Detection of Acute Renal Ischemia in a Swine Model with BOLD MR Imaging

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INTRODUCTION

Acute renal ischemia is a clinical problem resulting from the cessation of blood flow to the kidney due to a variety of causes such as renal artery stenosis and obstruction. Due to the lack of diagnostic techniques specific for renal ischemia, ischemic conditions may be present but remain undiagnosed until further complications arise. Therefore, a non-invasive imaging technique would be advantageous. Blood oxygen level dependent (BOLD) MR imaging can provide information on renal function by measuring intrarenal oxygenation through the spin-spin relaxation rate, $R2^*$. The technique was validated by Prasad *et al.* [1] and used in studies investigating the effects of pharmacological agents [2] and water diuresis [3] on the kidney. However, BOLD MR imaging has not been used to measure renal ischemia due to vascular compromise. The objective of this study is to assess the potential of BOLD MR imaging to detect acute renal ischemia.

MATERIALS AND METHODS

Five medium sized (50-65 lb) pigs were studied under a protocol approved by the University of Wisconsin Research Animal Resources Center. Pigs were anesthetized and a balloon catheter was placed into the renal artery. MR imaging was performed on a 1.5 T whole-body scanner (Signa LX, GE Medical Systems, Milwaukee, WI) with a cardiac or torso phased array coil. A multi-gradient echo (mGRE) sequence was used to acquire sixteen T2* weighted images (TR/TE/Flip = 87ms/8.0-44.8ms/40°). Three axial slices were prescribed per kidney with a FOV of 26 cm, matrix of 256x128, NEX of 1, and slice thickness of 10 mm. Breathing was suspended for a scan time of fifteen seconds per slice. Baseline and inflated balloon catheter measurements were obtained. Color R2* maps were calculated offline from each set of sixteen mGRE images (Figure 1). Average R2* values for the medulla and cortex were obtained through analysis of the three slices. The R2* changes in the cortex and medulla were calculated. Two-tailed student paired t-tests were used to determine significance ($p \leq 0.05$).

RESULTS AND DISCUSSION

Average R2* values are summarized in Table 1. The average baseline R2* values were 13.7 ± 0.5 s^{-1} for the cortex and 19.3 ± 2.2 s^{-1} for the medulla. This matched well with normal renal R2* values present in the literature [1-3] and the physiological nature of the kidney [4]. Baseline R2* values ranged from 12.6-15.9 s^{-1} for the cortex and 15.6 – 25.3 s^{-1} in the medulla. Inflation of the balloon catheter occluded the renal artery and ischemic conditions were created. Four out of five pigs displayed an instantaneous R2* change. However, one pig exhibited only a slight cortical change and no real medullary change. This may be indicative of inadequate blockage by the balloon catheter or accessory arteries feeding the kidney with oxygenated blood. During occlusion of the renal artery, the range of R2* values was 19.4-40.6 s^{-1} (mean = 24.9 ± 7.6 s^{-1}) and 26.7 – 40.9 s^{-1} (mean = 31.9 ± 5.5) in the cortex and medulla respectively. The average change was 11.2 s^{-1} and 12.6 s^{-1} in the cortex and medulla respectively. Two-tailed paired t-tests indicated significance for cortical ($p \leq 0.04$) and medullary ($p \leq 0.02$) R2* changes. A threshold for detecting renal ischemia was established to distinguish ischemic kidneys. R2* values higher than twenty in the cortex and thirty in the medulla corresponded to acute renal ischemia.

CONCLUSIONS

In the swine model, a significantly higher R2* value is present in the cortex and medulla of an acute ischemic kidney. BOLD MR is a sensitive imaging technique that can detect the intrarenal oxygenation differences and has potential as a diagnostic tool for the detection of acute renal ischemia.
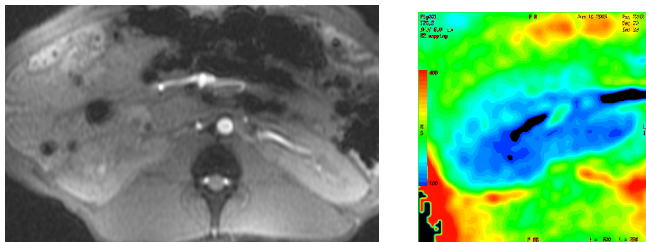
Cortex			Medulla		
Pre	Occluded	ΔR2*	Pre	Occluded	ΔR2*
14.1 ± 1.0	27.1 ± 3.3	13.0	17.3 ± 1.1	33.5 ± 2.3	16.2
13.3 ± 0.6	35.7 ± 3.9	22.4	18.0 ± 1.0	35.1 ± 2.4	17.1
14.1 ± 1.2	20.3 ± 0.8	6.2	19.5 ± 1.5	30.0 ± 3.4	10.5
13.1 ± 0.4	15.4 ± 0.3	2.3	22.9 ± 2.8	23.5 ± 0.6	0.6
13.9 ± 0.8	25.8 ± 1.6	11.9	18.8 ± 2.2	37.6 ± 3.2	18.8

Table 1: Summary of Axial R2* Values. Each row represents measurements from a separate pig experiment. R2* values are expressed as mean ± SD and have units s^{-1}.

Figure 1: (Left) Axial mGRE image. Each BOLD scan consists of three slices of sixteen images with increasing echo times.

(Right) R2* Map for Right Kidney. ROIs are averaged to acquire R2* values for the kidney's cortex and medulla. In this R2* map, the cortex is shown as dark blue and a medulla is light green.

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