

PAPER • OPEN ACCESS

## Development of methods for analysis of knee articular cartilage degeneration by magnetic resonance imaging data

To cite this article: Artjoms Suponenkovs *et al* 2017 *J. Phys.: Conf. Ser.* **818** 012001

View the [article online](#) for updates and enhancements.

### Related content

- [The accuracy and reliability of a novel handheld dynamic indentation probe for analysing articular cartilage](#)  
Richard C Appleyard, Michael V Swain, Sam Khanna *et al*.
- [A spectroscopic approach to imaging and quantification of cartilage lesions in human knee joints](#)  
A Johansson, T Sundqvist, J-H Kuiper *et al*.
- [Removal of artifacts in knee joint vibroarthrographic signals using ensemble empirical mode decomposition and detrended fluctuation analysis](#)  
Yunfeng Wu, Shanshan Yang, Fang Zheng *et al*.

### Recent citations

- [Computer Analysis of Knee by Magnetic Resonance Imaging Data](#)  
Artjoms Suponenkovs *et al*



**IOP | ebooks™**

Bringing together innovative digital publishing with leading authors from the global scientific community.

Start exploring the collection—download the first chapter of every title for free.

# Development of methods for analysis of knee articular cartilage degeneration by magnetic resonance imaging data

Artjoms Suponenkovs<sup>1</sup>, Aleksandrs Glazs<sup>1</sup>, Ardis Platkajis<sup>2</sup>

<sup>1</sup> Riga Technical University, Faculty of computer science and information technology, Setas str. 1, LV-1048, Riga, Latvia

<sup>2</sup> Medical Academy of Latvia, Dzirciema str. 16, LV-1007, Riga, Latvia

**E-Mail:** artjoke@inbox.lv(Artjoms Suponenkovs), glaz@egle.cs.rtu.lv(Aleksandrs Glazs)

**Keywords:** early diagnosis of osteoarthritis, magnetic resonance imaging, medical imaging, knee joint, cartilage, image segmentation, relaxation time

**Abstract.** The aim of this paper is to describe the new methods for analyzing knee articular cartilage degeneration. The most important aspects regarding research about magnetic resonance imaging, knee joint anatomy, stages of knee osteoarthritis, medical image segmentation and relaxation times calculation. This paper proposes new methods for relaxation times calculation and medical image segmentation. The experimental part describes the most important aspect regarding analysing of articular cartilage relaxation times changing. This part contains experimental results, which show the codependence between relaxation times and organic structure. These experimental results and proposed methods can be helpful for early osteoarthritis diagnostics.

## 1. Introduction

The analysis of knee articular cartilage degeneration by magnetic resonance imaging data is very important due to decreasing human physical activity and increasing number of people with osteoarthritis(OA) [5]. Every tenth American adult has OA, this causes economic losses. Therefore, timely OA diagnosis is very significant. While the patient is still in the first stage of their OA, it is possible to completely the disease. Magnetic resonance imaging (MRI) is the most effective noninvasive technique for analyzing and displaying articular cartilage damage. Thus, this paper describes new methods for knee cartilage early osteoarthritis diagnostic by magnetic resonance imaging data.

## 2. Problem statement

An early osteoarthritis diagnosis is very important because it gives us the possibility to completely cure osteoarthritis. The knee articular cartilage changes are recoverable at the early stage of the OA. Unfortunately, doctors can't see OA at an early stage of the disease, this makes early diagnosis of OA even more important. Another important problem is cartilage segmentation [6-9]. By solving the problem of cartilage segmentation, we will be able to solve cartilage degeneration analysis



problem. The cartilage degeneration analysis is useful for automatic cartilage degeneration analysis. This paper will discuss the following problems: OA early stage displaying, cartilage segmentation, cartilage degeneration analysis. In the paper, various different methods are proposed for solving these problems.

### 3. Proposed approach

Osteoarthritis has 5 grades (figure 1) [12, 13]. Doctors are unable to see the first grade of the OA using simple grayscale MRI images. But the knee articular cartilage changes are recoverable at the first grade of the OA. So, OA first grade displaying is a very important problem.

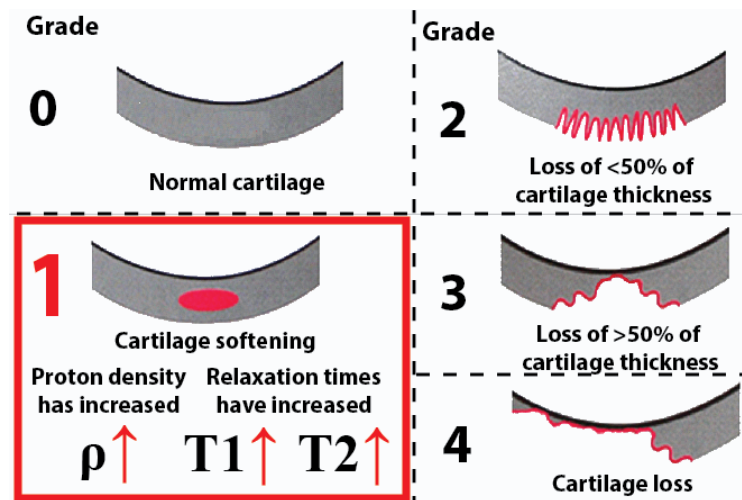


Figure 1. Outerbridge classification.

The first grade of OA has the following features: increase in the proton density and increase in relaxation times [10], where proton density – is number of hydrogen resonating proton per unit volume and T1/T2 relaxation times – is the recovery times of the protons spin magnetization after RF exposure. Thus, this paper describes methods for relaxation times calculation using one MRI image, two MRI images and multiple MRI images. The result of calculation (relaxation times) is shown by colorful images. This colorful image is useful for displaying relaxation time changes. Image pixel colors (eg. we can use Hue Saturation Value color system) are displayed according to calculated relaxation times.

After relaxation time calculation it is important to make cartilage segmentation. If cartilage segmentation has been done successfully, you will be able to make a cartilage analysis by relaxation time. In the experimental part has been used interactive segmentation method. For cartilage analysing we can use the dispersional analysis method and histogram analysis method. Common flowchart is shown in figure (figure 2).

Simple MRI image pixels value is dependent on MRI signal (S). But the MRI signal is dependent on relaxation times T2, T1 as well as proton density  $\rho$  [2]. We can change relaxation times and proton density influence on MRI signal. The dependence between signals and relaxation times for SE (Spin-Echo signal sequence) is shown in follow equation (1) [2]:

$$S = M_0 * (1 - \exp(\frac{-TR}{T1})) * (\exp(\frac{-TE}{T2})) \quad (1)$$

where:  $M_0$  - initial magnetization or start state, TR – Time to Repeat, TE – Echo Time, T1 – relaxation time, T2 – relaxation time, S – MRI signal.

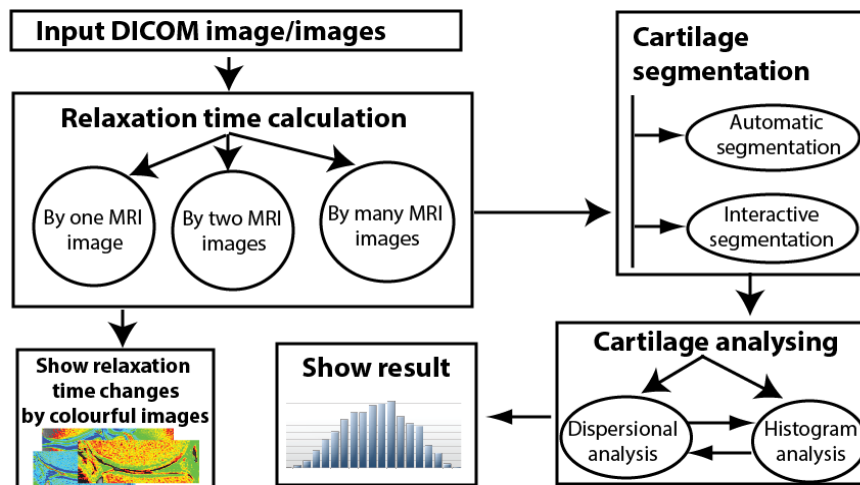


Figure 2. Common flowchart.

The initial magnetization( $M_0$ ) is foremost depending on proton density and magnetic field power ( $B_0$ ) measured in tesla(T). This is shown in equation (2). Usually is using MRI with 1 T, 1.5 T and 3 T.

$$M_0 \sim \rho * B_0 \quad (2)$$

where:  $\rho$  - proton density,  $B_0$  - magnetic field power.

Manipulate with TR and TE parameters we can change relaxation times and proton density influence on MRI signal. In the manipulation result with these parameters we can get three types MRI images: T1 weighted, T2 weighted and proton density (PD) image (table 1) [1]. According to MRI image type PD/T1/T2 the MRI signal foremost is depending on proton density, relaxation time(T1) relaxation time(T2) [11].

Table 1. TR and TE parameters for SE sequence.

Sequence	MRI image type	Parameters TR	Parameters TE
SE	T1	600 ms	10-30 ms
	PD	1000 ms	10-30 ms
	T2	2000 ms	80-250 ms

Usually a doctor gets from MRI DICOM images. Each DICOM image pixels contain intense value which is proportional to MRI signal (S). Assume that MRI signal is approximately equal with DICOM image pixel containing intense value (SI). This is shown in follow equal:  $SI \approx S$ .

When we get MRI images we know only MRI images pixels values (SI) and images parameters TE and TR. But we want to know T2 and T1 relaxation times.

### 3.1. Relaxation time calculation by one MRI image

This method “relaxation time calculation by one MRI image” is very useful for doctors, because of doctors that usually use only one MRI image which shows only one slice. This method is very efficient because the time it takes to get an MRI image decreases. One MRI image is easier to obtain than multiple ones. If we use this method, we'll be able to save MRI working time and reduce RF (radio frequency) influence on patient health.

But this method has some disadvantages, as it doesn't bear in mind some parameters which influence on pixels intense value (SI). As a result T1 and T2 relaxation time calculation is very approximate. That method is useful for T1 and T2 changes displaying.

For T2 and T1 times calculation is assumed that proton density ( $\rho$ ) is constant and magnetic field power ( $B_0$ ) is constant. If assumed that density ( $\rho$ ) is constant and magnetic field power ( $B_0$ ) is constant, than initial magnetization ( $M_0$ ) is constant.

If we want calculate T2 relaxation time, than we must use T2 weighted MRI image. When we use T2 weighted MRI image we can don't consider the second part of equation (1):  $(1 - \exp(-TR/T1))$ . So, now we have the follow equation (3):

$$T2 = \frac{-TE}{\ln\left(\frac{SI}{SI_{MAX}}\right)} \quad (3)$$

where  $SI_{MAX} \approx M_0$ .

Now we can calculate T2. For T1 calculation we can use the same method.

### 3.2. Relaxation time calculation by two MRI images

For relaxation time calculation we can use two MRI images [4]. When we have use two MRI images, than we have more information and we can calculate T1/T2 relaxation time more precise than in the previous method. For T1 calculating it possible use the follow equation (4):

$$T1 = \frac{-TR_1}{\ln\left(\frac{SI_2 - SI_1}{SI_1}\right)} \quad (4)$$

where:  $TR_1$  - Time to Repeat of first image,  $SI_1$  - intense value of first image,  $SI_2$  - intense value of second image,  $TR_2 = 2*TR_1$  and  $TE_1 = TE_2$ . There is a proof (5) of equation (4):  $-TR_1 / T1$  are denoted by letter ( $a$ )

$$\begin{aligned} \frac{SI_2 - SI_1}{SI_1} &= \frac{M_0 * (1 - \exp(2a)) * \exp\left(\frac{-TE}{T2}\right) - M_0 * (1 - \exp(a)) * \exp\left(\frac{-TE}{T2}\right)}{M_0 * (1 - \exp(a)) * \exp\left(\frac{-TE}{T2}\right)} = \\ &= \frac{(1 - \exp(2a)) - (1 - \exp(a))}{(1 - \exp(a))} = \frac{-\exp(a) * \exp(a) + \exp(a)}{(1 - \exp(a))} = \frac{\exp(a) * (1 - \exp(a))}{(1 - \exp(a))} = \exp\left(\frac{-TR_1}{T1}\right) \end{aligned} \quad (5)$$

### 3.3. Relaxation time calculation by many MRI images

For relaxation time calculation we can use many MRI images [3]. This method gets possibility modulate relaxation process. Usually when we use this method we have 7 or 8 images, which show one slice. These images have different TE parameters (when we want calculate T2), and TR parameters (when we want calculate T1). So, for each MRI images pixel we have 7 or 8 intense values, which show signal intense in different times. This gives us the possibility approximate relaxation process. The approximation we can make for two parameters: initial magnetization ( $M_0$ ) and relaxation time (T2). For approximation task solving can use least square method and partial derivatives. This we can see from the following formula (6):

$$\begin{aligned}
 S(P1, P2) &= \sum_{i=1}^n (SI_i - P1 * \exp(\frac{-TE_i}{P2}))^2 \rightarrow \min \\
 \begin{cases} \frac{\partial S}{\partial P1} = -2 \sum_{i=1}^n (e^{\frac{-TE_i}{P2}} * (SI_i - P1 * e^{\frac{-TE_i}{P2}})) = 0 \\ \frac{\partial S}{\partial P2} = -\frac{2}{P2^2} * P1 * \sum_{i=1}^n (e^{\frac{-TE_i}{P2}} * (SI_i - P1 * e^{\frac{-TE_i}{P2}}) * TE_i) = 0 \end{cases} & \quad (6)
 \end{aligned}$$

where: P1 - initial magnetization (**M<sub>0</sub>**), P2 - relaxation time (**T<sub>2</sub>**).

### 3.4. Cartilage segmentation

The cartilage segmentation is useful procedure for cartilage analyzing. The cartilage segmentation aim is detect cartilage pixels. When we work with MRI images we have a lot of segmentation problems: different images planes, many MRI parameters, which strongly change MRI signal, different sequence, artifacts, patient movement and noise. Therefore, in the experiments has been used interactive segmentation method, which is universal and give possibility use different MRI images.

Interactive method can make different organic structure segmentation. For this method developing was taken two other methods clusterization segmentation and region growing segmentation. These methods symbiosis give very good result.

### 3.5. Cartilage analysing

After successful cartilage segmentation is possible make cartilage analyzing. For cartilage analyzing we can use dispersional analysis and histogram analysis.

## 4. Experimental Results

In this experimental part is shown that proposed method allow detect OA grade and find cartilage pathogen zone.

A doctor can't see the first grade of the OA due to he use simple grayscale MRI images. But the knee articular cartilage changes are recoverable at the first grade of the OA. So, OA first grade displaying is very important. In figure 5 is shown that proposed methods allow calculate and displaying relaxation times changes which is marked by red color. These results show that thanks to proposed methods a doctor can see cartilage pathogen zone and make OA early diagnostic.


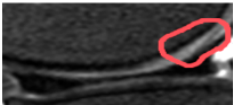
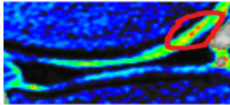
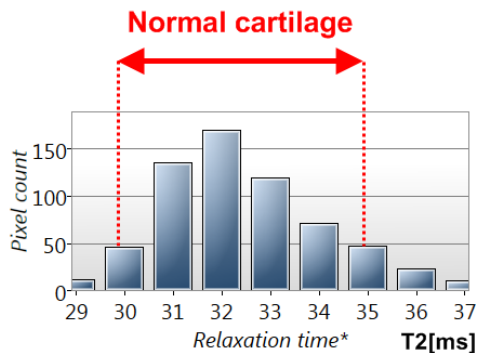
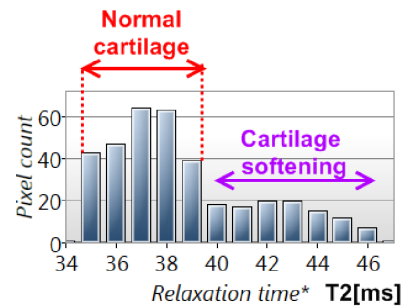
Grade	Description	Grayscale MRI image	After relaxation time calculation
1	 Cartilage softening	 Nothing	 Two red dots

Figure 5. OA early stage detection.



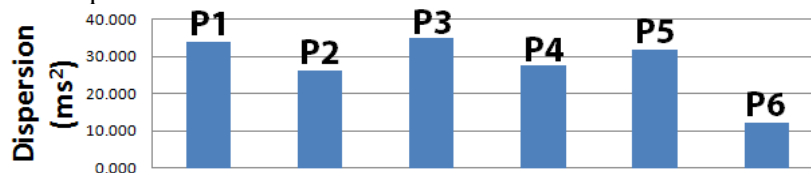
**Figure 6.** Healthy cartilage.



**Figure 7.** OA first grade.

In the figures 6 is shown healthy histogram cartilage. In the figures 7 is shown fist grade of OA. Each histogram has unique form. Therefore, the OA grades can be detected by histograms unique forms. Each OA grades have unique histograms forms.

The experimental results is shown that patient with damaged cartilage has grater disperse than patient with healthy cartilage. In figure 8 we can see six patients. The sixth patient hasn't problems, because of this patient disperse is the smallest.



**Figure 8.** The healthy patient has smallest dispersion. P1...P6 - patient number.

## 5. Conclusion

In this paper, methods are proposed, which allow to make an early osteoarthritis diagnostic. Proposed methods consist of three parts: relaxation time calculation, cartilage segmentation, cartilage analysing.

The most commonly is used many MRI images (7 or 8 images) for relaxation time calculation [2, 14]. Proposed relaxation time calculations methods are universal, that allow calculating relaxation time by any MRI images count. It is very useful for old MRI, which can't get many MRI images in the same moment. "Relaxation time calculation by one MRI image" method is very effective, because the time of MRI imaging is decreasing. One MRI image we can get faster than many images. If we use this method, will be able to save MRI working time and reduce RF (radio frequency) influence on patient health. When we have use more MRI images, than we have more information and we can calculate T1/T2 relaxation time more precise. "Relaxation time calculation by many MRI images" method gets possibilities modulate relaxation process. All these methods allow calculate T2/T1 relaxation times. After it is important to show relaxation time changes by colorful images, that allow displaying relaxation times changes. Experimental results show that thanks to proposed methods a doctor can see cartilage pathogen zone and make OA early diagnostic.

## References

- [1] Evert B 2004 *Basic MRI Physics* p 76
- [2] Hornak J P 1997 *The Basics of NMR*
- [3] Bruce C Po 2001 *Graphical Interface for Quantitative T1 and T2 Mapping of MRI Data* (Massachusetts Institute of Technology) p 119
- [4] Fanea L and Sfrangeu S A 2010 *Relaxation times mapping using magnetic resonance imagin*
- [5] Murphy L and Helmick C G 2012 The impact of osteoarthritis in the United States: a population-health perspective *American Journal of Nursing* **112** S13-S19

- [6] Mallikarjuna M S and Mallikarjun S 2012 Knee joint articular cartilage segmentation, visualization and quantification using image processing techniques: a review *International Journal of Computer Applications* **42** 36-43
- [7] Dam E B, Folkesson J, Pettersen P C and other 2006 *Semi-Automatic Knee Cartilage Segmentation* p 9
- [8] Fripp J, Lucas E and Engstrom C 2013 *Automated Morphological Knee Cartilage Analysis of 3D MRI at 3T*
- [9] Tamez-Pena J G, Barbu-McInnis M and Totterman S 2004 *Knee Cartilage Extraction and Bone-Cartilage Interface Analysis from 3D MRI Data Sets*
- [10] Nasnikova I U, Morozov S P and Filisteev P A 2011 Magnetic resonance tomography: quantitative assessment methods in articular cartilage structure analysis of in patients with osteoarthritis *Russian Electronic Journal of Radiology* **1** 75-81
- [11] Haacke E M, Brown R W, Thompson M R and Venkatesan R 1999 *Magnetic Resonance Imaging Physical Principles and Sequence Design* (New York: Wiley-Liss) p 973
- [12] Roach H I and Tilley S 2007 *The Pathogenesis of Osteoarthritis*
- [13] Klusmann A, Gebhardt H, Liebers F, Lars V E and others 2008 *Individual and Occupational Risk Factors for Knee Osteoarthritis – Study Protocol of a Case Control Study*
- [14] Blumenkrantz G and Majumdar S 2007 Quantitative magnetic resonance imaging of articular cartilage in osteoarthritis *European Cell and Materials* **13** 75-86