In Vitro Imaging of Kidney Stones in Pig Kidneys with Ultra-short Echo-time MRI

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INTRODUCTION: Nephrolithiasis is a common chronic kidney disease, second only to hypertension. Approximately 11% of men and 7% of women will have a kidney stone event in their lives, and these numbers appear to be increasing [1]. Many of these patients are likely to be repeated stone formers with 40% likelihood of developing a second stone in 5 years [2]. Computed tomography (CT) has been established as the method of choice for kidney stone imaging with a 90-100% sensitivity [3]. Further, the recent introduction of dual-energy CT (DECT) scanners adds the capability of differentiating uric-acid (UA) from non-UA stones [4]. Nevertheless, a drawback of CT scanning is the associated ionizing radiation exposure, which may be a concern in certain groups of patients, e.g. children, pregnant women, and frequent stone formers.

MRI has shown a huge potential for noninvasive evaluation of multiple parameters of renal function such as glomerular filtration, tubular concentration, regional perfusion, water movements, and oxygenation, as well as demonstrating secondary effects of renal obstruction [5]. However, current MRI pulse sequences with conventional echo times (TE's) are insensitive to direct imaging of kidney stones due to the stones' very short T2 time constants (few ms). This results in the stones appearing as a non-specific signal void that can be confused with blood, gas, or tumors, although stone visibility is improved with larger stone size (> 1 cm) and in the presence of high signal intensity from surrounding urine [6]. Nevertheless, with the development of ultra-short echo time (UTE) MRI sequences, adequate imaging of kidney stones becomes possible [7]. The UTE sequence design allows for TE's in the range of tens of microseconds, which provides the opportunity for imaging tissues with rapid signal decay, e.g. kidney stones.

Although a few studies investigated imaging stones in certain experimental settings, e.g. in gel phantoms and using volumetric head or knee coils [7], no study so far investigated the results of imaging stones with natural surroundings (inside kidneys) and using the body surface coil (which is typically used for in vivo imaging), which is the purpose of this work.

METHODS: A total of 24 kidney stones passed / extracted from patients were obtained. The stones represent eight different types (confirmed by micro CT): calcium oxalate monohydrate (COM), calcium oxalate dehydrate (COD), brushite, apatite, uric acid, struvite, cystine, and mixed-composition. Each stone type is represented by three stones of different sizes: small (2-3 mm), medium (4-6 mm), and large (7-10 mm). A total of eight pig kidneys, purchased from a local meat store, were used in the experiments. Three stones (large, medium, and small) of the same type were inserted in each kidney in different calyces using a small cut, which was sutured after inserting the stone (Figure 1(a)). The stones were stacked in a small plastic container, which was filled with water and covered with a sealed lid (Figure 1(b)).

The kidneys were imaged on a Siemens Skyra 3T MRI scanner (Siemens Healthcare, Erlangen, Germany) using a 18-channel body surface coil. The point-wise encoding time reduction with radial acquisition (PETRA) UTE pulse sequence was used for imaging the stones [8]. In the PETRA pulse sequence (Figure 2(a)), the outer k-space is filled with radial half-projections, whereas the k-space center is measured point-wise on a Cartesian trajectory (Figure 2(b)). Gradient ramping delays and associated eddy current artifacts are removed by turning on the imaging gradients prior to excitation. Further, short RF excitation pulses with wide bandwidth are used to equally excite the whole volume regardless of the imaging gradient strength. 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 = 0.79 mm; field of view (FOV) = 280×280 mm^2; matrix = 352×352; number of radials = 2500; bandwidth = 1895 Hz/pixel; number of averages = 1; and scan time = 3:21 min. During image reconstruction, the longer-TE image was automatically subtracted from the shorter-TE image, which removed the signals from the background tissues and left only the signals from the stones.

RESULTS AND DISCUSSION: The MRI images showed all stones with different types and sizes. The resulting images clearly showed the stones' shape with high resolution (Figure 3). Although efforts were made to avoid air bubbles in the imaged container, air gaps still existed inside some of the kidneys, which resulted in some artifacts in the images.

The current study shows the potential of using MRI for in vitro imaging of stones in kidneys using the body surface coil, which is one step closer to in vivo imaging than previous studies that used gel phantoms imaged using a volume (e.g. head or knee) coil. All stones were successfully visualized in the resulting images. Using the body surface coil and large FOV did not affect the stones visualization, which is promising for successful in vivo imaging in the future. It should be noted that some difficulties were faced, e.g. the existence of air bubble in the imaged container, which should not pose a difficulty for in vivo imaging, which is our next research step for this project.

Although CT is the modality of choice for imaging kidney stones, the developed technique could serve as an alternative means for imaging vulnerable patients with concerns for radiation exposure, e.g. younger patients, pregnant women (or those of childbearing age), or repeated stone formers. It could be also added to abdominal MRI protocols for comprehensive evaluation of the genitourinary system including scanning for stones.

CONCLUSIONS: MRI has the potential for imaging kidney stones of different types and sizes. If successful for in vivo imaging, the developed technique could be a valuable alternative to CT for imaging patients with higher sensitivity to radiation exposure.

REFERENCES: [1] Eur Urol 62:160-5; [2] N Engl J Med 363:954-63; [3] AJR 172:1485-90; [4] Radiology 250:813-20; [5] Abdom Imaging 28:164-75; [6] J Magn Reson Imaging 32:1012-23; [7] Acad Radiol 19:1566-72; [8] Magn Reson Med 67:510-8.

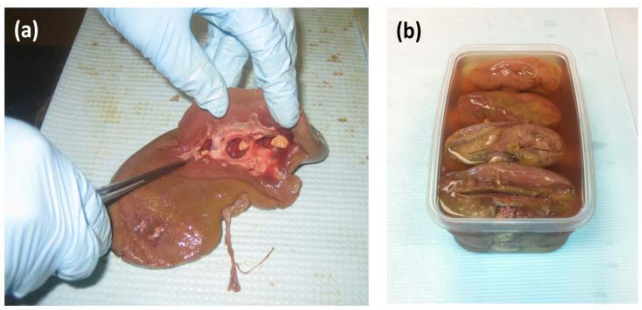

Figure 1. Kidneys preparation. (a) Three stones of the same type, but with different sizes (small, medium, and large), were inserted in different calyces of each pig kidney. The stones are inserted inside the calyces using small incisions, which were sutured afterwards to avoid stone movement. This picture was taken after the MRI scan to show stones positions. (b) Different kidneys were stacked in a plastic pin, which was then filled with water and covered with a sealed lid.

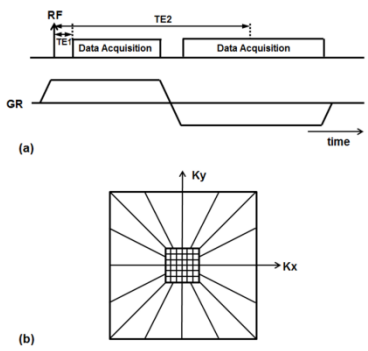

Figure 2. UTE PETRA pulse sequence. (a) Radial acquisition of k-space periphery, where the gradients are ramped before RF excitation. (b) k-space sampling, where the k-space center is acquired in Cartesian fashion.

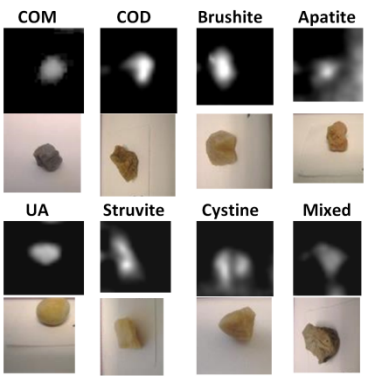

Figure 3. Different kidney stones imaged with MRI, and the actual stones.