Figure 3. Segmented regions of the knee joint: a) Kellgren – Lawrence classification criteria I, and b) Kellgren – Lawrence classification criteria II

Diagnosis of the gonarthrosis is more noticeable by using proposed methodology. Fig. 3a shows a segmented region of I stage of the gonarthrosis. It is noticeable reduction of the knee joint space. Fig. 3b shows segmented region of II stage of the gonarthrosis where the osteophytes existence is noticeable, as well as more significant reduction of the knee joint space.



a) b)

Figure 4. Segmented regions of the knee joint: a) Kellgren – Lawrence classification criteria III, and b) Kellgren – Lawrence classification criteria IV

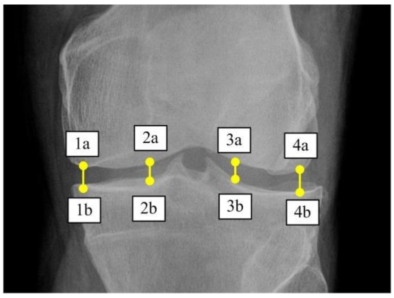
Fig. 4a shows a segmented region of III stage of the gonarthrosis in which clearly formed subchondral sclerosis exist with osteophyte. Lastly, non-existence of the knee joint space with a significant contact of the bone structures is shown in Fig. 4b which suits IV stage of the gonarthrosis.
Based on segmented regions, the values of the knee joint space for every category of gonarthrosis were measured. The values are shown in Tab.2.

5. Discussion and conclusion

Measuring of the joint space narrowing belongs to the methods for the estimation of the disease progression which are analyzed in X-ray images (Miyazaki T et al 2002). Degenerative disease progression leads to the pain increase in patients, which further influences on their quality of life. In order to provide a better quality of life to the patients, many researchers have been dealing with this topic for a long time (Lanyon P et al 1998).
Although Kellgren-Lawrence classification may be considered as the gold standard in the X-ray images interpretation, modern radiographic devices have exceptional sensitivity and can provide additional information for characterization and description of numerous degenerative diseases, for example gonarthrosis. In other words, decision making whether the gonarthrosis level belongs to the category I or category II, respectively category III or category IV may be debatable because it depends on the personal estimation of the clinician (Shamir L et al 2009, Rajpoot MS et al 2016). By automatic segmentation of the knee joint (or any other object of interest in the X-ray image), objectivity in decision making may be achieved. In this way, it is possible to highlight some important features and determine level of the degenerative disease more closely. X-ray images have a lot of limitations (for example, one image in one plane), but even so, they are represent in clinical practice. Far more information can be obtained by analyzing CT or MRI images, but

the question arises about additional radiation of the patients, respectively to the additional time (Georgiev T et al 2016, Evangelopouls DS et al 2015).

Table 2. The values of the measured knee joint space



Kellgren – Lawrence category	SB Point 1a and Point 1b	SB Point 2a and Point 2b	SB Point 3a and Point 3b	SB Point 4a and Point 4b
I	3.83±0.65	3.18±0.26	4.13±0.37	4.73±0.82
II	2.94±0.32	2.62±0.43	2.96±0.21	1.36±0.53
III	1.63±0.58	2.12±0.51	2.04±0.42	2.05±0.98
IV	Definite narrowing			

*Space between - SB

Anyway, researchers try to suggest different methods for X-ray images segmentation to facilitate and expedite work for clinicians. In addition to detection of degenerative diseases in bones, researchers suggest different methods for detection of the fractures, cancers, people identification, etc (Saini PK and Singh M 2015, Khandare KP and Gurjar A 2016, Dukov N et al 2019).

In our study, preprocessing of the X-ray images was performed by using median filtering and by threshold adjusting. A similar approach, for the treatment prediction of the bones fractures (surgical interventions or not), was used also by Haq A. et al (Haq A et al 2019). In this way, all imperfections and noises in the images are removed and the image becomes clearer and prepared for segmentation.

Researchers suggest different segmentation methods. For example, Gajjar B. et al, respectively Myint S. et al. suggested Canny algorithm for fracture detection in the tibia bone (Gajjar B et al 2017, Myint S et al 2016, Petrovic Savic S et al 2018). Opposite to them, because of the nature of the degenerative disease and the complexity of the shapes, we decided to perform segmentation of the knee joint by using active contours algorithm. In that way, the precise identification of the bone tissue affected by degenerative disease is provided. As in our case, researchers who met with the segmentation of the complex shape used active contours algorithm (Hasan M et al 2016).

Measuring of the joint space narrowing was performed by manual selection of the key points (Petrovic Savic S et al 2018), thereby securing insight in values which

characterize certain gonarthrosis category. Also, the clinicians can measure any region of the interest, not just knee joint space narrowing.
In this study, characteristic values of the knee joint space narrowing and the shape of the gonarthrosis are shown. This is enabled by image segmentation by using active shape method. Further research is geared toward the creation of the digital repositories with a sufficient number of specimens, the improvement of the suggested algorithm and the implementation method for automatic decision making.

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Haviv B, Bronak S, Thein R (2013). The complexity of pain around the knee in patients with osteoarthritis, *Israel Medical Association Journal*, 15(4), 178-181.
Altintas Y, Weck M (2004). Chatter stability of metal cutting and grinding, *CIRP Annals - Manufacturing Technology*, 53 (2), 619–642.
Hinman RS, Rachel ML, Crossley KM (2006). Is there an alternative to the full-leg radiograph for determining knee joint alignment in osteoarthritis? *Arthritis & Rheumatism (Arthritis Care & Research)*, 55(2), 306-313.
Kohn MD, Sassoon AA, Fernando ND (2016). Classification in brief: Kellgren-Lawrence classification of osteoarthritis, *Clinical Orthopedics and Related Research*, 474(8), 1886-1893.
Wright RW, MARS Group (2014). Osteoarthritis classification scales: Interobserver reliability and arthroscopic correlation, *The Journal of Bone and Joint Surgery*, 96(14), 1145-1151.
Taşkin G, Koz M , Gülşen M , Yemişci O , Akalan C (2018). Does physical activity levels have effect on pain in patients undergoing physical therapy? A survey study, *Spormetre Beden Eğitimi ve Spor Bilimleri Dergisi*, 16 (2), 237-244.
Fryzowicz A, Dworak LB, Koczewaki P (2018). Prophylaxis of medial compartment gonarthrosis in varus knee – current state of knowledge, *Archives of Medical Science*, 14(2), 454-459.
Nikolova V, Prakova G (2018). Degenerative joint diseases (osteoarthrosis) and quality of life, *Trakia Journal of Science*, 16(1), 180-183.
Güvenç K, Şahap CA, Ergin M, Özcan E, İlik F (2019). Dynamic thiol-disulphide homeostasis in grade 3-4 gonarthrosis, *The European Research Journal*, DOI: 10.18621/eurj.414367
Mahmood N, Shah A, Waqas A, Abubakar A, Kamran S, Zaidi SB (2015). Image segmentation methods and edge detection: An application to knee joint articular cartilage edge detection, *Journal of Theoretical and Applied Information Technology*, 71(1), 87-96.
Kohut P, Holak K, Obuchowicz R (2017). Image processing in detection of knee joints injuries based on MRI images, *International Journal of Vibroengineering*, 19(5), 3822-3831.

Elbaz A, Mor A, Segal G, Dbi R, Shazar N, Herman A (2014). Novel classification of knee osteoarthritis severity based on spatiotemporal gait analysis, *Osteoarthritis and Cartilage*, 22, 457-463.
Shamir L, Ling SM, Scott WW, Bos A, Orlov N, Macura T, Eckley DM, Ferrucci L, Goldberg IG (2009). Knee X-ray image analysis method for automated detection of osteoarthritis, *IEEE Transactions on Biomedical Engineering*, 56(2), 407-415.
Miyazaki T, Wada M, Kawahara H, Sato M, Baba H, Shimada S (2002). Dynamic load at baseline can predict radiographic disease progression in medial compartment knee osteoarthritis, *Annals of the Rheumatic Diseases*, 61, 617-622.
Lanyon P, O'Reilly S, Jones A, Doherty M (1998). Radiographic assessment os symptomatic knee osteoarthritis in the community: definitions and normal joint space, *Annals of the Rheumatic Diseases*, 57, 595-601.
Rajpoot MS, Peepra D, Pandey KK, Varma HS (2016). Clinico-radiological correlation of osteoarthritis knee using Western Ontario and McMaster Universities score and Kellegren and Lawrance grading, *International Journal of research inMedical Sciences*, 4(11), 4873-4876.
Georgiev T, Stoilov R, Penkov M, Ivanova M, Trifonov A (2016). Radiographic assessment of knee osteoarthritis. *Revmatologiia (Bulgaria*) 24(2), 16–24.
Evangelopouls DS, Huesler M, Ahmad SS, Aghayev E, Neukamp M, Röder C, Exadaktylos A, Bonel H, Khol S (2015). Mapping tibiofemoral gonarthrosis: an MRI analysis of non-traumaticknee cartilage defects, *British Institute of Radiology*, 88, 20140542.
Gajjar B, Patel S, Vaghela A (2017) Fracture detection in X-ray images of long bone, International Journal of Computer Science and Engineering, 5(6), 129-133.
Haq A, Wilk S, Abello A (2019). Fusion of clinical data: A case study to the type of treatment of bone fracture, *International Journal of Applied Mathematics and Computer Science*, 29(1), 51-67.
Saini PK, Singh M (2015). Brain tumor detection in medical imaging using Matlab, *International Journal of Engineering and Technology*, 2(2), 191-196.
Khandare KP, Gurjar A (2016). Dental Biometric Approach for Human Identification using Dental X-ray Images of Maxillary Bone, *International Journal of Engineering and Technology*, 3(2), 1566-1570.
Dukov N, Bliznakova K, Feraov F, Buliev I, Bosmans H, Mettivier G, Russo P, Cockmartin L, Bliznakov Z (2019). Models of breast lesions based on three-dimensional X-ray breast images, *Physica Medica*, 57, 80-87.
Myint S, Khaing AS, Tun HM (2016). Detecting leg bone fracture in X-ray images, International Journal of scientific & technology research, 5(6), 140-144.
Hasan M, Hassan R, Ismail W, Yoshitaka A (2016). Automatic segmentation of jaw from panoramic dental X-ray images using GVF snakes, *in 2016 World Automation Congres, IEEE*, 31. July-4. August, 16357820.
Petrovic Savic S, Ristic B, Jovanovic Z, Matic A, Prodanovic N, Anwer N, Qiao L, Devedzic G (2018). Parametric Model Variability Of The Proximal Femoral Sculptural Shape, *International Journal of Precision Engineering and Manufacturing*, 19(7), 1047-1054.