Does T2' Depend on the Measurement Method? Considerations for Quantitative BOLD Oxygenation

Wendy W Ni[1,2], Thomas Christen[1], Zungho Zun[1], and Greg Zaharchuk[1]

[1]*Department of Radiology, Stanford University, Stanford, CA, United States,* [2]*Department of Electrical Engineering, Stanford University, Stanford, CA, United States*

Introduction: The reversible transverse relaxation rate R2'=1/T2' is a critical parameter in quantitative BOLD (qBOLD) oxygenation measurement[1]. To date, several methods have been used to measure R2' with the assumption of equivalency. In this study, we hypothesize that T2' depends on the measurement method. Specifically, we compare three approaches: 1) asymmetric spin echo (ASE)[2]; 2) GESFIDE[3], a method in which multiple echoes are acquired during 3 different intervals: FID, post 180°, pre spin echo (SE) recovering, and post-SE sections (parts A, B and C respectively [Fig. 1]); 3) a combined approach[4] (COMBO) where echoes from GESFIDE are used for R2*, while R2 is measured using a different sequence.

Material and Methods: With IRB approval, five normal subjects (ages 22-30) were scanned at 3T (MR750, GE Healthcare) using an 8-channel head coil with 2D GESFIDE (1.6×1.6×1.5mm^3, 12 interleaved slices at 1mm spacing, TE_{SE}/TR 100/2000ms, 40 echoes with TE 5-130ms) and CubeQuant (0.5×0.5×2mm^3, TR 2646ms, 11 echoes with TE 6-129ms acquired in two series), a multi-echo T2-prepped 3D FSE sequence with optimized refocusing pulses[5]. For ASE, we reduced GESFIDE's TE_{SE} by intervals of 8.9ms to give 5 data sets with shift 0-36ms. For analysis, all images were co-registered, and gray matter (GM) and white matter (WM) ROIs were extracted from the GESFIDE images using a custom algorithm. The GESFIDE signal is assumed to experience exponential decay constants of $R2^*_A$=R2+R2', $R2^*_B$=R2-R2' and $R2^*_C$=R2+R2' in parts A, B and C (Fig. 1), while CubeQuant signal is assumed to experience exponential decay. Using various combinations of selected GESFIDE and CubeQuant echoes, we investigated 8 R2' measurement methods (Fig. 2) using different time periods of the GESFIDE sequence, with and without corrections from CubeQuant-derived T2 measurements (COMBO).

Results and Discussion: Applying the long-τ approximation[2] to the last three ASE data points, the R2' maps had very high spatial noise, high inter-subject variability and no GM/WM differentiation, making ASE with our range of echo time shifts unsuitable for evaluating R2', hence no further details are included due to space constraints. GESFIDE methods demonstrated relatively low spatial and inter-subject variation (Fig. 3). After R2 correction, remnant discrepancy between GESFIDE $R2'_{AB}$ and $R2'_{BC}$ maps may be caused by diffusion effects and insufficient range and spacing of TEs. Lastly, COMBO variants produced comparable R2' values to GESFIDE $R2'_{AB}$, though the standard deviation was slightly higher (Fig. 3, possibly because the R2 maps were derived from a separate sequence. Overall, all methods using GESFIDE parts A and B echoes produced R2' close to or within the range of literature R2' values[3]. As expected, spatial SD increased using the B and C echoes due to lower SNR. However, ranking the methods is difficult, as there is no gold-standard method for measuring R2'. In the future, we plan to verify the suitability of each method for qBOLD using an oxygenation challenge paradigm and non-MR oxygenation measurement methods.

Conclusion: Comparison between multiple methods revealed systematic differences in R2' maps. Therefore, researchers performing qBOLD oxygenation measurements must carefully consider the choice of R2' measurement method, and take into account its impact on the final outcomes.

References: 1. T Christen *et al.*, MRM, 2012. 2. L Stables *et al.*, MRM, 1998. 3. N Fujita *et al.*, NeuroImage, 2003. 4. T Christen *et al.*, Proc. ISMRM, 2011 #4452. 5. W Chen *et al.*, Proc. ISMRM, 2012 #3419. **Acknowledgements**: Supported in part by NIH 1R01NS066506, NIH 2R01NS047607, NCRR 5P41RR09784, and the Stanford Graduate Interdisciplinary Fellowship program.

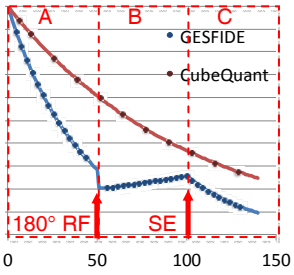

Fig. 1: Idealized GESFIDE and CubeQuant signal curves. TE ranges are 5-43ms (A), 56-100ms (B) and 103-130ms (C) for GESFIDE, and 6-39ms (A), 51-90ms (B) and 103-128ms (C) for CubeQuant.

	GESFIDE			CubeQuant		
	A	**B**	**C**	**A**	**B**	**C**
GESFIDE AB	X	X				
AB, R2c	X	X		X	X	
BC		X	X			
BC, R2c		X	X		X	X
COMBO A-all	X			X	X	X
A-A	X			X		
B-all		X		X	X	X
B-B		X		X		

Fig. 2: Echoes used in each method. Columns denote subsets of echoes from each sequence. Rows denote the methods in the GESFIDE and COMBO approaches. "R2c" indicates R2 correction.

	GM			WM		
	Mean	**Spatial SD**	**Sample SD**	**Mean**	**Spatial SD**	**Sample SD**
GESFIDE AB	1.8	1.6	0.3	3.7	1.5	0.1
AB, R2c	1.5	1.6	0.3	3.2	1.6	0.3
BC	0.8	2.4	0.2	0.7	2.7	0.3
BC, R2c	1.2	3.2	0.5	1.1	2.9	0.4
COMBO A-all	1.9	2.0	0.5	3.6	1.9	0.5
A-A	2.2	2.1	0.6	4.1	1.8	0.4
B-all	1.5	3.1	0.6	2.9	2.5	0.3
B-B	1.7	2.9	0.5	3.4	2.4	0.4

Fig. 3: Aggregated mean, spatial standard deviation and sample (inter-subject) standard deviation of GM and WM R2' values. Whole brain mean R2' (not shown) for all methods except GESFIDE BC and R2-corrected BC fall within the range reported by Fujita *et al*[2].

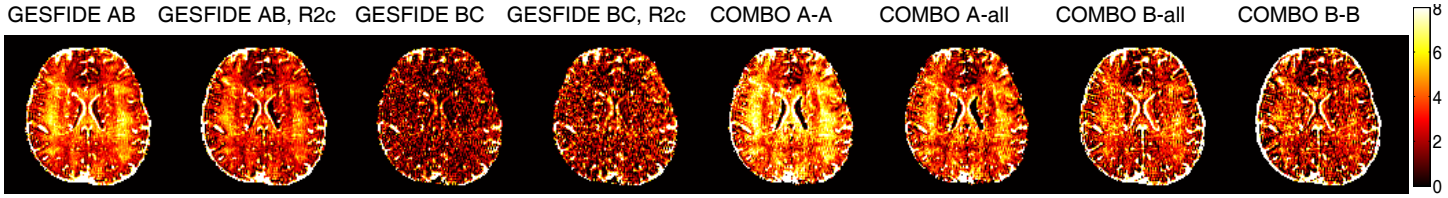

Fig. 4: Typical R2' maps from each of the 8 methods. We observe that GM/WM values and differences are strongly dependent on the range of TEs, whether R2 correction is applied and whether the CubeQuant echoes matches the GESFIDE echoes in TE range.