MRI of acute (<6 hours) ischemic stroke patients: a comparison between diffusion-related parameters

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Introduction

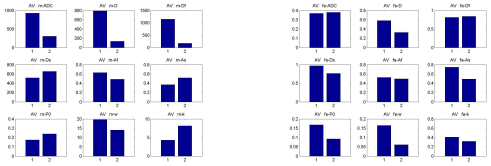
MR diffusion-weighted imaging (DWI) has proven major relevance in acute ischemic stroke patients (1). In routine practice, only the ADC is measured. The mechanism explaining the decrease in ADC observed in the acute phase is still controversial, and the most commonly proposed model is that of a transfer of water molecules between the extra- and intra-cellular spaces. Therefore, analysis of the MR signal in terms of a bi-exponential decay (2), separating a fast from a slow diffusion compartment could be relevant. Moreover, significant changes of fractional anisotropy over time have been described in stroke patients (3). Unfortunately, when restrictions or hindrance of the water molecules are present, these models can not lead to an accurate description of diffusion changes because they assume a Gaussian probability density function (PDF) of the diffusion process. The PDF of the diffusion process can be directly measured using q-space imaging (QSI) (4) which yields parameters reflecting the shape of the distribution (height, width, kurtosis, etc…) obviating inexact assumption of a Gaussian distribution of the diffusion. We applied different analyses (2-point ADC, mono-and bi-exponential fits and QSI) in a preliminary cohort of hyperacute (<6 hours) stroke patients.

Material and methods

Seven ischemic stroke patients presenting to the ER of our hospital less than six hours after symptoms onset gave informed consent to be included into the study. A standardized 'basic' MR protocol was performed in five of them (group 1) which included DWI, Fast-FLAIR, EPI-GRE-T2*, and TOF-MRA plus QSI sequence (see infra) at admission and 24 hours later. To avoid interference with the treatment, thrombolysis was initiated within the MR system - when indicated - before performing QSI acquisition. Two patients (group 2) accepted an extended protocol in which they had the 'basic' protocol and additional MR sessions using the QSI sequence every 6 hours after admission for 24 hours. Acquisitions were all performed on a 3T system equipped with 80mT/m gradients (Achieva 3T, Philips Health Care, Best, The Netherlands). The SE-EPI QSI sequence had diffusion weighting for 16 b-values ranging from 0 to 22 000 s/mm^2 (or equivalently: 16 equidistant q-values in the range 0 – 110 mm^{-1}) and for 6 diffusion gradient directions. Five 5-mm-thick axial slices covering the central area of infarction (delineated on standard higher spatial resolution DWI images) were obtained. The in plane resolution was 1.5 mm, 2 signal averages and a SENSE-factor of 2 were used. The acquisition time was about 10 minutes. Data was processed using a homemade software developed with Matlab (The Mathworks Inc). Data for b=1000 s/mm^2 was used to reconstruct the standard ADC images. A mono-exponential fit using all 16 b-values yielded a diffusion coefficient D and a bi-exponential fit yielded Df (fast), Ds (slow) and amplitudes Af and As. Q-space analysis yielded PDFs for all six directions. The PDFs were characterized by three quantities: the height (RTOP: return to origin probability), the width (FWHM: full width at half maximum) and the excess kurtosis (k). A tensor analysis of the different quantities enabled the generation of mean value (trace/3) and fractional anisotropy (FA) maps for each diffusion parameter. Several ROIs were manually drawn which included infarcted areas which did not evolve to larger infarction (stable infarcts), areas of infarction which decreased in size at 24 hours (regressing infarcts) and areas adjacent to infracted zones which were not infarcted at admission but evolved to infarction after 24 hours (ischemic 'penumbra'). Evolution of diffusion parameters over time (24 hours) was monitored by two time points in group 1 and five in group 2. For all ROIs, the following quantities were calculated for all diffusion parameters: average and standard deviation (i.e. contrast) over the full area of the ROIs.

Results and discussion

Figure 1 and 2 show a case where the size of the infarcted area did not change over 24 hours. Figure 1a displays the evolution of the average over the ROI for the mean value of the nine diffusion parameters. The observed changes were mutually consistent: ADC, D, Df and FWHM (or width) decreased. Slow diffusion Ds increased and there was an exchange between the fast and slow compartments (Af versus As). RTOP (P0) increased (the PDF was normalized), and kurtosis also did. All these findings were consistent with the model of a transfer of water molecules from the extra-cellular into the intra-cellular space. However, in other cases, such an exchange (Af versus As) was not observed (not shown here). The fractional anisotropies in Fig. 2b revealed that decreases observed for QSI parameters and slow diffusion as well as D, were not detected by ADC. This observation emphasizes the value of high b (or q)-values measurements. The diffusion maps in Fig.2 (corresponding to the patient featured in Figure 1) demonstrate that the different maps delineated differently the contours of the diseased area. Figure 3 displays the ROI-average of the mean value for the nine diffusion parameters in another patient who had concomitantly a regressive infarcted zone (left sided #1 bars) and a worsening one (right sided #2 bars) at admission (blue bars) and 24 hours later (red bars). Almost all parameters - except Af and As - evolved in a 'mirror' opposite way regarding increase versus decrease. In conclusion, those preliminary results revealed that depending on the model used to analyze the data different results can be obtained and highlight the value of using high b-values for stroke diagnosis. Anisotropic diffusion and QSI analysis added significantly to standard isotropic DWI and could have the potential to discriminate between stable infarction, regressive infarction and – maybe - penumbra at admission work-up.



(a) **(b)**

Figure 1: Bar diagram of the diffusion parameters obtained from a ROI within infarcted area for two time points: admission (1) and 24 hours later (2). The texture parameter "average (AV)" is displayed. **(a):** mean values of the tensor, **(b):** fractional anisotropies.

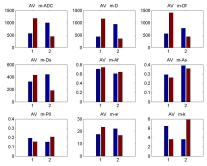


Figure 3: 'Mirror' evolution of AV for the mean values in two ROIs, the #1 corresponding to a regressive infarct and the #2 to a worsening infarct.

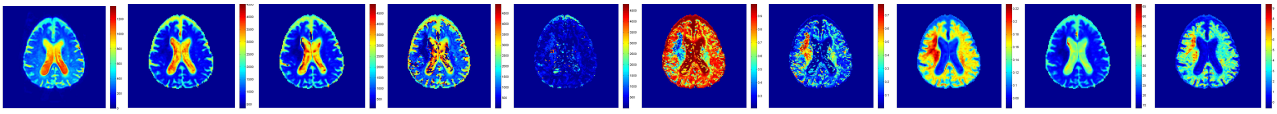


Figure 2: Diffusion maps (mean value) for the same slice location in the patient featured in Figure 1. From left to right: b0-image, ADC-, D-, Df-, Ds-, Af-, As-, RTOP-, FWHM- and k-maps.

References: **(1)** S. Warach et al, Ann Neurol., 37(2):231-41 (1995). **(2)** S.E. Maier et al, Magn. Reson. Med., 51(2), 321-330 (2004) **(3)** C.H. Sotak, NMR Biomed,15,561-569 (2002). **(4)**Y. Assaf et al, Magn. Reson. Med., 47(1), 115-126 (2002)