Quantitative study of oedema in acute stroke: a protocol for water content mapping

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Target Audience: Researchers with interest in stroke and/or quantitative imaging.

Introduction: Water concentration is tightly regulated in the healthy human brain and changes only slightly with age and sex in normal volunteers. Changes in water content are highly relevant for the characterisation of disease, but they are usually in the low percentage range, requiring methods with high accuracy for detection. We have developed such a method with an acquisition time of 7:21 minutes [1]. The aim of the present study was to: (a) test the applicability of the method on a new generation 3T scanner using two new receiver coil arrays, and compare to previous results; and (b) apply it to stroke patients.

Material and Methods: Nine healthy volunteers (4 male, 5 female, mean age 28 y, between 23y and 46y) and a single male patient (age 59y) were scanned after granting informed consent. All measurements were performed on a 3T (Siemens, PRISMA) scanner equipped with a gradient coil delivering 80 mT/m @ 200 T/m/s slew rate. A body coil was used for radiofrequency (RF) transmit and either a 20-channel or a 64-channel head array coil was used for signal detection. The examination of the sub-acute stroke patient was performed with the 20-channel head coil, was a clinical follow-up examination 7 days after stroke and included standard FLAIR and trace ADC (b=1000 s/mm^2) acquisitions. A CT scan was obtained on day 2 after stroke. The stroke was localised in the territory of the right posterior inferior cerebellar artery. We show in Fig. 1 a slice where various types of pathological tissue changes accompanied by oedema can be seen. A CT image is shown together with the clinical images and quantitative maps. Quantitative MRI was performed using a 2D multiple-echo gradient echo sequence provided by the manufacturer (GRE), acquired with TR=10s and nominal flip angle of 90^o. Other parameters were: field-of-view FOV=220x178mm^2; resolution 1.15x1.15x1.75 mm^3; 75 slices (1mm thick, 0.75mm gap); phase resolution 75%; TE1=4.03ms, ΔTE=4.88ms, 12 echoes; iPAT=2. The acquisition time (TA) was TA=7:21 min. Magnitude and phase data were saved for each echo and processed off-line. A mono-exponential fit to the signal decay as a function of echo time delivered the transversal relaxation time T2* and signal intensity at TE=0. Correction for transmit and receive inhomogeneities was performed by SPM [2]; tissue masks (WM, GM and CSF) were produced as part of the procedure and calibration was done using the CSF value after T_1 correction as described previously [1]. The phase data were unwrapped, background field corrected and used to calculate the magnetic susceptibility of tissue [3]. A mask of voxels affected by oedema was defined on FLAIR by thresholding. Analysis was performed using Matlab [4] and ImageJ.

Results: The water content distribution in the brain of healthy volunteers was bimodal, with a mean value of white matter (WM) and grey matter (GM) centroids of 69.2% (1.9%) and 82.6% (1.6%). The distributions were not significantly different for the different coil arrays, and the values are in good agreement with previously published results [1] (69.1(1.7)% for WM and 83.7(1.2)% for GM; 20 volunteers). Despite the fact that the stroke patient has a large portion of white matter affected by oedema/gliosis caused by periventricular CSF absorption and gliosis due to microvascular disease (see Fig. 1), the SPM-based inhomogeneity correction and segmentation worked well, with oedema classified as grey matter. In order to assess the accuracy of the method, we compared the MRI-determined water content to CT results. Fig. 2 shows the histograms obtained for different tissue classes (WM and GM defined from SPM segmentation and oedema from FLAIR): water content (top row) and X-ray absorbtion from CT (bottom). We use the mode of the histogram as a representative value for a given tissue type, and assume that the CT and MR properties of voxels in 'oedema region' are due to a superposition of CSF-like water (which also gives rise to an increased ADC for this patient) and normal tissue. The histogram of the water content of 'oedema voxels' can be described as the superposition of two Gaussians (79.4+87.5 pu), one for oedema in WM, one from oedema in GM regions (cerebellum, not shown). The same description is applied to the histogram of radiodensity of oedema (24+30.2HU). We can determine the increase in water content in WM from the changed radiodensity of oedema regions in WM as follows: $\text{oedema}_{HU}=(1-x)*WM_{HU}+x*CSF_{HU}$ with values determined from histograms. The factor x is determined to be 0.41 and can be used to predict the water content of oedema in WM: $\text{oedema}_{H2O}=(1-x)*WM_{H2O}+x*CSF_{H2O}$. The predicted value is 78.5pu and agrees well with the measured one of 79.4 pu. The same can be done for GM obtaining x=0.34 and water content of oedema regions in GM 86.4% (87.5pu measured). The agreement is surprisingly good, given all the simplifying assumptions which were made.

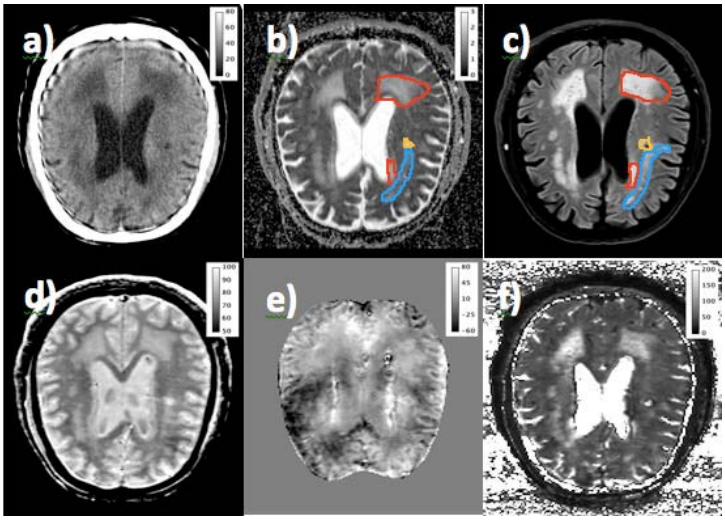

Figure 1. (a) CT scan at day 2 (HU); (b) ADC map (10^{-3} mm^2/s); (c) FLAIR; (d) water content (percent units, pu); (e) susceptibility distribution (a.u.); (f) T2* (ms). Red= CSF diapedesis & gliosis; blue = white matter lesions (WML) due to microvascular stroke; yellow = cystic lacunar lesion.

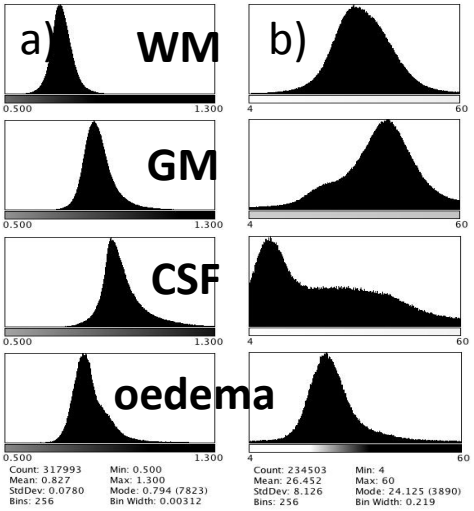

Figure 2. (a) water content ; (b) radiodensity of tissue (HU) from CT scan at day 2. Values for WM, GM, CSF (masks from SPM) and oedema (mask from FLAIR).

Discussion and Conclusions: The study demonstrates the feasibility of water content, T2* and susceptibility mapping in a clinical setting. The measurement time for the three maps was 7:20min. The T2* map and late-echo images (not shown) are very useful at visualising the regions affected by oedema. Further evaluation on more patients will show whether all the regions visible in FLAIR can also be identified in T2* contrast. Water content in oedema (caused by gliosis and microvascular stroke in this case, not by teritorial stroke) was found to correlate well with the CT findings. Further refinements of the protocol and processing methods are investigated and will allow us to acquire acurate water content maps in less than 5 minutes, to be applied routinely in the clinic, most interestingly in acute stroke.

References: [1] A.M. Oros-Peusquens et al, NIMA 45, 185 (2013); [2] fil.ion.ucl.ac.uk; [3] J. Lindemeyer et al., ISMRM. 20, 2329, (2012); [4] mathworks.com