Setup for Quick 2D Glomerular Imaging in a Clinical 3 T MRI System

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Target Audience

Scientists and clinicians investigating glomeruli and related kidney diseases

Purpose

The glomerular area is determined by the glomerular size and number and can provide valuable information when evaluating kidney diseases such as glomerulosclerosis and chronic kidney disease (1). The feasibility of glomerular imaging and quantification using MRI was first presented in 2008 (2) and 2011 (3). In vitro rat kidneys labeled with cationized-ferritin and scanned in preclinical scanners with ultra-high-fields (B_0 = 7 T) were used for this purpose. Despite its relevance, the study of glomeruli with MRI has remained unexploited with only a few studies until now (4-5). This is due to the high technical requirements in performing glomerular imaging in terms of both main magnetic field strength and scanning time (reported to be in the order of hours). In this study, we present a setup for glomerular imaging of ex vivo rat kidneys in a 3 T human clinical scanner whereby glomeruli are visible with the imaging being performed in 7 minutes and 40 seconds, a factor ~13 reduction in comparison to, what is to our knowledge, the only study showing glomeruli at 3 T (6).

Methods

One rat kidney was labeled with cationized-ferritin, perfused and dissected following the protocol presented in (2). The extracted rat kidney (Sprague-Dawley rats) was embedded in a tube filled with agarose gel. A purpose-built solenoid transmission/reception (TxRx) resonator was developed and used for the ex vivo ^{1}H-MRI of the rat kidney. Prior to the MR measurement the resonator was tuned and matched to the resonance frequency of 123.25 MHz via a non-magnetic network analyzer (VIA Echo MRI, AEA Technology Inc., USA) since different loadings strongly affect the Q-factor due to the high filling factor of the solenoid coil.

The connection of a self-built transceiver (TxRx) coil to the clinical scanner required special hardware. A custom-built RF coil interface (STARK CONTRAST, Erlangen, Germany) was used which was composed of a frequency power splitter, a ^{1}H switch between linear transmit and receive modes, and an X-nuclei switch between linear or quadrature transmit and receive modes (see Figure 1). For the ^{1}H MRI the signal was generated and acquired in linear mode. The ^{1}H TxRx solenoid RF resonator was connected to the linear port of the RF coil interface and then, the interface was connected to the scanner via the Siemens ODU connector.

The imaging was performed in a 3 T whole body clinical MAGNETOM Trio a Tim system (Siemens Medical, Erlangen, Germany) using a 2D gradient echo sequence with the parameters: TE / TR = 40 / 72 ms, flip angle = 10°, FOV = 28 x 20 mm², slice thickness = 1.5 mm, matrix size = 384 x 276, in-plane resolution = 72 x 72 µm², bandwidth = 50 Hz/pixel, averages = 32 and an acquisition time = 7m40s.

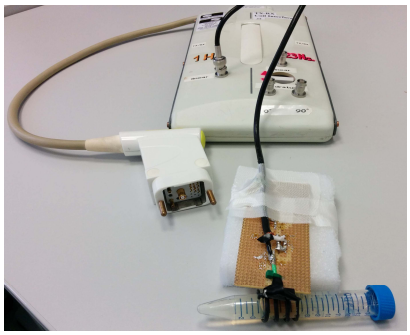

Figure 1 *Ex vivo rat kidney labeled with cationized-ferritin embedded in agarose gel and placed in the purpose built solenoid coil connected to a custom-built RF coil interface*

Results

Cationized-ferritin labeled glomeruli in a rat kidney were imaged ex vivo in a 3 T clinical scanner using a purpose-built solenoid coil. A 2D slice showing glomeruli as dark spots in the cortex was acquired in only 7m40s (Fig. 2). A purpose-built solenoid resonator was successfully developed and connected via a purpose-built interface. The size of the resonator was determined by the kidney to be 18 mm of diameter, 25 mm of length and with 4 turns using copper wire (ø 1.2 mm). The dimensions of the resonator covered the whole kidney and maximized the measured ^{1}H signal intensity in vitro. For balancing purposes at 123.25 MHz, two fixed value capacitors (33 pF) and a variable capacitor in parallel (0.8 - 8 pF) for tuning and in series for matching (136.8 - 144.8 pF) were used. Remotely variable matching and tuning was achieved on a separate circuit board to which the resonance coil was connected directly to reduce ohmic losses. The unloaded to loaded Q-factor ratio was measured to be 17.9/17.6 with negligible variation. The transmit power was adjusted such that the flip angle accounted to 10°. Due to the small dimensions of the solenoid coil the reference voltage needed was 4.3 volts.

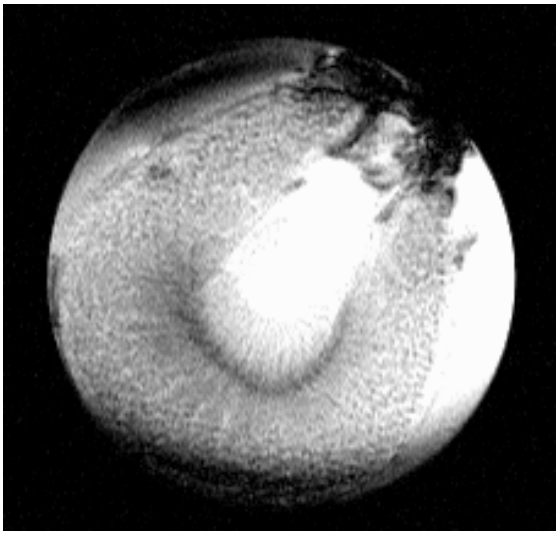

Figure 2 *Ex vivo rat kidney labeled with cationized-ferritin showing glomeruli in the cortex as dark spots. The image was acquired in a 3 T human clinical scanner using a 2D gradient echo sequence in 7 minutes and 40 seconds.*

Discussion

The susceptibility and dephasing effect of cationized-ferritin in the neighboring spins was visible in a 2D T_2* weighted image despite the lower field (3 T) used in this study in comparison to previous studies (>7 T). In 2014, glomeruli were imaged in a 3 T scanner with a minimum acquisition time of 1 hour and 40 minutes using a 3D sequence but even there, glomerular quantification was not possible (6). In this study we demonstrate the feasibility to image glomeruli with more than a factor 13 time reduction using 2D imaging despite partial volume effects. In figure 1, the signal of the cortex is decreased by the sum of the individual effects of the cationized-ferritin labeled glomeruli included in the volume of proton density acquired, i.e. the image displays a limited filtration volume, which itself contains useful qualitative information. The estimation of the glomerular area could be performed with a statistical approach based on either the glomerular number per volume or the mean size of the glomeruli. This is in the scope of our future work.

Conclusion

Although the quantification of glomeruli remains an important research topic, we envisage qualitative glomerular imaging and the estimation of glomerular areas to be of use in the clinical area before the whole kidney 3D assessments given the reduced scanning times needed. Once motion is considered and a more suitable contrast agent is found, a similar image showing glomeruli in a human kidney could be helpful to trained professionals in detecting abnormalities in glomeruli and thereby kidney diseases.

References

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