Systematic investigation of various strategies for T2* mapping for liver iron quantification in the presence of noise

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TARGET AUDIENCE: Physicists, clinical radiologists and clinical researchers in the field of liver T2* mapping

PURPOSE: To systematically investigate various strategies for T2* mapping for liver iron quantification in the presence of noise.

METHODS: Hemochromatosis is a genetic disease that adversely affects the iron metabolism, resulting in abnormally high iron concentration in various organs, including the liver. Due to its cytotoxic effect, iron chelation therapy may be indicated in severe iron overload. Multiecho gradient-recalled echo (MGRE) T2* mapping is emerging as a promising noninvasive method for monitoring liver iron overload. Due to (super)paramagnetic effect of iron particles, the transverse relaxation rate increases with concentration of iron. Hence the decay time constant T2* (or equivalently the decay rate R2*) may serve as a noninvasive surrogate marker for liver iron concentration.

The complex and magnitude MGRE signal equation with noise can be respectively written as

$s(t) = Ae^{-R_2^* t}e^{i\psi t} + Z$ ... [Eq. 1]

$|s(t)| = Ae^{-R_2^* t} + |Z|$ ... [Eq.2]

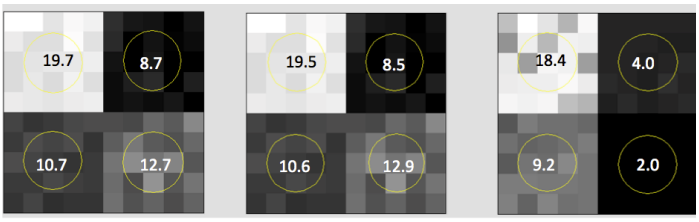

Figure 1: Comparison of different T2* estimation methods on simulated data. The true T2* are 20, 10, 5, and 2.5 ms. Modeling of noise is necessary to correctly estimate short T2*.

where *s(t)* is the echo time-dependent complex signal, A is the scaling factor, R2* the transverse relaxation rate, $e^{i\psi t}$ the phase term, and Z a complex-valued Gaussian random variable with mean 0 and variance σ^2. |Z| is a real-valued Rician random variable with mean $\sigma\sqrt{\pi/2}$ and variance $(2-\pi/2)\sigma^2$ [2].

Complex log-linear fit: One approach is to assume that Z is negligibly small, perform log transform of Eq. 1, $\ln s(t) = \ln A + (-R_2^* + i\psi)t$ and complex-valued linear regression. R2* is the real part of the slope estimate. This method requires acquisition of complex imaging data, which is not routinely done in clinical practice.

Magnitude log-linear fit: Another perhaps more practical approach is to log-transform the magnitude signal Eq. 2 $\ln|s(t)| = \ln A - R_2^* t$ and perform real-valued linear regression. R2* is the regression slope. This method does not require acquisition of complex imaging data.

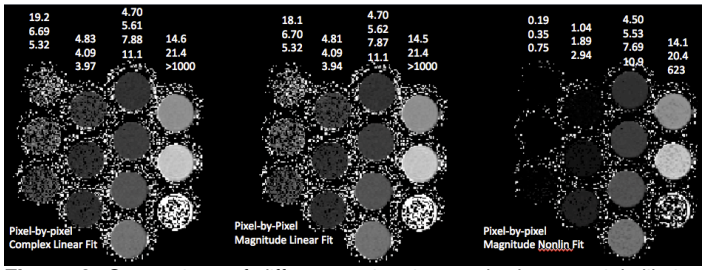

Figure 2: Comparison of different estimation methods on serial dilution $MnCl_2$ phantom data. Monotonic T2* shortening with increasing $MnCl_2$ concentration is only observed with explicit modeling of noise.

Magnitude nonlinear fit with noise: When noise is explicitly modeled as in Eq. 2, log-linear regression approach above is no longer possible. The alternative is to employ iterative nonlinear fitting algorithm using a model $|s(t)| = Ae^{-R_2^* t} + n$, where *n* models the nonzero-mean of Rician noise |Z| [1]. The model parameters A, R_2*, and n are estimated in the least-square sense. Compared to the log-linear fitting methods, the computation is significantly more time-consuming due to the iterative nature of the algorithm.

These three T2* estimation methods were tested against simulated and phantom datasets. Simulated data was constructed based on Eq. 1 on a 10x10 pixel grid, using T2* values of 20, 10, 5, and 2.5ms, TE = 0-20ms with ΔTE 1ms. Complex zero-mean Gaussian noise was added at signal-to-noise ratio (SNR, A/σ) 10. T2* phantom was constructed by dissolving $MnCl_2$ at 13 concentrations, 25, 16, 12, 8, 5, 3.5, 2.5, 2.0, 1.5, 1.0, 0.75, 0.5, and 0 mM as done in [2]. 2D MGRE imaging was performed on a 1.5T whole-body system, TE 1.15-18.86ms with ΔTE 1.61ms, TR 253ms, flip angle 45°. Three T2* mapping methods were applied to assess for accuracy in the simulated data and consistency in the phantom data.

RESULTS/DISCUSSION: In the simulated dataset, the log-linear methods (both complex and magnitude) failed to accurately estimate short T2* values (**Fig 1**), whereas nonlinear fitting with noise accurately estimated short T2*. In the phantom dataset, the log-linear methods did not show monotonic T2* shortening with increasing $MnCl_2$ concentration (**Fig 2**), whereas nonlinear fitting with noise demonstrated expected monotonic T2* shortening. The reason for inaccuracy is likely due to the rapidly decaying signal and rapidly increasing SNR with longer TEs. Since noise does not decay with TE, data dominated by noise exhibit long apparent T2*. Thus, explicit noise modeling is likely required when estimating T2* in severely iron overloaded patients.

CONCLUSION: Log-linear regression method for T2* estimation are inaccurate in estimating short T2* in the presence of noise. Explicit noise modeling is necessary to improve estimation accuracy.

References: [1] Gudbjartsson and Patz. Magn Reson Med. 1995 34(6): 910–914.; [2] Wood et al., Blood. 2005, 106(4): 1460–1465.