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Original Research Article

Multi-step process in computer assisted diagnosis of posterior cruciate ligaments

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ABSTRACT

A multi-step methodology resulting in a three-dimensional visualization and construction of feature vector of posterior cruciate ligament is presented. In the first step the location of the posterior cruciate ligament is established using the fuzzy image concept. The fuzzy image concept is based on the entropy measure of fuzziness extended to two dimensions. In order to reduce the area of analysis, the region of interest including the ligament structures is detected. In this case, the fuzzy C-means algorithm with median modification helping to reduce blurred edges was implemented. After finding the region of interest, the fuzzy connectedness procedure was performed. This procedure permitted to extract the ligament structures. On the basis of the extracted posterior cruciate ligament structures, the three-dimensional visualization of this ligament was built and, with the support of experts' knowledge, an appropriate feature vector was constructed and its values assigned for normal and pathological cases. Correct results were obtained for over 88% of 97 cases.

1. Introduction

The knee joint is the largest joint of the human body. The anatomy of the knee joint is the cause for which it is considered in the medical theory as the most complex joint in the human body. This anatomical structure is sensitive, fragile and unfortunately frequently susceptible to injuries [1–3]. The elements of this joint being particularly vulnerable to injuries are: the anterior cruciate ligaments (ACLs) and posterior cruciate ligaments (PCLs). The primary function of the cruciate ligaments (ACL and PCL) consists in a passive stabilization of the knee joint in three planes: sagittal, coronal and transverse (Fig. 1). Cruciate ligaments also connect very strongly two large bones of the human body: the femur and the tibia, respectively. ACLs and PCLs ensure proper kinematics of the knee joint. They take care of the smooth movement of the knee joint and protect the articular cartilage. As the knee moves, two activities can be distinguished. The first one is called active motion and during this motion of flexion, extension and rotation ACLs and PCLs resist translations within the joint caused by the action of muscles and reduce shear forces. The second one is called passive motion and during this motion ACLs and PCLs help to change rolling into sliding movements. Preliminary ACL tension at the movement of flexion initiates tension of PCL and vice versa. Cruciate ligaments always remain partially

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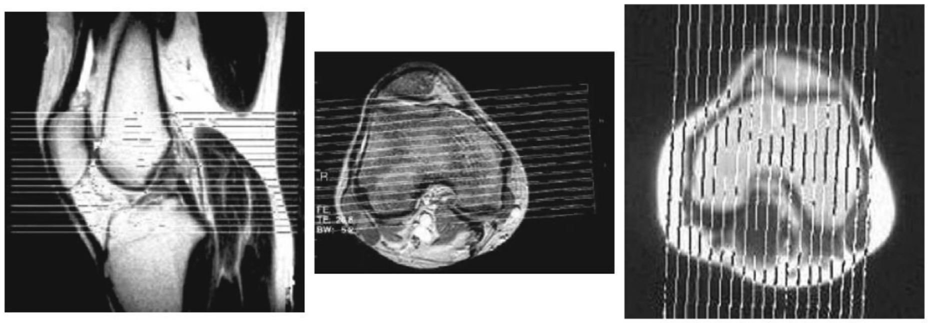

(a) (b) (c)

Fig. 1 – MRI of the knee joint – a pilot study in the planes: (a) transverse, (b) coronal, and (c) sagittal [4].

strained as a result of non-uniform shape and unequal length of their fibers.

Nowadays clinical diagnosis and treatment verification are often based on medical imaging. The most popular techniques for medical imaging are: X-ray imaging, MRI (magnetic resonance imaging), CT (computed tomography), and USG (ultrasonography). These techniques provide information concerning the anatomic structure of the human body. Magnetic resonance imaging is today the elementary method for diagnostics of the knee joint, and especially cruciate ligaments injuries. MRI allows the visualization of cruciate ligaments throughout their length. This method gives the possibility to assess the shape and internal structure of cruciate ligaments in a completely non-invasive manner. MRI of the knee joint is typically performed on T1-weighted sequences and various T2-weighted sequences. In the T1-weighted sequences the anatomy of the muscles, ligaments, tendons is clearly visible. The T2-weighted sequences are very sensitive to damage, swelling, inflammation of soft tissues, bones. MRI of the knee joint is always done in three planes: transverse, coronal and sagittal. The PCL is a relatively thick, oval structure, characterized by uniform low signal intensity (dark color). It has a slightly arcuate shape and smoothly goes from attachment to the femur to attachment to the tibia. PCL is well visible in the sagittal plane (Fig. 2). Usually this structure is present on 4–6 slices of the T1- or T2-weighted MRI sequences of the knee joint. The application of computed tomography (CT) in the evaluation of injuries to the cruciate ligaments is of limited value because of the interpreting difficulties particularly immediately after the injury. In ultrasonography (USG) the anterior cruciate ligaments are reflected in the posterior transverse plane, and the posterior cruciate ligaments in the posterior sagittal plane. However, the diagnosis of cruciate ligaments injuries in this way is difficult and requires a lot of experience.

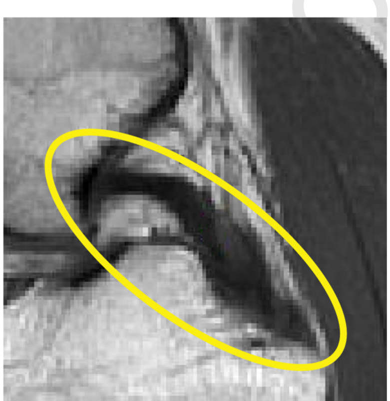

Fig. 2 – Posterior cruciate ligament in the sagittal plane.

Cruciate ligament injuries are a common cause of chronic knee instability. Complete rupture of the posterior cruciate ligament alters knee kinematics and may result in functional limitations in sports and daily activities. The rule is that, in case of PCLs being damaged (regardless of damage level), the fibers of the ligament tear apart over its entire length giving the effect of ligament swelling. Therefore, the image of the posterior cruciate ligament rupture is based on one fundamental criterion – the swelling of the ligament. In this case the diagnostic method of choice is MRI. For that reason, in this paper the computer analysis of posterior cruciate ligaments is shown on the example of MRI of the knee joint.

From the clinical point of view, the proposed method can be particularly helpful in cases of doubt relating to PCL pathology (partial tears, avulsion from the femoral and/or tibial attachment), where the visual assessment may be questionable. Then, this method can be helpful for the radiologist in the diagnostic process, the success of the treatment depending on many factors, primarily on accurate diagnosis. The diagnosis in many complex cases can be based on a combination of information from multiple sources. Particularly important information (especially in the case of cruciate ligament lesion) in addition to MRI of the knee joint is provided by: 3D structure of the cruciate ligaments, 3D visualization of bony structures in the knee joint and the data flowing from a properly constructed feature vector. Preliminary studies show [5,6] that orthopedists find it very important and able to contribute to improve this diagnostic procedure.

A review of the literature shows that the damage to cruciate ligaments of the knee is now a steadily growing problem. It is estimated that this problem affects approximately 1 person in every 3000 [7]. Among the people who are particularly vulnerable to injuries of the cruciate ligaments are active people, athletes, as well as the elderly. The cruciate ligament injury meant formerly the end of an active life. Nowadays it does not, but it is especially important to make a fast and correct diagnosis. This greatly facilitates the possible process of reconstruction [8–10] and then rehabilitation [11–14]. Papers dedicated to the knee joint in recent years also deal with computational modeling of the knee [15,16,18–20]. Such

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