^{23}Na MRI of the human kidney at 3T: Improving image quality by different image filters

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Introduction

One of the main purposes of the human kidneys is the maintenance and the regulation of the fluid and electrolyte homeostasis. About 80% of the filtrated substances are sodium (^{23}Na) and potassium. The reabsorption of NaCl dominates almost all processes of the kidney. In-vivo MR imaging of sodium is limited due to its electro-physiological characteristics. The combination of relative low in-vivo concentration and MR sensitivity of ^{23}Na compared to ^{1}H results in relative low in-vivo MR signal. Therefore, a logical step forward is to enhance image intensity by applying post-processing filters while Gibb's ringing could also be suppressed. Recently, Fermi filters were applied to sodium MRI [1]. Lowe et al. compared several filters in ^{1}H MRI [2]. To the best of our knowledge, a comparison of such filters in sodium MRI has not been performed so far. Therefore, we compared the performance of different filters (Gaussian, Hamming, and Fermi) in sodium imaging of the human kidney.

Gaussian	$G(x,y)=\frac{1}{\sqrt{2\pi\sigma^2}}\times e^{\frac{(x^2\times y^2)}{(2\sigma^2)}}$
Hamming	$H(v)=0{,}54+0{,}46\times\cos\frac{2\pi v}{v_{max}}$
Fermi	$H(v)=\left(1+\exp\frac{(v-r_f)}{w_f}\right)^{-1}$

Tab. 1: Formulas for filter functions.

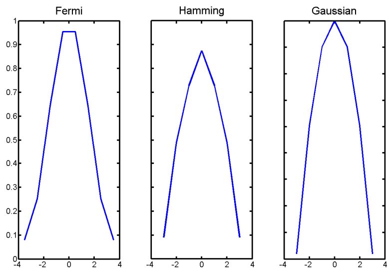

Fig. 1: 1D filter function windows at optimal parameters.

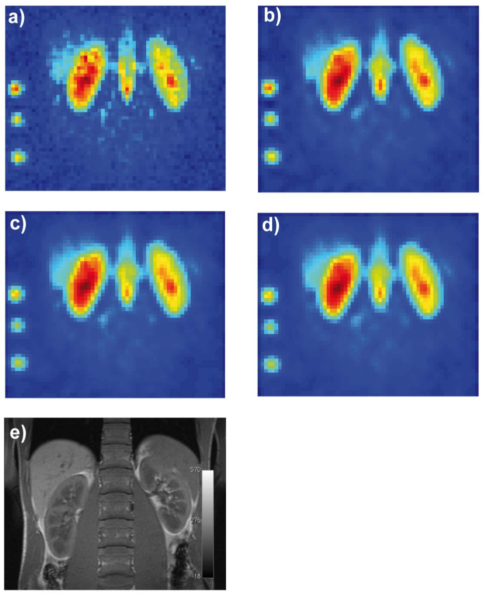

Fig. 2: Results of applying optimal parameterized filters to ^{23}Na MR images. a) Original image, b) Gaussian filtered image, c) Hamming filtered image, d) Fermi filtered image, and e) T1-weighted morphological image as reference. Colors refer to intensity values of ^{23}Na, high signals are depicted in red.

Materials and Methods

Four data sets were acquired on a 3.0 Tesla clinical whole-body MR scanner. For ^{23}Na-signal reception a commercially-available dedicated ^{23}Na-tuned cardiac coil with 8-coil elements was used, consisting of two identical halves with a transmit loop and four receive-only channels each. For sodium imaging, a density adapted three-dimensional gradient-echo sequence with radial trajectories was used for acquisition [3] with TR/TE/FA = 120 ms/ 0.55 ms/ 85°, field of view (FOV) = 320 x 320 mm^2, readout length per spoke = 20 ms, projections = 8000 resulting in a total acquisition time of 16 min. A nominal isotropic spatial resolution of 5 mm was achieved. Imaging was performed during free breathing. To avoid repeated time consuming reconstruction of the images, all filters were applied in image space. All three filters were implemented as 2D symmetric finite impulse response (FIR) filters. Table 1 gives the equations for the three filters. Except for the Hamming filter, all filters are dependent on initial parameters. Optimal parameters were estimated by grid search. Evaluation of filters performance was achieved by calculating SNR and by visual inspection.

Results

Optimal Fermi filter parameter were r=32 and w=2 and σ=10 for the Gaussian filter, respectively. Figure 1 depicts the different filter windows at these parameters while figure 3 shows a plot of filter window size vs. SNR. A peak SNR value is depicted for m=7 for all three filters in one data set. For all four data sets and filters SNR improves compared to the unfiltered cases. Figure 2 indicates sample slices of the corresponding data set shown in Fig. 3. Visual inspection shows clearly the smoothing of the images by the filters. Comparing SNR before and after filtering, on average the SNR is improved by a factor of 3.6 for the Fermi, 3.2 for the Hamming and 3.2 for the Gaussian filter.

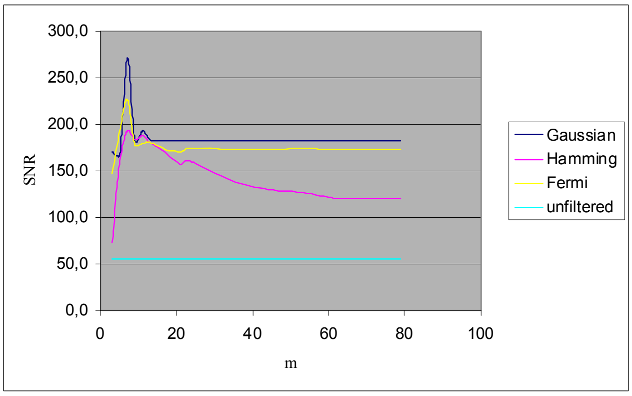

Fig. 3: Plot of SNR at different window sizes (m) for each filter. Gaussian and Fermi filter applied with parameters at σ=10 and r=32 and w=2, respectively.

Discussion

Filtering of sodium MR images is reasonable as the intrinsic low SNR could be significantly improved. Thereby, selecting a particular filter seems not to be a major issue, at least for our experiments, as all three filters improves the SNR by a factor of 3-4. Thereby, using the Fermi filter best results with respect to SNR improvement could be achieved. However, increasing SNR by filtering always reduces the resolution, i.e. the images are blurred and discrimination of renal compartments like medulla and cortex might get more difficult which is important when analysing the ^{23}Na gradient along the cortico-medullary axis. Therefore, a good compromise between filter settings and SNR gain and resolution of the renal structures on the other hand has to be found. Nevertheless, filtering sodium MR images could help to improve the SNR while allowing to restrict image acquisition time to realistic values for a clinical application and to keep a sufficient image resolution.

References

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[3] Nagel AM, et al.,Magn Reson Med. 2009. 62 (6), pp.1565-1573