A Novel Scheme for Producing Multi-Parametric Volumes

Lawrence Kenning[1], Martin Lowry[1], and Lindsay W Turnbull[1]
[1]*Centre for MR Investigations, Hull York Medical School at University of Hull, Hull, East Yorkshire, United Kingdom*

Introduction: MR studies for brain tumours are increasingly producing more images for radiologists to report. This, coupled with the increasing frequency of scans for patients on drug trials, and with aggressive tumours means assessing treatment response due to subtle differences and changing image obliquities can prove difficult. This work demonstrates a method for observing subtle changes and sampling multi-parametric data in glioma patients while reducing the number of images.

Methods: Multi-parametric MR data was acquired from 17 patients with biopsy proven gliomas that underwent chemo-radiotherapy following surgery. Baseline scans were conducted prior to therapeutic treatment with subsequent imaging obtained shortly after completion of chemo-radiotherapy. Patients were scanned on a 3.0T GE 750 Discovery using an eight channel phased array head coil. Conventional imaging in the form of T_2 FLAIR and T_1 contrast imaging (120 slices) was acquired along with 32 direction diffusion tensor imaging (DTI; ~1400 images), T_1 Dynamics (DCE; tdel= 5sec, 60 phases. ~960 images), multi-flip angle T_1 volumes (MFA; 3°,5°,10°,20°,40° flip angles,~80 images) and EPI T_2* dynamics (DSC; tdel= 2secs, 50 phases, ~1050 images). DCE-MRI preceded DSC-MRI to preload the tissue, reducing leakage effects that affect quantification. Motion within sequences, between sequences and between exams was minimised by applying a series of motion correcting registrations. Raw images were skull stripped using the Functional MRI of the Brain Software Library (FSL) Brain Extraction Tool[1] (BET). This was necessary for rigid registration using FMRIB's Linear Image Registration Tool[2] (FLIRT). DTI images were registered using the eddy current correct tool employing FLIRT with 12 degrees of freedom (dof) to register the b=1000sec/mm^2 images to the higher SNR b=0sec/mm^2 images and account for the changing gradient directions and AP direction warping that occurs with EPI. MFA data was registered to the 10° flip images, given its improved contrast, using FLIRT with 6 dof. DCE-MRI data was subsequently aligned to the same (10°) MFA data using the MFA estimated transformation matrix (T_{mx}). The DSC-MRI was processed in a manner similar to the DTI but registering all the data to the 4th phase images where SNR and T_1 weighting were high. Following internal motion corrections using FSL, parameter maps were computed using in house software. Pharmacokinetic (PK) modelling using a two compartment Tofts-Kety model and a population AIF was applied to the DCE-MRI data transformed to contrast concentration using T_1 calculated from the MFA data. DSC-MRI was processed using the Boxerman model[3]. Cerebral blood volume (CBV) maps were then normalised to contralateral white matter (rCBV). DTI data was processed to calculate the apparent diffusion coefficient (ADC) and the fraction anisotropy (FA). Parametric volumes were created by registering the FLAIR, T_1 post contrast, ADC, FA, R_1, K_{trans}, v_e, v_b, and rCBV into a single 4D [x, y, z, parameter] volume. This was done by first applying a 6 dof rigid registration (FLIRT) of the T_1 post contrast images to the FA volume, thus producing a T_1 volume of the same voxel size as the diffusion acquisition (0.94mm x 0.94mm x 3mm). This T_1 volume became the target for the FLAIR images (6 dof), the FA volume (12 dof) and the MFA R_1 volume (6 dof) since they shared similar tissue contrast characteristics. With the DCE-MRI in the same space as the R_1 volume, the same T_{mx} was applied to the combined K_{trans}, v_e and v_b volume. The resampled FLAIR volume was registered to the 1st phase of the DSC-MRI with 12 dof since the FLAIR images had greater contrast and SNR. Inverting and applying the determined T_{mx} produced CBV maps aligned to the re-sampled FLAIR. These were aligned to the T_1 volume using the appropriate predetermined T_{mx}. With all volumes now in the same space as the post contrast T_1 volume, fslmerge was run to combine parameter and anatomical volumes together. Parametric volumes consisted of FLAIR T_2 signal, post contrast T_1 signal, ADC, FA, R_1, K_{trans}, v_e, v_b, and rCBV. Post-therapy parametric volumes were registered to pre-therapy volumes using FLIRT with 6 dof and a least squares cost function between the corresponding post contrast T_1 volumes.

Results: We have demonstrated a processing scheme for registering parametric and anatomical scans together both within, and between examinations. Visual inspection between scans suggests good intra-modal registration as shown in figure 1. Registration was successful in all cases.

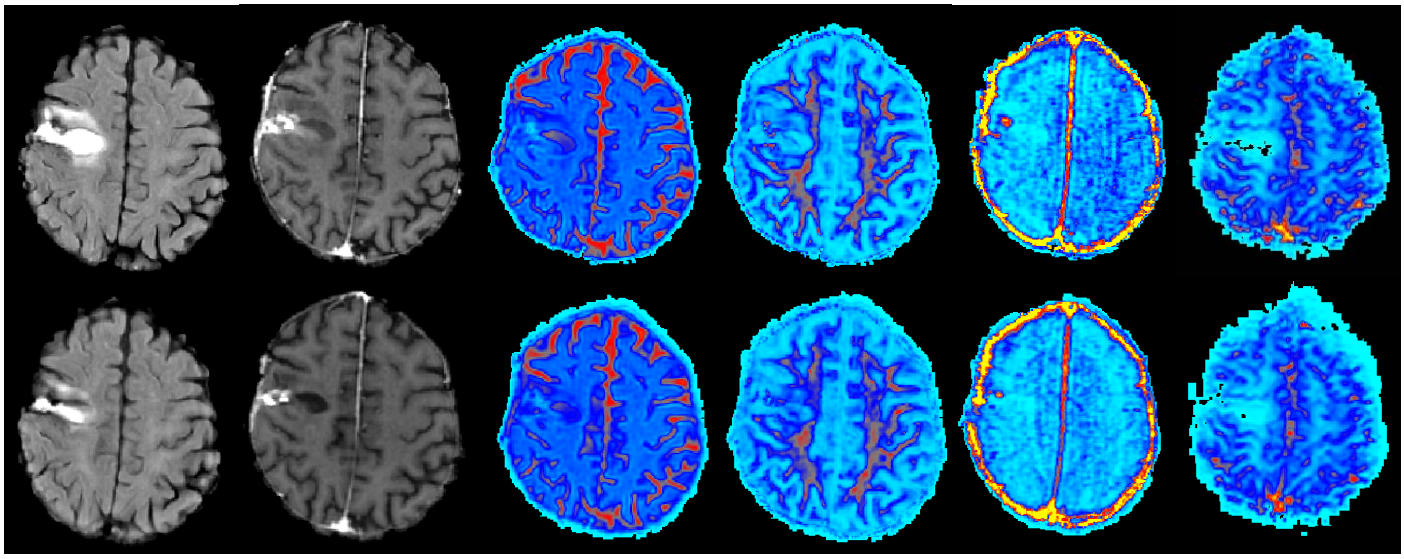

Figure 1. Paired pre (top) and post (bottom) therapy images for: FLAIR T_2 signal, post contrast T_1 signal, ADC, FA, v_e and rCBV (from left to right). Scale: maps (yellow highest, red high, dark blue middle, light blue low, black = 0)

Discussion: The advantages of this technique include a significant level of data reduction. By registering the different types of maps together, radiologists and researchers can cross examine areas of abnormality with ease using any image reader. Volumetric regions of interest drawn on a single type of anatomical imaging can then be used to sample all functional parameters simultaneously. Subtle changes are more likely to be identified on images that are co-planar, thus benefiting researchers and patients greatly. Subtraction of paired volumes could be used to create functional parameter maps to assess treatment response.

Conclusions: This work demonstrates a scheme for registering functional maps between scans and within a single examination for brain tumour patients. The multiparametric volumes will considerably reduce the effort required to assess associations between parameters and their changes in response to therapeutic interventions.

References: 1. *S*mith *et al,* Human Brain Mapping (2002) **17**: 143-155. **2**. Jenkinson *et al*, Medical Image Analysis (2001) **5**: 143-156. **3**. Boxerman *et al*, Am J Neuroradiol. (2006) **27**: 859-67.