An improved quantification method to characterize cerebral hemodynamic changes after carotid endarterectomy surgery: a dynamic susceptibility contrast MRI study.

D. E. Crane[1], B. J. MacIntosh[1,2], E. Sideso[3], J. Kennedy[3], A. Handa[4], M. J. Donahue[5], and P. Jezzard[5]

[1]Heart and Stroke Foundation Centre for Stroke Recovery, Sunnybrook Research Institute, Toronto, ON, Canada, [2]Medical Biophysics, University of Toronto, Toronto, ON, Canada, [3]Nuffield Department of Medicine, University of Oxford, Oxford, United Kingdom, [4]Nuffield Department of Surgery, University of Oxford, Oxford, United Kingdom, [5]Clinical Neurology, FMRIB Centre, University of Oxford, Oxford, United Kingdom

Introduction: Dynamic Susceptibility Contrast (DSC) is the industry standard for acute stroke MR imaging. DSC is capable of resolving ischemic tissue through metrics such as the mean transit time or Tmax, the bolus delay time from middle cerebral artery to tissue. Using standard clinical DSC acquisition parameters, interpretation of cerebral blood flow (CBF) maps tends to be limited to within-subject or within-session analyses because of the challenges of longitudinal comparison (1,2). Recently, however, others have developed a way to improve CBF quantification in DSC (3) by using the T1-weighted steady-state measurement of CBV to calibrate DSC, in what is known as the "bookend" technique (4). In the current study we apply the "bookend" technique to investigate the reliability of CBF measurements in a cohort of cerebrovascular patients that undergo carotid endarterectomy (CEA). It is our hypothesis that improved CBF-DSC quantification techniques will permit longitudinal analysis and thereby the characterization of the effects of CEA surgery. Others have used single photon emission tomography (SPECT) to show that poor cerebrovascular reactivity, measured before CEA, contributes to an adverse post-CEA hyperperfusion syndrome (5). Another dimension of this work is the development of our understanding of "sub-clinical" adverse events known as silent brain infarcts, which occur in ~17% of patients (6). The ultimate goal of this work is to determine whether DSC-based absolute CBF can be used to characterize the effects of CEA and thus help identify patients who are more likely to benefit from surgery.

Methods: Eighteen carotid patients, who underwent CEA for stenosis >65%, participated in this longitudinal study that was approved by the local ethics committee (5 females, mean age 70 ±10 years). Imaging consisted of: GRE-DSC (TR/TE=1481/30ms, 22 slices, 78 volumes, FA=70deg, 128x128 matrix, 1.7x1.7x5mm^3 voxels, GRAPPA=2), diffusion-weighted imaging (DWI, 27 slices, b=0 and 1000 s/mm^2), pre-Gadolinium contrast and 10-min post-contrast T1-weighted acquisitions (TR/TI/TE= 1800/900/4.4ms, FA=8deg, 6/8th partial k-space, axial MP-RAGE, matched to DSC, 1.7x1.7x2mm^3 voxels), with all data collected on a TIM Trio 3T Siemens MRI scanner. Imaging was performed prior to and within 24-hours following surgery. DWI images were evaluated manually for ischemic lesions. DSC CBF and CBV maps were calculated using Penguin software (http://www.cfin.au.dk) with block-circulant SVD, followed by the "bookend" method involving T1 CBV values (4). This correction uses steady-state contrast-enhanced T1-weighted imaging to determine quantitative CBV values in the putamen (T1-CBV). The putamen was chosen as a robust grey matter (GM) region with negligible partial voluming and high contrast-enhanced signal change. The ratio of DSC-CBV to T1-CBV was used to calculate a correction factor that was then applied to all DSC-CBF and CBV voxels. Finally, mean CBF and CBV were calculated for ipsilateral cortical and subcortical GM regions that are fed by the middle cerebral artery, as defined by (7). Contralateral GM data were also considered. Analysis of results was conducted in SPSS and Matlab.

Results: Across the cohort, mean pre-CEA ipsilateral subcortical GM CBF and CBV were 40 +/-17 ml/100g/min and 2.2+/-0.60 ml/100g, respectively. Mean ipsilateral cortical CBF and CBV were 68+/-24 ml/100g/min and 4.0+/-18 ml/100g. Absolute ipsilateral subcortical CBF and CBV increased after CEA by 10% (non-significant), and 13% ($p<0.05$). DWI-analysis identified three sub-groups within our dataset: i) no infarcts (n=11), ii) presented with infarct (n=5), iii) developed infarct (n=2). An age-related analysis revealed that subcortical contralateral CBF decreased significantly at a rate of 4.3 ml/100g/min per decade ($p<0.05$), among lesion-free participants. Cortical CBF showed no significant trend with age or surgery. There was a significant positive correlation between pre vs. post-CEA contralateral CBF for lesion-free participants ($r^2=0.56$, $p<0.01$). With the caveat that sample sizes are still too small to make firm conclusions, participants with DWI lesions had higher variability in subcortical flow changes 24-hours after CEA than those without DWI lesions (figure 3). The patient with the greatest CBF increase (95%) developed DWI infarcts after surgery (figure 3).

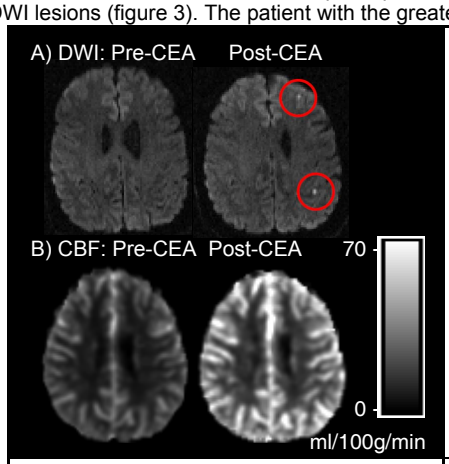

Figure 1. A) DWI and B) CBF images before and after surgery for a patient that developed a DWI infarct subsequent to surgery. DWI infarcts circled in red. CBF images are displayed with the same scale.

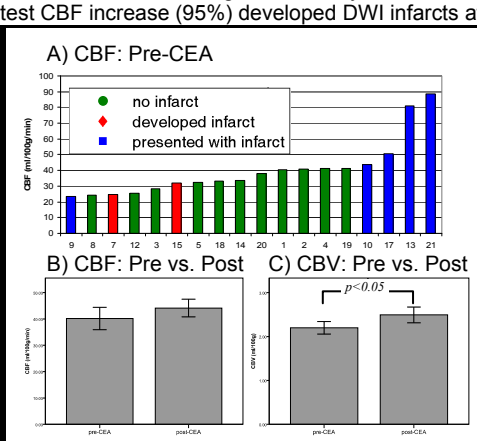

Figure 2. A) Pre-surgical CBF values of the subcortical MCA territory, ipsilateral to surgery, ordered by CBF and colour-coded by sub-group. B) CBF before and after surgery C) CBV before and after surgery.

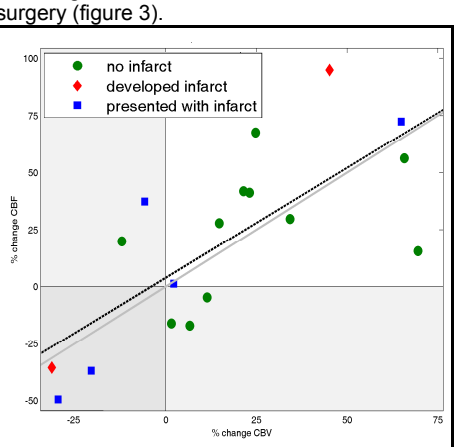

Figure 3. Percent change in CBF vs. CBV. Bold dashed line represents line of best fit (%CBF=0.96x%CBV + 3.9; R^2=.55). Grey line represents equal changes in CBF and CBV.

Discussion: Use of advanced DSC quantification methods permitted inter-session comparison of CBF data. Subcortical GM results were in agreement with previously-measured values and age trends for our sample population (9). Cortical GM results were less reliable, which may have been influenced by coregistration errors and inclusion of arterioles and sulci. The low inter-session variability and significant CBV group effects in this study suggest that the DSC-bookend approach may be useful in characterizing the interaction between hemodynamics and ischemic infarcts.

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