FUNCTIONAL EVALUATION OF ACUTE ISCHEMIA/REPERFUSION INJURY USING BOLD AND ARTERIAL SPIN LABELING MRI

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Purpose:

Ischemia/reperfusion (IR) injury is considered the leading cause of acute renal failure (ARF), and frequently occurs in clinic, such as renal transplantation [1,2]. During renal ischemia, the oxygen balance is vulnerable and would be titled in reperfusion phase due to increased demand for tubular transport [3]. Meanwhile, ischemia and subsequent reperfusion result in increased injury through decreasing microvascular blood flow [4]. Recent experimental researches have been conducted but hampered by simultaneous evaluations of oxygenation and perfusion. The purpose of our study is to investigate noninvasive monitoring by using BOLD and ASL techniques to evaluate oxygenation and perfusion, which potentially allow the early detection of renal pathology and function following normothermic IR injury.

Materials and Methods :

MRI: Four healthy male New Zealand White rabbits were examined in the unilateral renal IR injury experiment after anesthetization. Artery of the left kidney was ligated with silk line for 40 minutes. MR scans were performed before and after ligation on 1.5T MR scanner (GE Medical Systems, Milwaukee, WI, USA), as well as the reperfusions. The right kidneys were regarded as the control group. Detail flow chart was shown in Fig. 1. BOLD MRI was scanned with multiple TE (2.2-26.2 ms, 3.4ms echo spacing), TR=120ms, FA=45°, slice thickness=5mm with a 0.5mm gap, matrix=96×96, FOV=180mm. Axial FAIR-ASL (flow-sensitive alternating inversion recovery ASL) was scanned with the following parameters: TR/TE=3500/60ms, FA=90°, matrix=128×128, FOV=180mm and six tagging/control image pairs were acquired. Inversion time was set to 1400ms [5]. M_0 images were acquired without the FAIR tagging (TR was changed to 6000ms). T_1 images were scanned with an inversion-recovery SSFSE sequence and T_1=1300ms were used in perfusion calculation. ASL perfusion images were analyzed using custom scripts written in MATLAB (MathWorks Inc. Natick, MA, USA).

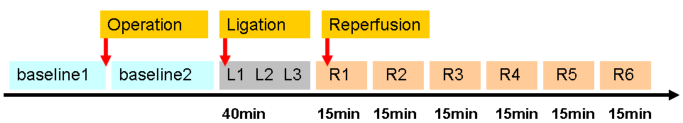

Fig. 1 Flow chart of the IR injury experiment.

The apparent transverse relaxation rate R2* is commonly used to demonstrate oxygenation alterations, and described as: R2*=1/T2*. An increase in R2* indicates a decreased oxygenation. In quantitative estimate of regions, R2* maps were analyzed by drawing three ROIs at cortex (CO), outer medulla (OM) and inner medulla (IM), respectively.

Results:

Typical BOLD images of the left kidney were shown in Fig. 2. Three ligation time points were scanned and significant changes were found in both cortex and medulla. Corresponding R2* values were shown in Fig. 3. When ligation occurred, R2* were extremely increased: from 19.8 to 42.6 Hz in CO, $p<0.01$; 20.5 to 52.4 Hz in OM, $p<0.01$; and 21.6 to 24.3 Hz in IM, $p=0.591$. During the ischemia condition, R2* of each time point was significantly higher than baseline1 and baseline2, $p<0.01$ for both cortex and outer medulla, but not for the inner medulla ($p>0.05$). There is no statistical difference between baseline1 and baseline2, $p>0.05$ for all the regions. In addition, significant difference was found between ligation1 and ligation3 in outer medulla ($p=0.043$), and R2* maintained significantly lower in inner medulla during reperfusion ($p<0.05$), which might indicate that oxygenation in medulla is more vulnerable than cortex. In the control group, no statistical differences were found.

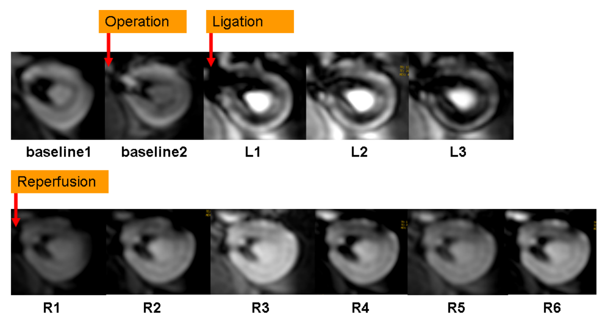

Fig. 2 Typical BOLD images before/after ligation, and during reperfusion. Low signals were found in outer medulla and high signals were found in cortex during ligation, and appreciably recovered during reperfusion.

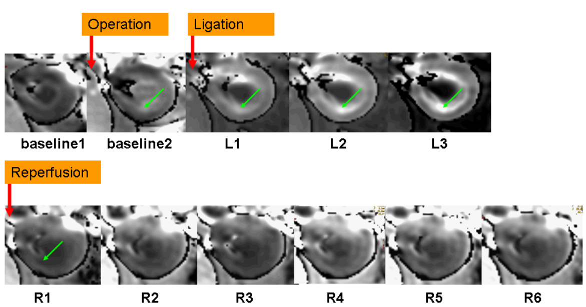

Fig. 3 R2* maps before/after ligation, and during reperfusion phases.

Fig. 4 illustrates the renal perfusion before/after ligation and reperfusion after release of 40 min ligation. The corresponding renal blood flow (RBF) was obviously shown: high perfusion in cortex and relative low values in medulla. Renal perfusions during ligation were stop as the blood flow was cut off. However, in the control group, the last point of ligation was significantly lower than baseline1 in medulla ($p=0.042$), and it maintained lower values during post-reperfusion (after 1h reperfusion, $p<0.05$), which may demonstrate a compensation way of the normal kidney after the left kidney perfusion was blocked for influence the station. During reperfusion, relative lower RBF values were found in regions for both left and right kidneys, except the medulla of the ligated kidney which was higher than baseline2 (124.3±4.0 in mean vs. 108.36 ml g^{-1} min^{-1}).

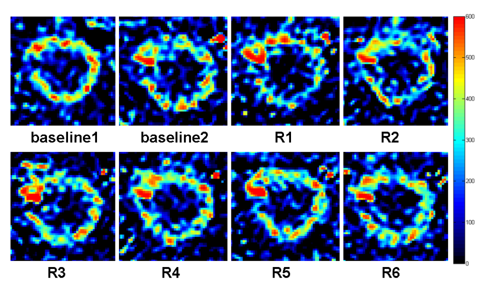

Fig. 4 RBF maps before/after ligation, and during the reperfusion of the left kidney. The cortical perfusion baselines were 499.5 and 425.4 ml g^{-1} min^{-1}, and decreased to zero after the artery was ligated. The mean perfusion of cortex during reperfusion was 417.1±6.1 ml g^{-1} min^{-1}. The medullary perfusion baselines were 148.8 and 108.4 ml g^{-1} min^{-1}. Its mean perfusion in reperfusion phases was 124.3±4.0 ml g^{-1} min^{-1}.

Conclusions:

In this work, we demonstrated the feasibility of renal function evaluation using BOLD with ASL following acute ischemia and reperfusion injury. Results suggested that BOLD MRI could allow early detection of renal pathology, while ASL MRI could provide quantitative measurement of renal blood flow before, during, and after acute ischemia and detect the compensation of blood flow from contralateral normal kidney. In addition, decreased R2* and increased RBF in medulla of left kidney during reperfusion may suggest the presence of medullary tubular injury or local inflammation.

References:

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