

Arterial spin labeling (ASL) denoising with Markov random field (MRF) optimization

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Introduction. Arterial spin labeling (ASL) provides a noninvasive way to measure cerebral blood flow (CBF) and has been widely adopted in clinical and basic neuroscience research¹. However, ASL MRI has an intrinsic low signal-to-noise-ratio (SNR). Rather than taking more image pairs for averaging, denoising represents a promising way to increase ASL imaging SNR. A routine procedure is spatially smoothing², but it inevitably blurs the tissue boundaries. This study was to develop an alternative approach for ASL denoising without blurring image details.

Methods. Ten subjects were included from our existing database. Each subject had 40 tagged/control image pairs acquired using a pseudo continuous ASL sequence^{3,4} with TR/TE= 4.2s/17msec, labeling time/post label delay time=1.5/1.5sec, matrix = 64x64x20. CBF quantification was performed using ASLtbx⁵. Mean CBF map was calculated using the 40 pairs as a reference. The following denoising procedures were applied to the first 10 CBF images separately and the resultant denoised maps were averaged and compared with the reference. The method evaluated here was based on the Markov random field (MRF) theory. All voxels in a CBF image were modeled by an undirected graph with Markov property which stated that each voxel is only correlated with its direct neighboring voxels⁶. The MRF model is designed to suppress the random noise within the specified neighborhood but preserve data structure. In other words, the difference between the input and output and between neighboring voxels (the smoothness) should be both as small as possible. To do that, it introduces a weight for each voxel in the neighborhood which is inversely proportional to the local signal gradient. Voxels at the tissue boundaries will get smaller weights than other voxels so the boundary won't be blurred after taking the weighted sum. In homogeneous regions, weights of all neighboring voxels are evenly distributed, and the model works similarly to a regular smoothing process. Spatial smoothing with a 3D isotropic Gaussian kernel was applied to the data as a comparison. Parameters of both the MRF method and Gaussian smoothing were adjusted to yield similar SNR (mean gray matter and white matter signal over the standard deviation of background noise), and the blurring effects were measured with the full-width-at-half-maximum (FWHM) of the medial longitudinal fissure in the axial plane.

Results and discussion. With $SNR_{gain} = 150\%$, FWHM increased $34.55 \pm 15.72\%$ and $3.68 \pm 5.23\%$ for Gaussian and MRF denoising, respectively; for $SNR_{gain} = 400\%$ FWHM increased $74.90 \pm 24.76\%$ and $8.52 \pm 9.71\%$, respectively. Figure 1 showed the same slice of the mean CBF maps from a representative subject processed with different strategies. Gaussian smoothing yielded severe tissue boundary blurring, which worsened as SNR increased. By contrast, MRF did not show perceivable blurring effects even when the SNR improvement was up to 400%. These results clearly demonstrated that by using regionally adaptive filtering, the MRF denoising method successfully reduced random noise in ASL imaging; via using an anisotropic weighting mechanism, the MRF denoising method greatly preserved tissue boundaries. As technique advances have made the high resolution ASL CBF measurement possible, this structure preserving denoising method will have a great potential for spatially more localized brain function studies. Future work is needed to compare the proposed method with other state-of-art denoising methods such as wavelet-denoising² and local principal component analysis⁷.

References. [1] Detre, J.A., Clinical Neurology, 2008; 1: 6-9. [2] Bibic A. et.al., Magn Reson. Mater. Phy., 2010; 23:125-137, [3] Dai et al., MRM, 2008, 60: 1488-97. [4] Wu et al, MRM, 58(5):1020-7. [5] Wang et al., MRI 2008, 26(2):261-9. [6] Boykov, Y., et.al., CVPR, 1998; 648-655. [7] Wang, Regional Coherence-based Denoising (RECODE) for Arterial Spin Labeled Perfusion MRI, ISMRM 2011, p3990.

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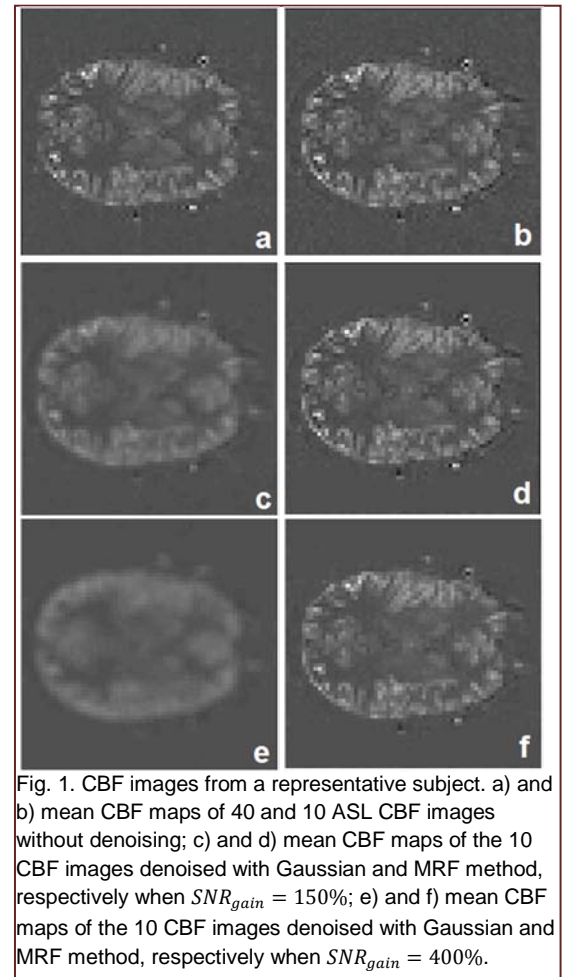


Fig. 1. CBF images from a representative subject. a) and b) mean CBF maps of 40 and 10 ASL CBF images without denoising; c) and d) mean CBF maps of the 10 CBF images denoised with Gaussian and MRF method, respectively when $SNR_{gain} = 150\%$; e) and f) mean CBF maps of the 10 CBF images denoised with Gaussian and MRF method, respectively when $SNR_{gain} = 400\%$.