THREE-DIMENSIONAL ULTRA-SHORT ECHO TIME (UTE) 3.0T MRI FOR IMAGING KIDNEY STONES

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INTRODUCTION: Nephrolithiasis is a common chronic kidney disease that has been associated with a number of other diseases. Approximately 11% of men and 7% of women will have a kidney stone event in their lives, and many of these patients are likely to become repeat stone formers [1]. Computed tomography (CT) has been established as the method of choice for kidney stone imaging with a 90-100% sensitivity [2]. A drawback of CT scanning is the associated ionizing radiation exposure, especially in vulnerable patient groups including children and pregnant women, as well as in patients requiring multiple repeated scans. Magnetic resonance imaging (MRI) is a potential alternative to CT in patients in whom radiation exposure is an issue. However, conventional MRI techniques are insensitive for direct imaging of kidney stones, which appear as a non-specific signal void and can therefore be confused with blood, gas, and tumors (Figure 1). Kidney stones have very short T2 time constant, which makes the RF signal emitted by them decay very rapidly, and therefore, the stones appear dark with the echo times (TEs) available in conventional MRI techniques.

With the advent of ultra-short echo time (UTE) MRI sequences, adequate imaging of kidney stones becomes possible [3]. UTE sequences use half excitation RF pulses combined with radial acquisition starting from the k-space center [4], which allows the shortest TE possible to be achieved in the range of tens of micro seconds. However, UTE sequences are sensitive to delays in coil switching and eddy currents which may produce a mottled effect. Recently, Yassin et al [3] implemented a 2D UTE imaging sequence on a 1.5T scanner to characterize the relaxation times of different kidney stone specimens in vitro. The imaging sequence required more than 5 minutes of scan time and detected 58% of the stones with a size threshold of 0.9 cm for stone detection. This sub-optimal performance may be attributed to the use of a 2D imaging sequence and imaging on a 1.5T scanner. The point-wise encoding time reduction with radial acquisition (PETRA) 3D UTE imaging sequence has been recently developed [5], leveraging the capabilities of 3D imaging for improving SNR and spatial resolution. In this study, we optimize the PETRA sequence for in vitro imaging of kidney stones at 3.0T.

Figure 1. MRI artifacts mimicking kidney stones. Signal void due to T2* artifact.

METHODS: Five 50-mL vials were filled with an agarose-based material that has T1 and T2 values similar to those in the kidney, in which eight kidney stones of different sizes and compositions were inserted (Figure 2 and Table 1). The phantom was imaged using the 3D PETRA pulse sequence on a 3.0T Siemens MRI scanner using a commercial knee coil. In the PETRA sequence, the outer k-space is filled with radial half-projections whereas the k-space center is measured point-wise on a Cartesian trajectory [5]. Further, the imaging gradients are switched on prior to excitation, and very short RF excitation pulses with wide bandwidth are used to equally excite the whole volume regardless of the imaging gradient strength [4].

The imaging parameters were as follows: flip angle = 6°; repetition time (TR) = 25 ms; first echo time (TE1) = 0.07 ms; second echo time (TE2) = 15 ms; slice thickness = 0.59 mm; field of view (FOV) = 150×150 mm^2; matrix = 256×256; number of radials = 2500; and scan time = 65 s. During image reconstruction, the longer TE image was subtracted from the shorter TE image, which removed the signals from the background tissues and left only the signals from the stones. The imaging sequence was repeated with different TEs ranging from 0.1 to 15 ms to measure T2 time constants of the stones.

Figure 2. Picture of phantom.

RESULTS: Figure 3 shows representative 2D cross-sectional and 3D maximum intensity projection (MIP) images of the phantom. The imaging sequence successfully detected all the stones and showed them with high resolution, such that a sub-millimeter stone fraction was successfully detected. The 3D images provide better information about the stone shape, orientation, and size. The resulting T2 values ranged from 3.8 to 8.5 ms, which varied with different stone compositions, as shown in Table 1.

DISCUSSION AND CONCLUSIONS: The 3D PETRA pulse sequence design as well as its 3D nature of data acquisition combined with imaging at 3.0T field strength allowed for detecting sub-millimeter stones in one fifth of the scan time used for 2D UTE imaging at 1.5T [3]. Compared to conventional 2D UTE sequences, PETRA provides much shorter TE over the whole k-space, which allows for better imaging of tissues with very short T2. The preliminary results in this study show the possibility of using PETRA for imaging kidney stones in vivo with high resolution and reasonable scan time. Future work includes optimizing the sequence for imaging kidney stone patients with the phased-array pelvis coil and addressing potential artifacts associated with in vivo imaging. The developed imaging sequence could serve as an alternative technique for imaging vulnerable patients with concerns for radiation exposure, and it could be added to other MRI sequences for a comprehensive evaluation of the genitourinary system that includes scanning for stones.

REFERENCES: [1] Review Urol,12:e86-96; [2] Am J Roent, 172:1485-90; [3] Acad Rad, 19:1566-72;; [4] NMR Biomed, 19:765-80; [5] Magn Reson Med, 67:510-8.

Table 1. Characterization of imaged stones.

Vial #	# Stones	Size (mm)	Composition	T2 (ms)
1	3	2, 5, 7	70% Uric Acid 30% Ca Ox m.	5.2
2	2	3, 4	70% Brushite 20% Apatite 10% Ca Ox dih.	3.8
3	1	3	100% Ca Ox mon.	8.5
4	1	4	50% Ca Ox mon. 40% Ca Ox dih. 10% Apatite	6.8
5	1	4	80% Ca Ox mon. 10% Ca Ox dih. 10% Apatite	7.9

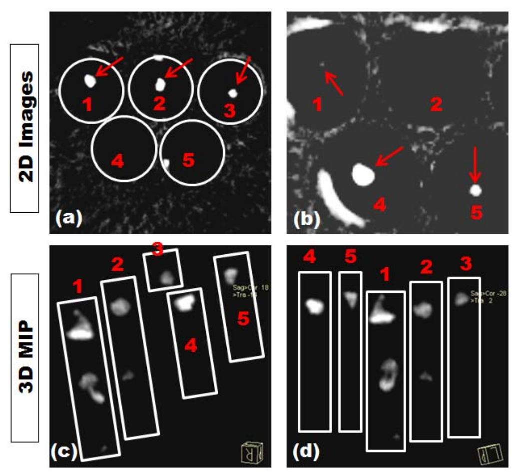

Figure 3. Phantom results. (a,b) Two-dimensional images showing cross-sections of the stones (arrows). Image ‘b’ shows a particle fractioned from a stone in tube #1, which was detected by the imaging sequence. (c,d) 3D maximum intensity projection (MIP) reconstruction showing the stones from different angles, which clearly reveal the stones’ shapes.