Fully Automated Prediction of Irreversible Cerebral Infarction Using Diffusion and Perfusion MRI in the Multi-Center MR RESCUE Clinical Trial

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Introduction

Numerous methods for predicting the extent of irreversible infarct versus salvageable tissue (penumbra) in acute stroke cases using MR [1,2], CT [3,4] and nuclear medicine [5] images have been proposed, all of which require some form of user input (region of interest definition, arterial voxel selection, co-registration landmarks, etc.) to generate a result. For the MR and Recanalization of Stroke Clots Using Mechanical Embolectomy (MR RESCUE) trial of mechanical embolectomy versus medical management using MRI selection criteria we developed a system that is, to our knowledge, the first to fully automate the infarct prediction process for rapid assessment of acute stroke using diffusion- and perfusion-weighted MR images.

Methods

The system consists of a workstation that is networked to MR scanners and configured to receive images via DICOM transfer. Software for automated image analysis is implemented using the IDL programming language (Research Systems Inc., Boulder, CO). The following operations are performed on the received perfusion- and diffusion-weighted (PWI and DWI) images: 1) ADC Computation; 2) Brain Segmentation; 3) Arterial Input Function Determination; 4) Perfusion Measures Computation; 5) DWI/PWI Co-Registration; and 6) Infarct Prediction. The only user input required is left/right identification of the hemisphere to be analyzed. Each analysis sub-process is described below.

ADC Computation: A voxel-wise log-linear fit on the input DWI data is performed to produce an apparent diffusion coefficient (ADC) map [6]. The ADC computation relies on a priori knowledge of the b-values used for DWI acquisition, which are not always available in image file headers but may be pre-programmed as parameters associated with a particular DWI imaging sequence.

Brain Segmentation: A brain mask volume is computed from the PWI and DWI inputs using a statistically derived intensity threshold and a second-pass of morphological operations to fill in voids and eliminate small, outlying connected regions.

Arterial Input Function Determination: Multiple ranking algorithms using various curve fitting schemes (gamma variate and Gaussian) and signal quality measures (area under fitted curve, estimated bolus arrival time, etc.) are employed to generate a list of candidate AIF voxels [7,8] in the MCA territory of the opposite (non-infarcted) hemisphere. The top-ranked candidates are combined to generate a composite AIF signal using a heuristic based on the confidence measures generated by the individual search algorithms.

Perfusion Measures Computation: After conversion of the time-series PWI signal data to pseudo-concentration, the tissue and AIF time series data are input to a deconvolution process [9] that computes a residue function for each brain voxel. Perfusion measures including cerebral blood volume (CBV), cerebral blood flow (CBF), mean transit time (MTT) and residue peak time (TMAX) are derived from the residues.

DWI/PWI Co-Registration: A rigid-body transformation is computed using mutual information as the measure of image alignment [10] and applied to the PWI image volume and computed parameter maps to optimize spatial correlation of the PWI-derived image volumes with the input DWI volume and computed ADC volume. The resulting co-registered volumes are used as inputs to the infarct prediction process.

Infarct Prediction: A statistical classifier based on refinement of a previously derived prediction model [11] is employed to categorize each voxel in the hemisphere of interest as either irreversibly infarcted (red, see right side of figure below) or potentially salvageable (green, below) using relative ADC, MTT, CBF and TMAX measurements as classifier inputs. Relative measures are computed using average value in the opposite hemisphere as the baseline. The resulting infarct/penumbra map and predicted infarct/penumbra volumes may be used as prognostic information to guide treatment.

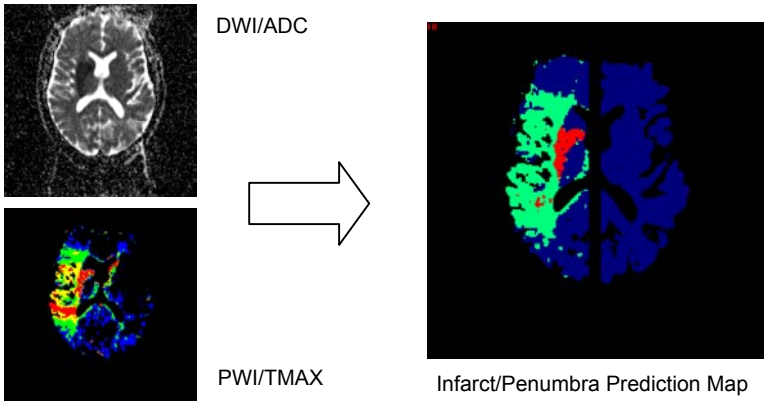

Figure 1: Multi-spectral analysis of co-registered DWI- and PWI-derived measurements is used to compute an infarct/penumbra prediction map.

Results and Conclusions

We have developed a system that automatically predicts the extent of irreversible infarct in acute stroke patients from MR DWI and PWI data and have deployed this system at multiple clinical imaging centers participating in a clinical trial. The computer system described is presently deployed at 10 (of 20 planned) sites in the United States and Canada participating in the NIH-sponsored MR RESCUE clinical trial where computed infarct/penumbra maps are used for MRI-based stratification and randomization of volunteers.

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