Optimization of the Determination of the Corticomedullary Sodium Gradient from Na-23 Images of the Human Kidney

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INTRODUCTION

The outer medulla of the kidney normally functions at very low oxygen tension, in part due to high oxygen consumption by the active reabsorption of Na^+ by ion pumps in the medullary thick ascending limb. This process is one of the ways in which a corticomedullary sodium gradient is maintained. The presence of a sodium gradient is a basic renal function that is required for urine concentration. The medullary thick ascending limb is vulnerable to hypoxic injury, which plays an important role in the evolution of hypoxic acute tubular necrosis and impaired renal function. In a rat model of acute tubular necrosis in which histological findings demonstrated outer medullary ATN involving 4% of medullary thick ascending limbs, Maril et al. [1] reported that ^{23}Na MRI showed a 40% change in concentration ratio between the cortex and the inner medulla in the ATN kidney when morphologic tubular injury was still focal and very limited. They concluded that the detection of changes in the corticomedullary sodium gradient might serve as an early indicator of renal damage at an early phase. This study clearly supports the view that the individual corticomedullary sodium gradients in the kidneys of patients should serve as an index of disease progression. We have shown that it is possible to acquire ^{23}Na images of the human kidney at 3T and use these images to determine the individual corticomedullary sodium gradients in each kidney. We have also shown that it is possible to use k-space weighted [2] ^{23}Na to improve the SNR of this examination. In the present work we have evaluated a combination of the k-space weighted and "matched" filtering to optimize the ability to determine the individual corticomedullary sodium gradients.

MATERIALS & METHODS

^{23}Na MR Imaging: Data were acquired on 3.0 T GE Signa short bore twin speed system (GE Healthcare, Milwaukee, WI) equipped with the standard multinuclear option. ^{23}Na MRI was performed using a 3D-GRE sequence modified for multinuclear imaging, with an FOV=38x38x24 cm, matrix size=128x128x16, TE/TR =1.8/30 ms. The short TE was achieved by applying a 66% partial Fourier echo, along with a hard, non-slice selective, 300 µsec RF excitation pulse. A standard acquisition was compared to a weighted k-space sampling in the phase encoding direction according to the diagram shown in Figure 1, maintaining the same amount of total phase-encoding steps. The quadrature surface coil described in reference 1 was used in all of these studies.

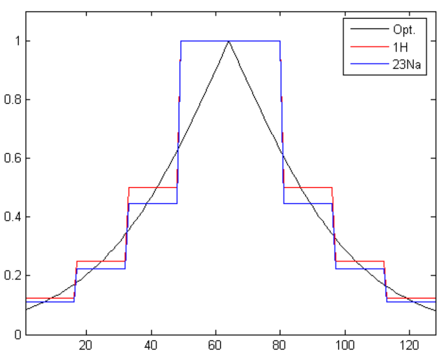
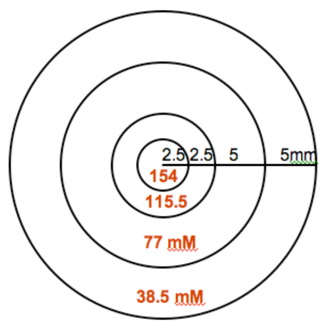
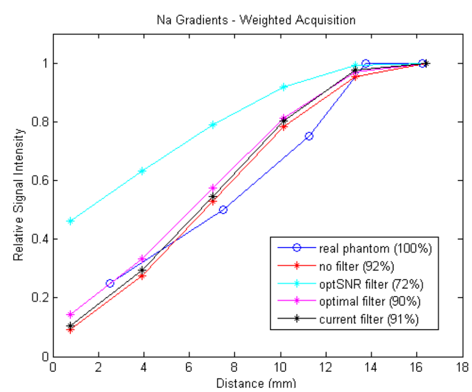


Figure 1. The acquistion weighted scheme used.



e **Figure 2.** The phantom used in these studies.



e **Figure 3.** The measured sodium gradient.

In Vitro Studies: We prepared the phantom shown in Figure 2. The data were acquired and processed off-line. The non-symmetric k-space data was processed by a heterodyne reconstruction algorithm. We then applied a variety of a 2D Fermi filters with a different radii and slopes applied on the time domain data before the 3D Fourier transformation, as was previously described. We employed the agreement factor, r, given by to assess the agreement between the measured and true gradient.

$$r = \sqrt{\sum (true - obs)^2 \Big/ \sum (true)^2}$$

RESULTS

We found a Fermi filter that gave an agreement of about 90% between the measured and true values of the ^{23}Na concentration gradient present in the phantom. This filter increased the SNR by a factor of 1.9 over the Fermi filter we described in Reference 1. We then applied this filter to non-weighted human imaging data. This filter produced a 90% agreement between the ^{23}Na concentration gradient measured using our current filter with an improvement of a factor of 1.6 in SNR.

DISCUSSION

These results show that the SNR of the ^{23}Na images can be improved significantly by a combination of weighted acquisition and Fermi filtering while maintaining the accuracy of the determination of the ^{23}Na concentration gradient in the kidney. This SNR improvement can be employed to reduce the scan time or improve the spatial resolution of the study.

REFERENCES

1. Maril N, Margalit R, Rosen S, Heyman SN, and Degani H. Kidney Int. 69:765-8,2006.
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