CONCENTRATING AND CLEARING MECHANISM OF THE KIDNEY REVEALED BY QSM AT ULTRA-SHORT TE

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Target Audience: Scientists and clinicians interested in renal physiology, quantitative susceptibility mapping (QSM), and ultrashort echo time (UTE)

Purpose

Dynamic contrast-enhanced (DCE) MRI can provide key insight into renal function (1). In addition to the T_1 quenching limitation associated with Gadolinium (Gd) complex, there are also significant T_2* effects that create blooming artifacts (2) in certain areas of the kidney and bladder. This is due to the fact that Gd concentration is so high, T_2* then becomes shorter than TE. One protocol used to alleviate this problem is the ultrashort echo time (UTE) sequence (3). In the present study, we applied UTE with a TE of 20 μs and we still see the T_2* blooming effect. We applied quantitative susceptibility mapping (QSM) to overcome this limitation and to quantify the contrast agent concentration. The resulting positive susceptibility enhancement confirmed the very high concentration of the agent. The temporal dynamics revealed the extraordinary mechanism of the kidney to concentrate and rid of the contrast agent. UTE-QSM can complement magnitude UTE and offer a powerful tool to study renal physiology.

Methods

Biological support: Mice (n=5) were imaged longitudinally at 6 points (3, 5, 7, 9, 13, 17 weeks). Animals were under isoflurane anesthesia and breathing freely. Contrast agent (gadofosveset trisodium) was injected as a bolus via tail vein catheter at a dose of 0.03 mmol/kg. MRI: Imaging was performed with a cryogenic surface coil on a 7T Bruker system. A 3D UTE (center out) radial sequence was used to sample 13 uniform subvolumes of Fourier space (total views=40222, polar undersampling=2, TR=2.5ms, TE=20μs, FA=10°). Images were reconstructed by interleaving and sharing projections from the unique subvolumes using a sliding window approach, a technique known as radial keyhole imaging (4). This yielded a 3D image (125×125×125 μm^3 resolution) every 7.7 sec over 50 min (390 time points) of contrast enhancement and clearance. Post-processing and analysis: The local tissue phase of each keyhole dataset was extracted using an integrated Laplacian-based phase unwrapping and background phase removal (5). QSM was then calculated using an LSQR method (6). QSM values reported in this study were based on an effective TE of 1 ms considering the 2 ms radial readout duration. A temporal maximum intensity project (tMIP) was produced to visualize the maximum susceptibility enhancement in the kidney. Time intensity curves (magnitude and QSM) were filtered using a moving average. Susceptibility values were measured from tMIPs in a center ROI of the inner medulla and plotted as a function of age. Linear regression was performed to determine the relation of maximum susceptibility with age.

Results

Fig. 1 compares magnitude and QSM of the DCE dataset. The blooming artifact in the magnitude corresponds spatially and temporally to an area of positive susceptibility enhancement in the inner medulla (green arrows). A QSM tMIP was calculated in the inner medulla (Fig. 2). Maximum enhancement occurs deep in the inner medulla towards the renal papilla (black arrows). Fig. 3 shows QSM tMIP at 6 age points with a corresponding plot. QSM (ppm) in the inner medulla decreased with age (x) as follows (linear regression): QSM = $-0.04x+1.3$ (R^2=0.84). We measured a maximum QSM value of 1.57 ppm in one kidney at 3 weeks. Based on phantom studies of various Gd concentrations (QSM = $0.27x+0.45$, where x is mM Gd), the inner medulla had a concentration of 4.2 mM Gd at that instant.

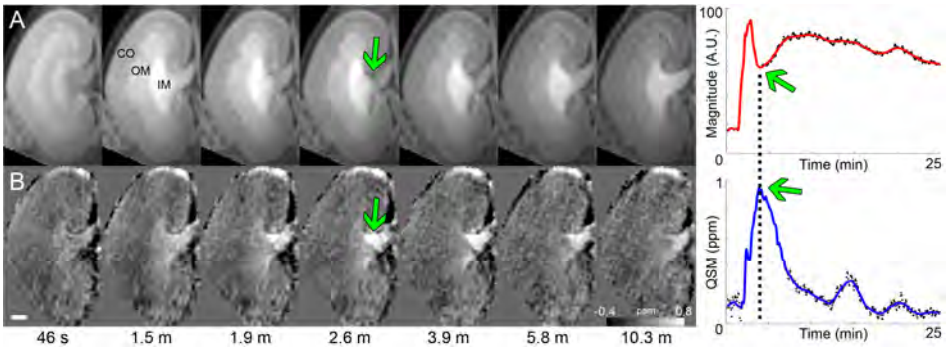

Fig. 1. Comparison of magnitude and QSM. A: Magnitude at 7 time points with corresponding time intensity curve. B: QSM with corresponding plot. Green arrows in images point to critical region. Green arrows in plots point to crucial time point. CO=cortex, OM=outer medulla, IM=inner medulla. Scalebar=1 mm.

Discussion and Conclusion

DCE-MRI is a useful tool to study function and characterize disease in a variety of organ systems. UTE typically resolves artifacts that are found in Cartesian imaging such as GRE for DCE. In the present study, we found the T_2* decay is significant even in UTE for DCE of the kidney. In the QSM images of the dataset, we found strong positive susceptibility values in the same region at the same time of the blooming artifact in the magnitude image. The large positive susceptibilities confirm the presence of the concentrated Gd contrast agent, a paramagnetic source. These results demonstrate the strong concentrating mechanism of the renal system. In conclusion, QSM can improve our ability to quantify very high concentrations of the contrast agent encountered in studies of renal function.

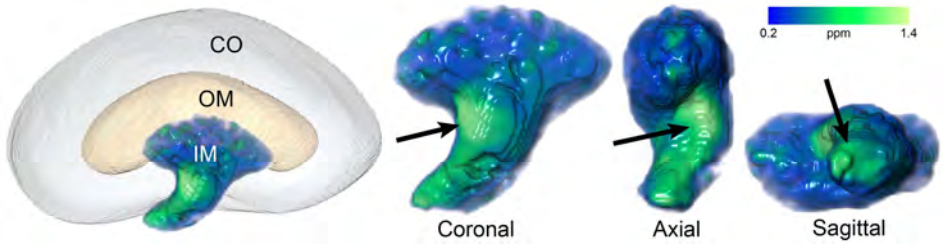

Fig. 2. Volume rendering of QSM tMIP in inner medulla. Arrows point to area of maximum enhancement. CO=cortex, OM=outer medulla, IM=inner medulla.

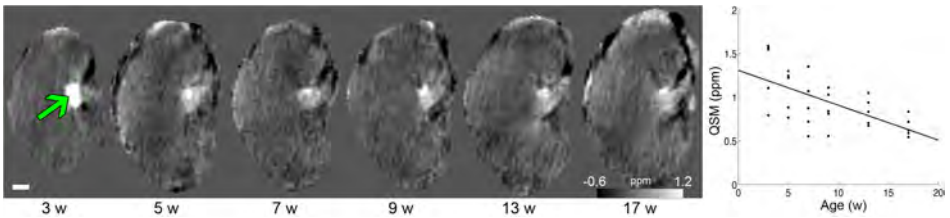

Fig. 3. QSM tMIP with age. Plot: QSM in inner medulla center vs. age (n=5 animals).

References

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