

Glomerular Imaging of Mouse Kidney using a Dedicated Alderman-Grant Probe

Jorge Chacon Caldera¹, Philipp Krämer¹, Raffi Kalayciyan¹, Lothar R Schad¹, Sabine Neudecker², Stefania Geraci², and Norbert Gretz²

¹Computer Assisted Clinical Medicine, Medical Faculty Mannheim, Heidelberg University, Mannheim, Germany, ²Institute for Medical Technology, Heidelberg University, Mannheim, Germany

Introduction

The filtration of the blood to maintain balance between salt and water and to eliminate waste is performed in the kidneys by the glomeruli. Glomerular number is, therefore, a very important indicator of the health status of the kidneys. Quantification of glomeruli could help diagnose kidney malfunctioning and prevent chronic kidney disease (CKD).

In recent publications, Glomeruli in rat and mouse kidneys have been imaged using solenoid coils [1] and quantified using a surface cryogenic probe [2] in MRI but disadvantages and complications appear when using those designs. A more appropriate probe design can be used to image the glomeruli. There are four main requirements: low cost, good coil profile homogeneity, good response in ultra high frequency (approximately 400MHz), and with dimensions that can be able to accommodate the containers where the samples are placed without compromising the Q factor, Inductance (L), field of view (FOV), sensitivity, B₁, or profile homogeneity of the images. An Alderman-Grant resonator (AGR) is a volumetric probe. It has good response in UHF so it can be flexible in the dimensions while being efficient at high fields [3].

A cost effective AGR probe was built to image glomeruli in mouse kidneys solving inhomogeneity profile problems that arise when using a surface coil.

Materials and Methods

Construction of the coil: The dimensions were determined by the sample's container size to be: diameter=16mm; Th_{segment}=12mm; L_{segment}=28mm; Th_w=9mm; L_w=24mm. Two guard rings were used and placed inside of the coil. The guardian rings had a diameter D_g=13.5mm and a thickness Th_g=6mm each. Copper tape was used to build the coil. Resonant frequency was achieved using C₀=10pF, from where the inductance of the coil was calculated to be L_{calculated}=16.65nH.

Balance improvement between the segments was achieved by using variable capacitors (5.3–16 pF) initially at 10pF on the connections between both superior wings. Balance was maintained as possible but it is clear that perfect balance cannot be achieved since the connection point is on the bottom side of the coil and on one half of it. The coil was connected using a "hot point" the initial Alderman-Grant suggestion described in [4]. Ground was connected to a guard ring that couples with the wings of the coil.

Tuning and matching were achieved by using variable capacitors 0-10 pF.

Glomerular Imaging: The coil was used to image glomeruli labeled with Ferritin as described in [2]. Imaging was performed using a 3D FLASH sequence using the following parameters: Flip angle: 15°; TR=50ms; TE=7.972ms; averages=20; matrix size=434x316x216; resolution=30μm/pixel (isotropic), Scan time:12h5m. The images taken with the volumetric AGR probe were obtained using a 3D FLASH sequence with the following parameters: Flip angle: 15°; TR=50ms; TE=6.412ms; averages=8; matrix size=608x378x308; resolution=25μm/pixel (isotropic), scan time:8h29m. The images were acquired using a 9.4T Bruker BioSpec 94/20USR small animal scanner (Bruker BioSpin GmbH, Ettlingen, Germany) and reconstructed using MATLAB.

Results

An Alderman-Grant resonator was built. Mouse kidney images were acquired with a Bruker surface CryoProbe and the dedicated AGR probe.

Coil: The properties and response of the probe were measured on a network analyzer, and found to be: Unloaded: BW=4.79MHz for f=402.66MHz. Q_{unloaded}=167.84. Loaded: BW=7.76MHz for f=399.46MHz. Q_{loaded}=102.95. Q_{unloaded}/Q_{loaded}=1.630. G_{max}=-40dB at 400Mhz.

Imaging: The same kidney was imaged using both probes. From the slab obtained, the center slice of each axis (coronal, sagittal and transverse) is presented in Figure 2 for a visual comparison of profile homogeneity. Images A to C were acquired with a surface cryogenic coil; images from D to F were acquired with the AGR probe.

Discussion and Conclusion

Despite the great signal-to-noise ratio (SNR) and sensitivity provided by the cryogenic surface coils, inhomogeneity coil profile problems arise when imaging mouse kidneys. This complicates the segmentation and the quantification of the glomerular number. A volumetric probe suits this type of imaging better than a surface coil. While solenoid probe designs provide good sensitivity, its use is preferred at low frequencies or for very small samples to avoid self-resonance. This limits the dimensions, L, and therefore Q. Additional disadvantages that the solenoid coil could present are: The field is heterogeneous near the edges (as the length of the coil decreases, the magnetic field distribution tends towards the highly heterogeneous distribution produced by the surface coil [5]). B₁ field is created along the main axis of the coil, which forces the sample to be placed perpendicular to the main static field B₀. This could complicate the access of the sample to the bore.

Glomeruli are visible in images acquired with the AGR probe. As expected, the volumetric AGR probe solved the inhomogeneous coil profile problem that was present when using the cryogenic surface coil. The obvious compromise that has to be done when using a non-cryogenic probe is the reduction of SNR due to the increased resistance of the circuitry at room temperature. To overcome this reduction of SNR, the averages had to be increased to 20. There was a reduction in the resolution and FOV causing a reduction in precision on volume and diameter information of glomeruli. Solving this problem will be the scope of our future work. Due to the change of imaging parameters, no exact quantitative comparison can be made at this point but the profile homogeneity is proven. An isometric resolution of 30μm is enough to observe them appearing as dark spots (see figure 3). It can be concluded then, that the Alderman-Grant dedicated coil is a good choice for glomerular imaging.

References

- [1] Vegh V et al. Magnetic Resonance Imaging 30 (2012) 1177–1185 [2] Heilmann M et al. Nephrol Dial Transplant (2012) 27: 100–107 [3] Leroy-Willig, A., et al., 1985; Cross, T.A., et al., 1985 [4] Leroy-Willig et al. MR. IN MEDICINE 2, 20-28 (1985) [5] Mispelter. NMR probeheads for biophysical and biomedical experiments

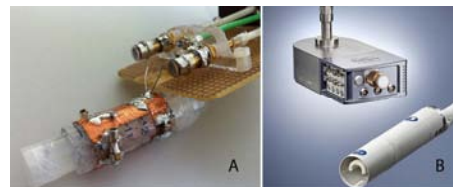


Figure 1: A) Dedicated AGR probe. B) Bruker CryoProbe. Image obtained from Bruker website.

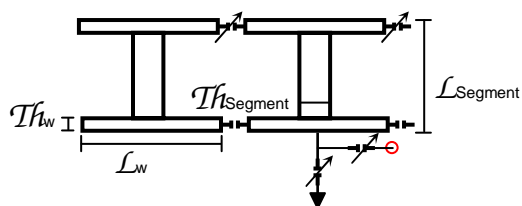


Figure 2: Schematic design of the Alderman-Grant Coil

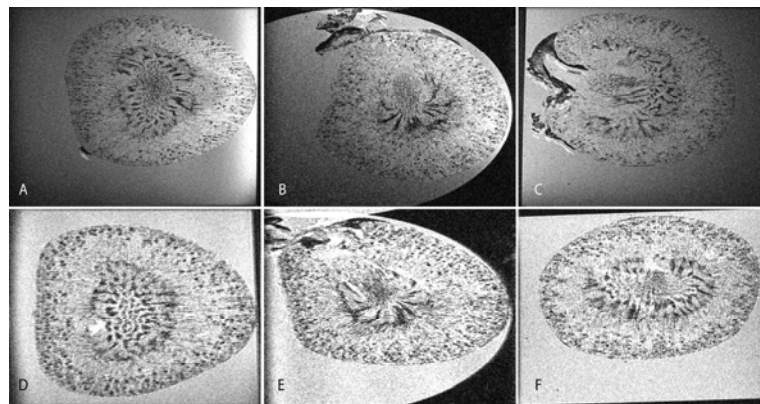


Figure 3: Improved homogeneity shown in centre slices in the slab for each axis. A to C were acquired with a cryogenic surface probe. D to F were acquired with a dedicated Alderman-Grant probe.