Using Jacobean determinants to map within-subject serial changes in brain volume in difficult contexts: implementation in traumatic brain injury with decompressive craniectomy

S. Sawiak[1], V. F. Newcombe[2], M. G. Abate[2], J. G. Outtrim[2], J. D. Pickard[1], T. A. Carpenter[1], G. B. Williams[1], and D. K. Menon[2]

[1]Wolfson Brain Imaging Centre, University of Cambridge, Cambridge, Cambridgeshire, United Kingdom, [2]Division of Anaesthesia, University of Cambridge, Cambridge, Cambridgeshire, United Kingdom

Introduction: Atrophy is common post traumatic brain injury (TBI) and may correlate with outcome.[1] Voxel based morphometry methods typically require group comparisons which may be confounded by patients with lesions, and provide no means of addressing serial change in individual subjects. Other approaches, including SIENA(X) rely on the dimensions of the skull being constant. We hypothesised that quantification of Jacobian determinants could assess progressive changes in brain volume in within subject analyses, even in contexts that produce major problems with comparative analyses. We show implementation of the approach in a single TBI subject with serial scans before and up to 12 months after decompressive craniectomy, compared to results from healthy controls.

Methods: One patient who had sustained a severe TBI was scanned at 5 time points (15 hours post TBI, 5.5 days, 10 days (post decompression), 6 months and 12 months) with the scanning protocol including a magnetization prepared rapid acquisition gradient echo (MPRAGE); matrix size 240x256x256, 1.08mm isotropic voxels. Six controls underwent identical sequences with two scans acquired approximately six months apart. All scans were performed on a 3 Tesla Siemens Magnetom Total Imaging Matrix (TIM) Trio system. Informed assent from next-of-kin for the first three scans and informed consent for the final two was obtained in the patient and informed consent was obtained in all controls. Ethical approval was obtained from the Local Research Ethics Committee. All of the longitudinal scans for the patient were coregistered to the first scan following injury with an affine transformation based on NMI using vtkCISG.[2] This was followed with a non-linear registration based on *b*-splines using the same software with control point spacing 8mm, regularised by a punitive term based on bending energy. Jacobian determinants were calculated from the deformation fields to produce maps of volume change over time. For controls, the Jacobian determinants were transformed to the space of the first scan of the subject. Brain extraction masks were calculated using SPM5.[3]

Results: Mean intracranial volume change in controls was 0.105% (mean standard error 2%). Figure 1 shows significant volume changes occurring in the patient's brain over time, corrected for multiple comparisons using a false-discovery rate $p_{FDR} < 0.01$ based on a voxel-wise two-tailed Student's *t*-test.

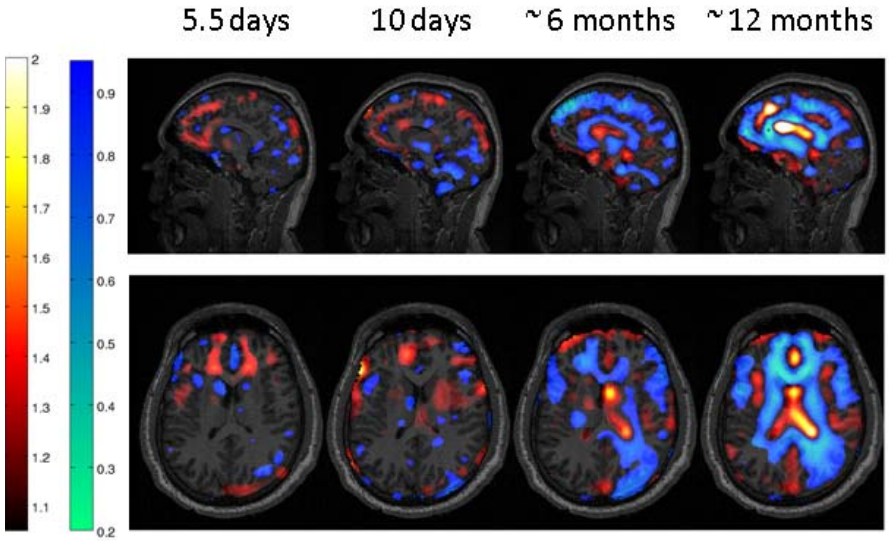

Figure 1: Significant volume changes post TBI over time. Each scan is compared to the first at 15 hours. The left (red based) colour bar indicates significant increases in brain volume and the right (blue based) one decreases in brain volume.

Discussion: The increase in volume change in the scans within the first 10 days is consistent with oedema. The 6 and 12 month scan indicate progressive atrophy most marked in white matter areas, with a concomitant increase in the CSF spaces. These results indicate it is possible to monitor the changes in brain volume over time post TBI in an individual. Potential problems with this technique include concerns that the injury changes the tissue contrast introducing a biasing effect in the registration process. There is a risk that misregistration will occur as damaged tissues change in appearance and the deformation fields will be rendered useless as a result. However, close visual inspection of the registered images here did not reveal any obvious mismatch, however. It should be noted that this may not be the case in more severe injuries resulting in (for example) focal lesions or severe oedema where our methods will have to be adapted. We are currently investigating the effect that the details of the regularisation term have on conclusions in this procedure and applying it to more patients, and will correlate with clinical outcome.

References:

1) Sidaros et al, Neuroimage (2009) 1;44(1):1-8
2) Rueckert D et al Lec. Notes in Comp Sci (1998) vol. 1496
3) Ashburner J et al. NeuroImage (2005) 26:839-51