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Automated assessment of synovitis in 0.2 T magnetic resonance images of the wrist

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ABSTRACT

According to the current recommendations in diagnosis of rheumatoid arthritis (RA), Magnetic Resonance (MR) images of wrist joints are used to evaluate three main types of lesions: synovitis, bone edema and bone erosions. In the clinical practice, the RA-related lesions seen in MR images are assessed manually with the semi-quantitative RAMRIS scoring system. In this paper we present an automated method for inflamed synovial membrane volume determination, based on the analysis of pre- and post-contrast MR images and segmentation of wrist bones seen in MR images. We found that the correlation between the automatically quantified volume of synovitis and RAMRIS scores was in the range from 0.76 to 0.87 for the total RAMRIS synovitis score. This can be compared with the correlation between the manually quantified volume of synovitis and RAMRIS scores which was in the range from 0.75 to 0.81 for the total synovitis score. The results of the study demonstrate that computer assisted methods for assessment of synovitis have great potential for clinical applications.

1. Introduction

Rheumatoid arthritis (RA) is a chronic systemic inflammatory disease of unknown cause. The hallmark feature of RA is progressive and irreversible destruction of articular and periarticular structures. Among affected joints, hand is one of the earliest sites to be involved in RA [1]. An early diagnosis of RA is essential for delaying joint destruction and functional disabilities. Accurate monitoring of the activity of already diagnosed disease, supported by sensitive diagnostic tools is crucial for successful therapy.

Currently, magnetic resonance imaging (MRI) becomes the tool of choice for early diagnosis of RA. MRI lesions which may be present within an RA wrist and seen in MRI are synovitis, bone edema, and bone erosions. In 2003 and 2005 the Outcome Measures in Rheumatology Clinical Trials MRI working group (OMERACT) developed an MRI-based RA scoring system (RAMRIS) [2–4] for synovitis, bone edema and bone erosions. Since its recommendation it has been shown that RAMRIS is reproducible and relatively sensitive to changes due to therapy or disease progress. However, because absolute values of the volumes of the lesions are not measured and instead some grades of the severity of the lesions are reported, RAMRIS is in fact a semi-quantitative scoring system. This can lead to a substantial inter-operator variability [5].

The procedure of assessing RAMRIS scores – as specified in the EULAR-OMERACT recommendation – is quite complicated and time-consuming. Depending on the type of lesion examined, different MRI sequences have to be retrieved from the picture database. To correctly assign scores to the lesions, small details have to be evaluated in three-dimensions. Moreover, because only a small number of grades is available, the RAMRIS scores may not reflect the true changes in the volumes of the lesions due to the disease progress or the applied therapy. In spite of these limitations, no comprehensive procedure for automated evaluation of the RAMRIS scores has been either introduced to the market or even published so far.

Although a fully automated algorithms for detection and evaluation of RA-related lesions have not been published yet, there are a few studies supporting conjecture about feasibility of such systems. In a series of studies [6,7] the volumes of lesions were outlined manually in slices of 3 T 3D MRI images and the absolute volumes of lesions were compared with the RAMRIS outcomes. In these studies good correlation was found between RAMRIS erosion scores and absolute volumes of erosions, mild correlation was reported between RAMRIS edema scores and absolute edema

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volumes and strong correlation was discovered between RAMRIS synovitis score and absolute volume of inflamed synovial tissue. In the study of Wojciechowski et al. [8] it was shown that the volume of manually segmented synovitis correlates well with RAMRIS scores for MR images captured with low-field 0.2 T MR scanner. This result is especially encouraging because recently low-field dedicated extremity MRI scanners became popular primarily as these modalities are considerably less expensive and more comfortable for patients than high-field scanners. In the study of Yang et al. [9] a semi-automated method was proposed to extract synovitis regions from post-contrast MR images. The method requires however substantial manual interaction – firstly, to select reference tissue volumes used to calculate threshold for synovitis segmentation and secondly, to outline bone contours. In this study a good correlation between semi-automated assessed synovitis volume and RAMRIS scores was demonstrated.

The results of [6–9] show that RAMRIS-based assessment of RA can be replaced with a CAD tool for estimating the volumes of lesions. Ideally, the emerging CAD systems should quantify synovitis in an automated way to enable objective estimation of the disease progress and the effects of therapy.

Actually there is no automatic system for inflamed synovial membrane volume determination. Motivated by the lack of existing solutions in this paper we present a framework for segmentation of the synovitis for the wrist. The framework assumes that as its input is an image of wrist bones segmented from the pre-contrast MR image. Automated wrist bone segmentation frameworks were described in our previous studies [10,11].

2. Material and methods

2.1. MRI data

Thirty-two patients (28 women and 4 men, aged from 23 to 74 years, mean age 47 ± 13 years) participated in the study. Before being recruited for the MRI study, each patient was examined by the same rheumatologist according to the 2010 ACR/EULAR criteria. In all patients the duration of the active RA was less than 5 years and RA was confirmed with clinical and laboratory disease variables (see [8] for further detail concerning the group of patients). Because the MRI examination includes contrast injection (which is a potential hazard), no healthy controls were recruited for the study. As some patients had two hands examined, we used 34 study cases in the experiments.

The details of the MR image acquisition protocols can be found in our previous study [8] and here we repeat them to make the description self-contained. Static MR tomography images were acquired with a 0.2 T musculoskeletal extremity E-scanner (ESAOTE Ltd, Genova, Italy). The examination procedure was consistent with the recommendations of the manufacturer of the MRI scanner and with the references of EULAR-OMERACT. In particular, before contrast injection gradient echo scout MR sequence, coronal short tau inversion recovery (STIR) MR sequence and a coronal turbo 3D T1-weighted gradient echo MR sequence (pixel spacing 0.75 mm, slice thickness 0.7 mm, TE 16 ms, TR 35 ms, FOV 120 mm $\times$ 120 mm) were acquired. Next gadolinium contrast was injected intravenously of 0.1 mmol/kg (0.2 cm^3/kg) body weight at constant rate of 1.5 cm^3/s. Simultaneously with contrast injection acquisition of dynamic contrast enhanced (DCE) MRI started (the dynamic sequences were used in another study [12]). Due to the variability of patients conditions, the acquisition of DCE MRI lasted for 12–14 min. Immediately after finishing the acquisition of DCE MRI the post-contrast coronal turbo 3D T1-weighted gradient echo sequence was acquired. In accordance with OMERACT-EULAR atlas [2], a pre- and post-contrast coronal turbo 3D T1-weighted gradient echo were used to evaluate synovitis. The acquired MR sequences were retrieved from the PACS database and exported to 16-bit per voxel unsigned integer raw image files.

2.2. Scoring MR data using RAMRIS

All MR images were independently scored using the RAMRIS scoring system by three readers for the presence and extent of synovitis within the three wrist joints (one reader—6 years experience with RAMRIS, two readers—two years experience with RAMRIS). Because inter-reader variability of RAMRIS scores can be expected [5], majority RAMRIS scores, based on the three independent readings were also calculated. They are equal to the score which received the biggest number of votes from the three readers. Majority scores can be considered to be more reliable estimates of the true synovitis conditions than scores assigned by a single reader. In the present study the results of automated evaluation of synovitis are correlated with the three independent RAMRIS scores and with the majority RAMRIS score. The observed correlations are then compared with the reference values of the correlations between the independent RAMRIS scores and the majority RAMRIS score.

The RAMRIS scoring was essentially based on the OMERACT atlas [4] which provides guidelines for assigning synovitis level to MR data within distal radioulnar joint (DRUJ), radiocarpal joint (RCJ), and intercarpal–carpometacarpal joint ICCMCJ. According to EULAR-OMERACT, synovitis is defined as “a region in the synovial compartment that shows above normal post-gadolinium enhancement of a thickness greater than the width of the normal synovium” [3].The RAMRIS synovitis scores can assume integer values in the range from 0 to 3, where 0 is normal, 1 is mild (inflammation present within at most 1/3 of the total volume of the synovial membrane), 2 is moderate (inflammation present within more than 1/3 and at most 2/3 of the total volume of the synovial membrane), and 3 is severe (inflammation present within more than 2/3 of the total volume of the synovial membrane). Additionally we calculated the total RAMRIS score equal to the sum of the RAMRIS scores assigned to DRUJ, RCJ and ICCMCJ.

The guidelines for selecting wrist regions within the three assessed joints are:

1. The distal radioulnar joint starts at the carpal articular surface of the radius and extends proximally for 10 mm.
2. The radiocarpal joint starts at the carpal articular surface and ends at the end of the radial styloid process.
3. The intercarpal–carpometacarpal joints start at the end of the radial styloid process and extend towards phalanges for 10 mm from the slice with maximum cross section area of metacarpal bases.

2.3. Statistical analysis

We used the Spearman's rank correlation coefficient (rs) to determine the association between RAMRIS scores and synovitis volume obtained as a result of either manual or automated measurements. We expressed volume of signal enhancing regions as an absolute value in cubic millimeters.

2.4. Method

Segmentation and evaluation of the inflamed synovial membrane consists of two steps: identifying image regions related to DRUJ, RCJ and ICCMCJ and evaluation of signal enhancing regions (synovitis regions) in each of the three joints. The method for extraction of joint regions is described in detail in the next sections. While these regions are identified, the synovitis can be