CASCADE: Computer Aided System for Cardiovascular Disease Evaluation

D. Xu[1], W. S. Kerwin[1], T. Saam[1], M. Ferguson[1], C. Yuan[1]
[1]Department of Radiology, University of Washington, Seattle, WA, United States

Purpose

The aims of this study are (1) to design and implement a quantitative vascular analysis system for atherosclerotic plaque tissue evaluation based on Multiple Contrast Weighting (MCW) MRI; and (2) to validate the agreement of analysis results using histological examination as the gold standard.

Introduction

Atherosclerotic plaque constituents are important determinants for plaque vulnerability. Evidence suggests that plaque components and the location of these components within the plaque may play an important role in plaque rupture. Thus, imaging and analysis techniques that are sensitive to plaque tissue types are needed. Recent studies have shown that any individual MR image can only distinguish between a limited numbers of plaque tissues, regardless of contrast weighting [1]. Therefore, integration of information from all contrast weightings, such as, T1W, T2W, PDW and TOF, is required, so as to provide a single representation of all plaque components. Multiple spectrum data analysis can be used to achieve this integration. In this study, a framework for *in vivo* MCW MRI analysis is proposed.

Methods and Experimental Results

1. Magnetic Resonance Imaging

Patients were scanned using a custom designed surface coil on a 1.5T GE SIGNA scanner, with the following contrast weightings: T1W, T2W, PDW and TOF. Previous work has shown that major tissues identified by paired T2W and PDW images share similar features. To reduce computation complexity in the segmentation process, T2W images were removed, reducing the data space dimensions to three. The imaging parameters selected were: T1W (TR/TE 550/12ms), PDW (TR/TE 4000/25), TOF (TR/TE 21/3.2). Serial histological sections were obtained from the CEA (Carotid Endarterectomy) specimen after surgery and analyzed to provide verification of MRI findings.

2. MCW Image Analysis Procedure

Figure 1 shows the basic structure of the proposed MCW MRI based analysis system.

In MR imaging process, slice thickness and distance in different contrast weighing MR images may vary, and the physical scanning range may change due to patients' movement between scans, thus, a location matching process is required to be done in the first step to assure that the same location from different contrast weighting will be analyzed. To achieve this, the bifurcation of carotid artery is employed as the landmark. By registering the bifurcation locations among all contrast weightings, the other matched locations can be identified automatically.

Within each matched location, a process of intra-location registration of MCW images is also needed due to the possible patient movement. Different from general image registration problem in which images have similar intensity pixels, the same tissue in different MCW MR images show different intensities. Therefore, a shape based registration algorithm, called "Active Edge Maps" [2], is used in this step. Given the lumen and outer wall contours for one image weighting, the algorithm can find the optimal alignment of MR images of different weightings by minimizing energy:

$$E_{reg} = \sum_{i=1}^{n} E_{image}(T(x_i)) + E_{\text{int }ernal}(T) \qquad (1)$$

where $E_{image}(T(x_i))$ is image based energy, $E_{\text{int }ernal}(T)$ is internal energy of the transformation $\boldsymbol{T}$.

Next, the plaque tissue type will be segmented and identified at each well-registered location in two steps: (1) automatic region-segmentation based on MCW MRI; (2) manual assignment of tissue type for each identified region. Manual tracing or adjustment of regions is also allowed. The automatic segmentation of MCW images is done generally based on T1W, PDW and TOF images. Assume image domain can be expressed as $x=[v_1, v_2, v_3]^T$, where v_1, v_2, v_3 are values at the same pixel in T1W, PDW and TOF images. The cluster center-searching algorithm used in our study is an enhanced MeanShift [4] based solution. The optimal solution is found by iteratively minimizing the vector difference between local mean and the sphere center.

$$E[x \mid x \in S_x] - x = \frac{r^2}{d+2}\frac{\nabla p(x)}{p(x)}, \qquad (2)$$

where S is given sphere with radius r, $p(x)$ is the gradient of probability density at location x, d is the dimension of space.

Following component analysis, measurements can be taken for lumen, wall, necrotic core, calcification etc. Furthermore, wall thickness (Maximum, Minimum, and mean) that is calculated using a newly devised algorithm [3], and other derived measurements, such as volumes calculations, can also included.

3. Comparison with Histology Sections

To validate the evaluation results of plaque tissue with MCW MR images, the corresponding histology sections were analyzed by a histologist blinded to the MR findings. Location matching for this comparison uses the carotid bifurcation, lumen size and shape, and special plaque features for location registration. Following are the results of comparison experiment conducted in this study.

Sensitivity for the different tissue types, such as loose fibrous matrix, calcification, lipid-rich/necrotic core and hemorrhage ranged from 62 to 93%, with the specificity ranging from 62 to 90% [5]. The Pearson correlation coefficient between MRI measurements and histology measurements ranged from 0.60 to 0.84 [5].

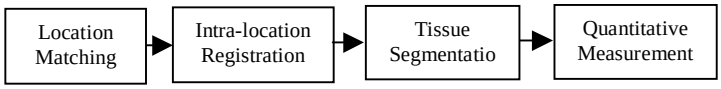

Figure. 1 Structure of System

Summary

This study introduces a quantitative vascular analysis framework for atherosclerotic plaque evaluation based on multiple contrast weighted MR images. The comparison with histology shows good agreement. Currently this system has been implemented as a software package, called CASCADE, and has been being used in drug trials funded by major pharmaceutical companies.

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Reference:

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