Improved T2* estimation technique in human carotid arteries

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Objectives: 1. Evaluate a novel technique for estimating T2* over thin semi-homogeneous regions of interest in an (a) arterial phantom, and (b) carotid arteries in human subjects. 2. To show how such a technique may be used to reduce inter-operator variability, making T2* evaluations in carotid arteries more clinically robust.

Background: The MR T2* relaxation time has been used to noninvasively quantify the concentration of iron present in liver, heart, and arteries [1,2]. Estimating this parameter is typically done by a mono-exponential pixel-wise fit of signal intensities observed using a gradient recalled echo over several echo times (TEs). This method has been shown to be successful in large tissue regions in the heart and liver [1,2]. However, when evaluating small vessels such as the carotid arteries, this method is prone to error from noise sources such as misregistration of voxels and blood flow because the majority of the voxels in the region of interest are against the borders of the vessel. In this work, we evaluate the use of a weighted least squares estimate (WLSE) with outlier removal to provide a semi-automated alternative to the manual approach of evaluating T2* in the carotid arteries vessel wall.

Methods:

T2* Estimation: The signal from a MR gradient recalled echo with sufficiently long TR will decay as : Signal = S_0 exp(-TE/T2*). To linearize estimation with respect to varying TEs, the signal was first transformed by a logarithm. Each data point (i.e. signal at each voxel for each echo time) was then weighted between 0 and 1. Data points were given an exponentially decaying weight with increasing TE because of known signal loss with longer TEs. All data points at a single voxel were also penalized by lowering their weight for each non-decaying signal intensity with increasing TE. The values were then fit using these weights in a WLSE with two parameters : T2* and S_0. Data points from a set of neighboring pixels were considered for each linear regression fit. Any fit that yielded a coefficient of determination, R^2, greater than 0.5 was considered an outlier and removed. A 3x3 sliding window was used to select neighboring voxels, and the resulting T2* value assigned to the center voxel. Any voxel within the window but outside the region of interest was excluded. The resulting T2* value for this region was then calculated as the mean value of the estimates for the entire region.

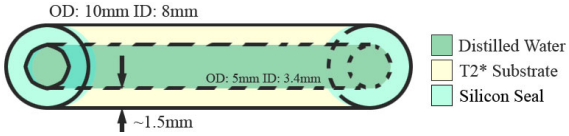

Figure 1: Phantom Design

Arterial phantoms: We prepared 7 phantoms using different weights of agarose: 1.5%, 2%, 2.5%, 2.75%, 3%, 3.25% and 3.5% mg/g of water. Agarose has been to shown to have decreasing T2* relaxation time with increasing weight and so was used to simulate T2* values over the range for normal vessel wall T2*. The agarose was implanted in two concentric glass tubes as described in Figure 1 to model the size and basic shape of a short section of the carotid artery. Signal intensity was acquired using a gradient recalled echo technique with the imaging parameters given in Table 1 on a 3T Siemens Verio scanner. Five slices with 4.5mm spacing were collected along the length of the tubes. Regions of interest were then drawn across the entire area containing agarose, making no attempt to avoid observed noise. The resulting regions were then analyzed using both the pixel-wise LSE (pLSE) model and neighborhood WLSE (nWLSE) model, recording the mean and standard deviation.

Table 1: Imaging parameters

Parameter	GRE
Echo times (ms)	2.73, 7.49 12.25, 17.08, 22.42
Matrix	320 x 320
Slice Thickness (mm)	3
Flip angle (degrees)	20
TR (ms)	740

Table 2: Phantom study results; T2* (ms)

Agarose Weight (%)	1.5	2	2.5	2.75	3	3.25	3.5
nWLSE Mean	57	43	39	35.5	25	25.7	19.3
nWLSE Variance	3.7	1.8	10.1	4.3	5.2	15.3	6.1
pLSE Mean	97	56	49.5	40.5	98.3	31	23.7
pLSE Variance	536	3.5	38.5	7.1	6068	88.6	39.7

Human subjects: 16 perimenopausal female patients with risk factors for atherosclerosis were scanned using the same gradient recalled echo technique as the arterial phantoms. Three slices were prescribed in each carotid artery, one in the common carotid artery (CCA) just below the bifurcation and two in the internal carotid artery (ICA) 2.5 and 5mm from the bifurcation. Two different methods of quantifying T2* were used by three operators. In the first method, three operators drew regions within each vessel wall in an area they determined to be homogeneous. The mean and standard deviation of these regions were recorded as calculated by the pLSE model. In the second method, two of these three operators then drew a region that encompassed the entire vessel wall. The mean and standard deviation of these regions were recorded as calculated by the nWLSE model. A Bland-Altman plot was used to characterize the inter-operator variability[3].

Results:

Arterial phantoms: From Table 2, the nWLSE model consistently yielded a smaller variability than the pLSE model. On average, the means for each phantom were always lower than both the pLSE and the expected T2* value of the phantom at 1.5T as seen in Figure 2. The pLSE all but once yielded a mean higher than that seen at 1.5T. The phantom with 3% agarose was contaminated with distilled water in the agarose layer and caused a spike of T2* estimate for the pLSE model, but did not affect the estimate with the nWLSE model.

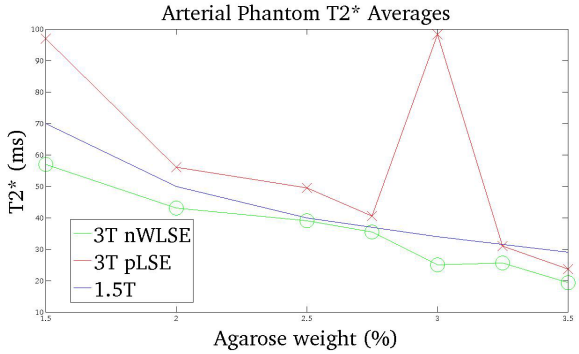

Figure 2: Phantom Results

Human subjects: The Bland-Altman plots in Figure 3, show more than a 50% reduction in the confidence bands in the nWLSE method as compared to the pLSE method. Similar results were seen when comparing to the third operator.

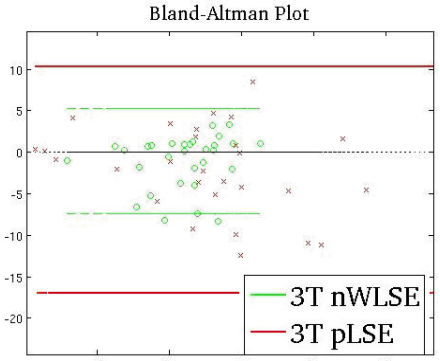

Figure 3: Bland-Altman plot characterizing inter-operator variability

Conclusion: A new technique for estimating T2* in human carotid artery vessel wall was evaluated that would reduce noise from registration errors due to wall motion and voxel mixing effects, especially along the borders of the vessel, and decrease inter-operator variability. From the phantoms study, the new technique showed more accurate results by following the expectation that T2* decreases with increasing magnetic strength of the background field. It also showed a significant reduction in variability between acquisitions, effectively detecting and minimizing sources of error. From the *in vivo* study, inter-observer variability was also significantly reduced, suggesting the new method has a greater reproducibility between observers.

References:

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2. Tanner MA, et al. Haematologica. 2006; 91:1388-91
3. Altman DG, Bland JM. Statistician. 1983; 32:307-17