Improving T_2^* mapping accuracy by spatially adaptive non local means noise filtering

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Target audience: This work is of interest for basic MR researchers, imaging scientists, clinical scientists and radiologists.

Purpose: Signal-to-noise ratio is the currency spent in MRI to balance the competing constraints of sensitivity and spatiotemporal resolution. SNR can be enhanced by using tailored RF coils, higher magnetic field strength, polarization transfer or simply by averaging. While the latter is the most obvious, it is often difficult to achieve since it may result in scan times which are not clinically acceptable, in particular for applications where data acquisition is dictated by physiological motion or other dynamic constraints. But also techniques using a range of heavy contrast weighting such as T_2^* mapping or diffusion MRI are subject to low SNR. Spatially adaptive non local means (SANLM) noise filtering has been shown to improve MRI image quality while maintaining subtle image details [1]. Non local means filtering has been reported to improve accuracy and inter subject variability in diffusion kurtosis imaging [2]. Despite these findings the use of such de-noising filters in MRI is still limited and commonly a concern with respect to diagnostic accuracy due to the lack of systematic studies investigating their impact on MRI data and diagnostic outcome. Recognizing the need for a systematic evaluation of noise filters, this work investigates the impact of SANLM filtering on T_2^* mapping accuracy using numerical simulations and *in vivo* data obtained for T_2^* mapping of the rat brain at 9.4 T and human myocardial T_2^* mapping at 7.0 T.

Methods: A numerical phantom consisting of 5 spheres with diameters ranging from 1 to 9 voxels at 5 different magnitudes was created. A mono exponential T_2^* decay was simulated for T_2^* times of 5,10,15, and 20ms using 10 echoes (min TE 1ms, ΔTE 1ms). Rician noise (σ=5%) was added resulting in an SNR of the first echo of 18,14,11,7,4 for the magnitudes used and T_2^* of 10ms. SANLM filtering was applied to remove the noise. T_2^* fitting was carried out for noisy and filtered data using a Levenberg Marquardt approach. Truncation of the decay series was performed using a truncation threshold of two times the noise standard deviation. This procedure was repeated in Monte Carlo simulations with 500 trials. Mean absolute T_2^* fitting errors were compared for T_2^* fits of noisy and de-noised images. In vivo measurements of rat brains were carried out on a 9.4 T small animal MRI (Biospec 94/20,Bruker Biospin,Ettlingen,Germany). A multi echo GRE technique was used (TR=620ms;TEs=8;first TE=2.14ms;TE incr.=2.14ms; averages 2, spatial res.=(137×137×1000)μm^3). *In vivo* human cardiac CINE T_2^* data was acquired on a 7.0 T whole body MR system (Siemens Healthcare,Erlangen,Germany) using a cardiac triggered interleaved multi-echo GRE technique (TE=(2.04-10.20)ms, spatial res.=(1.1x1.1x4.0)mm^3). T_2^* mapping of *in vivo* animal and human data was carried out for unfiltered and SANLM filtered images.

Results: Fig. 1a,b show error maps depicting the T_2^* fitting error in milliseconds for fits of noisy and de-noised virtual phantom images with a T_2^* of 10ms. Noise filtering substantially improved T_2^* fitting accuracy, except for very small structures or high contrast edges at very low SNR, which is highlighted by the error difference map shown in Fig. 1c. Performing the analysis for different T_2^* shows that T_2^* fitting accuracy after filtering increases with T_2^* (Fig. 1d), which is not surprising since higher SNR is maintained also for later echoes. Fig. 2 shows examples of *in vivo* T_2^* maps of a rat brain and a human heart calculated prior to and after SANLM filtering. The improved T_2^* map quality after filtering is obvious especially in areas of low SNR, for both, animal and human data.

Discussion: We have investigated the impact of SANLM filtering on T_2^* mapping accuracy using numerical simulations of a virtual phantom with different SNR and T_2^*. The presented results suggest, that SANLM filtering prior to T_2^* mapping can substantially improve T_2^* fitting accuracy. Performance of the SANLM de-noising is suboptimal for subtle structures consisting of only a few voxels and for high-contrast edges at very low SNR. Filtering of *in vivo* images prior to T_2^* fitting resulted in much smoother T_2^* maps, while no obvious filtering artifacts were observed. The fact that *in vivo* T_2^* map quality improved even in regions with low SNR − in contrast to simulations − can be attributed to the larger extend and lower contrast of anatomical structures versus the numerical phantom.

Conclusion: Spatially adaptive non local means filtering can improve T_2^* mapping accuracy but should be used with due caution for very small structures and very low SNR. The *in vivo* results provide encouragement and suggest that SANLM filtering provides means for improving parametric mapping for a broad range of applications including neurovascular and cardiac parametric mapping.

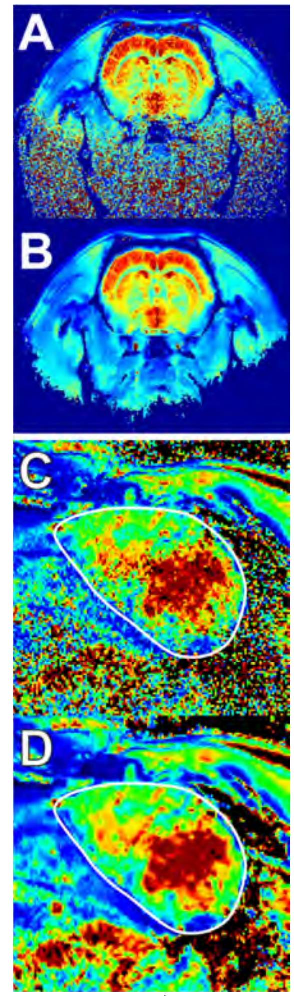

Figure 2: *In vivo* T_2^* maps of a rat brain **(a,b)** and a human heart **(c,d)** for fitting using original **(a,c)** and SANLM filtered images **(b,d).**

References: [1] Manjon et al. (2010) JMRI 31(1):192, [2] Andre et al. (2014) PLoS One 9(4):e94531.

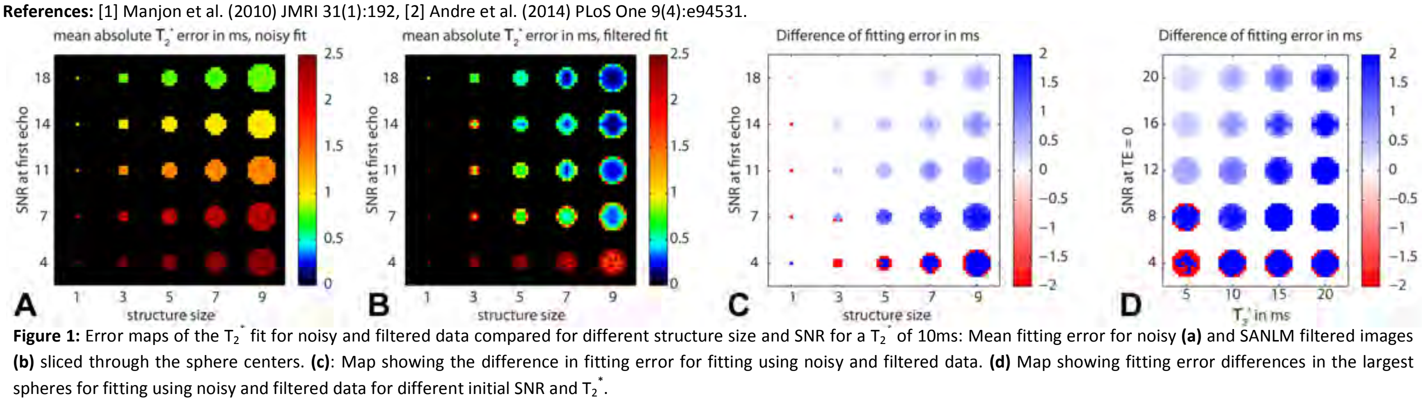

Figure 1: Error maps of the T_2^* fit for noisy and filtered data compared for different structure size and SNR for a T_2^* of 10ms: Mean fitting error for noisy **(a)** and SANLM filtered images **(b)** sliced through the sphere centers. **(c)**: Map showing the difference in fitting error for fitting using noisy and filtered data. **(d)** Map showing fitting error differences in the largest spheres for fitting using noisy and filtered data for different initial SNR and T_2^*.