

Estimation of CBF Values Using Multi-Echo DSC-MRI: a Comparison with a Xenon CT

M. STRAKA¹, G. ZAHARCHUK¹, R. D. NEWBOULD², G. W. ALBERS³, M. E. MOSELEY¹, AND R. BAMMER¹

¹LUCAS CENTER, DEPARTMENT OF RADIOLOGY, STANFORD UNIVERSITY, STANFORD, CA, UNITED STATES, ²GLAXOSMITHKLINE, LONDON, UNITED KINGDOM, ³STROKE CENTER, DEPARTMENT OF NEUROLOGY AND NEUROLOGICAL SCIENCES, STANFORD UNIVERSITY, STANFORD, CA, UNITED STATES

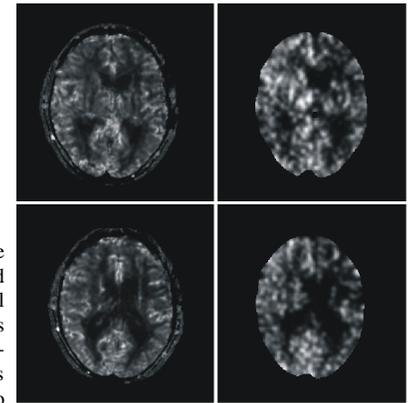


Fig.1: Coregistered DSC-MRI CBF maps (left) and XeCT CBF (right)

PURPOSE: Measurements of cerebral perfusion deliver important information about the brain tissue in case of acute stroke and other cerebrovascular diseases. Bolus-tracking (DSC-MRI) is often chosen as a feasible diagnostic method for assessment of the perfusion parameters as are CBV, CBF or MTT. Historically, the precision, accuracy and overall quality of quantitative perfusion maps determined by DSC-MRI have suffered compared to other techniques. To address the limited temporal resolution, spatial distortions in EPI sequences and clipping of vascular signals during bolus passage peak a scanning sequence for perfusion with multiple echoes and temporal enhancement (PERMEATE, [1]) was developed, in which the confounding artifacts should be reduced. Data acquired with first (short) echo should be used to properly recover the vascular signals, whereas the later echoes are used to determine signals in the tissue manifesting better signal-to-noise ratio therein. Such state-of-the-art perfusion acquisition is complemented by a PWI post-processing pipeline, including correction for partial-volume effect (PVE) in vascular signals and susceptibility effect of the paramagnetic tracer in large vessels [2]. The purpose of this study was to evaluate the benefits of such advanced acquisition scheme with the PVE and bulk-blood corrections and to quantify the improvement of values in the computed quantitative perfusion maps.

METHODS: We analyzed a set of 20 patients (7 stroke, 6 moya-moya, 7 cerebrovascular disease) who underwent both XeCT and DSC-MRI perfusion measurements within 48 hour window. The XeCT CBF maps were acquired using GE 8-slice CT, DDI, Inc., Houston, TX scanner (4 contiguous 10 mm slices), using xenon gas as a diffusible tracer. The CBF values were computed by Kety-Schmidt method in the scanner vendor software. The DSC-MRI data were acquired with the PERMEATE sequence [1], using parallel-imaging (R=3), multi-shot multi-echo GRE-EPI, TR=1.225s, TE=15/36/56ms, FA=70°, resolution 96x96, 15 slices, slice thickness 5mm, gap 2.5 mm, 74s total scan time). The post-processing of the raw perfusion data consisted of correction for patient motion, correction for slice acquisition time, automatic selection of arterial input- (AIF) and venous output- (VOF) functions and application of correction coefficients for susceptibility effect of the tracer in bulk blood [2]. The quantitative perfusion parameters were computed from residue functions, determined by deconvolving tissue signals with the AIF. The delay-invariant frequency-domain deconvolution was regularized using optimal Wiener filter [3]. Finally, the CBV/CBF values were corrected for possible PVE using ratio of areas under AIF and VOF signals. To evaluate the benefits of the PERMEATE acquisition deliver with respect to standard PWI sequences, we processed the resulting raw multi-echo data in two distinct ways: firstly, we used the first echo (15ms) values to determine vascular signals, to minimize the clipping artifacts. The tissue signals were computed using multi-echo fit to estimate the true R2* values in the tissue voxels and then the deconvolution pipeline was applied. Secondly, to mimic the standard single-echo acquisition and to allow comparison with previous studies [4], we computed both vascular and tissue signals using the last echo (56ms), again followed with the deconvolution. To analyze the effects of the PVE and bulk-blood corrections, for both multi-echo and single-echo processing we computed the perfusion parameter maps with and without these corrections, resulting in 2x4=8 sets of maps per patient.

To facilitate a statistical comparison of the XeCT and DSC-MRI CBF maps, we coregistered the anatomical CT data to pre-bolus baseline DSC-MRI data (Fig. 1) using SPM5 (Wellcome Trust Centre for Neuroimaging, UCL, London, UK).

There, for each of the 8 MRI PWI maps and XeCT maps we computed averages of CBF in 1 cm³ volumes, taking into account only voxels where both XeCT and DSC-MRI maps had valid values; the ventricle and CSF regions were outmasked. In the final evaluation, we computed the linear regression intercept and slope as well as the correlation of CBF values in respective XeCT and MRI PWI maps. We also determined the CBF averaged from the whole imaged area for both XeCT and MRI PWI maps ('avgCBF'). Finally, we analyzed the mean, standard deviation (SD) and coefficient of variation (COV = SD/mean) of the regression slope and correlation, as well as ratio of avgCBF values between MRI and XeCT.

RESULTS: The results are summarized in Tab. 1 and 2. The values in the 'slope' columns represent the mean, SD and COV of the linear regressions between XeCT and MRI CBF values. The 'slope' columns represent mean/SD/COV of the linear regression slopes, the 'avgCBF' columns represent mean/SD/COV of the CBF values averaged in the whole imaged brain area, the 'MRI /XeCT' columns represent mean /SD/COV for ratio of avgCBF between MRI and XeCT and the 'R' columns represent mean /SD/COV of the correlation coefficient between XeCT and MRI CBF values.

CONCLUSION: As indicated by the 'slope' and 'avgCBF' columns, the bulk-blood correction is just a scaling factor. As expected, it reduces the determined values of CBF by factor of ~ 4. By comparing the Tab. 1 and 2 (columns 'slope' and 'avgCBF') it is also clear that using the early echo for vascular signal reduces the clipping, resulting in larger area under the AIF curves and hence lowered CBF estimates. The effect of applied PVE correction using AIF/VOF area ratio is harder to interpret (columns 'slope', 'MRI/XeCT' and 'R') as the variability of MRI/XeCT avgCBF ratios marginally improved, but the variability of linear regressions slope and correlation marginally worsened (in case of the multi-echo acquisition). The single-echo results were very little influenced. Whereas this result might appear puzzling, one has to consider several facts: the PERMEATE sequence, due to its fast readout recovers signals also in areas with fast flow, e.g. in internal carotid arteries or superior sagittal sinuses. In these locations, the vascular signals have large amplitude and little partial voluming, thus are natural candidates for AIF and VOF. However, in these regions the flow varies according the heart cycle, which was not synchronized with the acquisition. Additionally, the signals acquired with short echo time are subject to stronger T1-weighting what also confounds the measured values. Variability of the susceptibility effects in respect to different vessel orientations is not negligible as well. Our conclusions from this study that the multi-echo acquisition reduces the clipping artifact in vascular signals, but also brings a whole new set of confounding factors that were not important previously.

ACKNOWLEDGEMENTS: This work was supported in part by the NIH (2R01EB002711, 1R21EB006860, P41RR09784), the Lucas foundation, and the Oak foundation. **REFERENCES:** [1] Newbould RD et al: Magn Reson Med. 2007 Jul;58(1):70-81; [2] Kjølbj, BF et al.: Magn Reson Med. 2006 Jul;56(1):187-97; [3] Gobbel, GT et al.: Phys Med Biol. 1994 Nov;39(11):1833-54; [4] Zaharchuk G et al., Proc ISMRM, Toronto, Canada 2008: 628

Corrections	Multi-echo processing																XeCT avgCBF
	VOF+BB				None				BB only				VOF only				
	Slope	avgCBF	MRI/XeCT	R	Slope	avgCBF	MRI/XeCT	R	Slope	avgCBF	XeCT/MRI	R	Slope	avgCBF	MRI/XeCT	R	
Mean	0.170	19.3	0.525	0.337	0.864	105.5	2.86	0.336	0.222	26.6	0.720	0.337	0.579	66.0	1.79	0.335	39.1
SD	0.093	6.27	0.213	0.118	0.391	38.4	1.29	0.115	0.102	8.26	0.268	0.116	0.306	20.5	0.681	0.117	9.87
COV	0.546	0.323	0.406	0.351	0.452	0.363	0.450	0.341	0.459	0.311	0.373	0.343	0.529	0.310	0.381	0.348	0.253

Tab. 1. Summary of effects that PVE correction (based on VOF) and correction for susceptibility effect in bulk-blood (BB) have on the determined CBF values, when multi-echo acquisition and processing is used.

Corrections	Single-echo (last-echo) processing																XeCT avgCBF
	VOF+BB				None				BB only				VOF only				
	Slope	avgCBF	MRI/XeCT	R	Slope	avgCBF	MRI/XeCT	R	Slope	avgCBF	MRI/XeCT	R	Slope	avgCBF	MRI/XeCT	R	
Mean	0.344	37.4	1.01	0.343	1.848	199	5.37	0.346	0.392	42.54	1.148	0.343	1.559	168.2	4.51	0.346	39.1
SD	0.193	14.05	0.403	0.112	1.056	73.7	2.19	0.114	0.224	16.23	0.479	0.112	0.879	61.8	1.76	0.114	9.87
COV	0.562	0.375	0.401	0.328	0.571	0.37	0.408	0.329	0.572	0.381	0.417	0.328	0.565	0.367	0.389	0.329	0.253

Tab. 2. Summary of effects that PVE correction correction for susceptibility effect in bulk-blood (BB) have on the determined CBF values, when single-echo acquisition and processing is used.