Free Breathing Renal BOLD Signal Frequency Assessment Following Diuresis

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Introduction: The kidneys are highly vascular organs, receiving 25% of the body's cardiac output, while weighing a mere 1% of the body's mass **[1]**. Most of this output is used to promote filtration of blood, an imperative process in the body's maintenance of homeostasis. As a consequence, they can become compromised and in many diseases hypoxic, potentially leading to acute renal failure (ARF) **[2]**. Current MR renal assessment methods rely on injecting contrast agents (e.g. Gadolinium chelates), which can cause complications leading to Nephrogenic Systemic Fibrosis (NSF) **[3]**. Blood oxygen level-dependent (BOLD) MRI utilizes endogenous (oxyhaemoglobin) contrast agent to assess renal function. This method has been applied to water-loaded subjects, predictably resulting in an increased BOLD signal **[4]**. The mechanism of the corresponding increase in BOLD signal was hypothesized to be a result of decreased renal metabolism, however, increased blood flow may also contribute. To further investigate this mechanism, we used a more sophisticated approach, the Fourier Transform, to assess BOLD signal temporal dynamics.

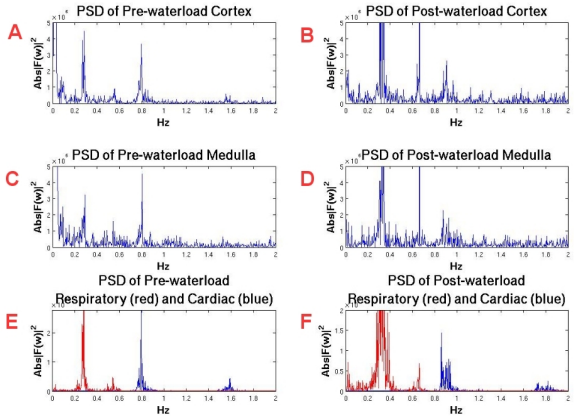

Figure 1: Power Spectral Density plots for pre- (left) and post-waterloading (right): **(A)-(B)** Cortex, **(C)-(D)** Medulla, and **(E)-(F)** Respiratory (red) and Cardiac (blue)

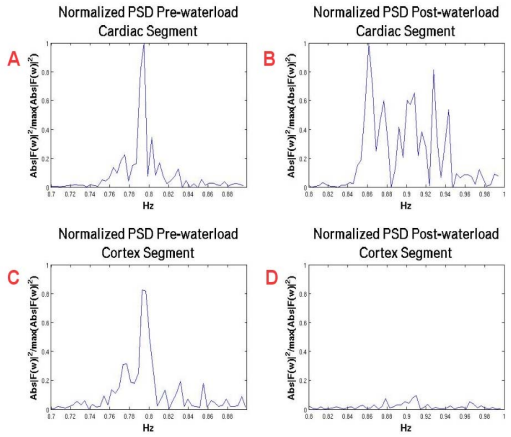

Figure 2: Normalized (to one) Power Spectral Density (PSD) plots, focusing on cardiac frequency peak range (0.8 ± 0.1, 0.9 ± 0.1 Hz): **(A)** Pre-waterload Cardiac **(B)** Post-waterload Cardiac, **(C)** Pre-waterload Cortex and **(D)** Post-waterload Cortex

Methods: In a study approved by our research ethics board, human kidneys were imaged using a free-breathing T2* weighted (BOLD) GRE EPI sequence (TR/TE=250/35ms, flip=70^o, FOV=30cm 96x96 matrix, 3 slices 5mm thick, 0mm skip, oblique coronal acquisition (20 ± 4 degree offset, 2400 temporal points, 10 minutes total time). All scans were done using a GE Healthcare 3T HD Signa MRI and 8 channel torso phased array RF coil. Cardiac and respiratory data was collected concurrent with BOLD data using a pulsed oximeter and MRI scanner respiratory bellows. Subjects fasted (no food or water) for 12 hours prior to the experiment. A 30-minute water-loading session (1L 50/50 Gatorade/Water per 30kg body mass) commenced immediately following the first scan. The second and final scan was then acquired after a 15 minute break, which allowed the induced diuresis to take effect. The MRI data was post-processed using a template-matching algorithm, as previously applied in assessment of liver hepatocellular carcinoma **[5]**. Region of interest (ROI) analysis could then be reliably performed on both the manually selected renal cortex and renal medulla (**Fig.3**) areas, using AFNI software **[6]**. The resultant averaged time-courses, along with the physiologic signals, could then be manipulated using the 'fft' function in Matlab (The Mathworks, Natick MA). From the Fourier tranformed data, the power spectral density (PSD) was computed, by taking the absolute value of the amplitude, and then squared. Although visual comparison of the spectral data was important, the 'corrcoef' function in Matlab was also utilized to report how statistically similar the spectra were. A value of P<0.05 was used for significance.

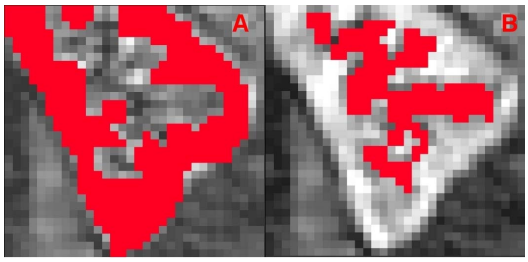

Figure 3: Regions of interest (ROI) selected for subject around both renal cortex (**A**) and medulla (**B**)

Results: The resulting spectral data is displayed in **Fig.1**, which shows the prominence of both the cardiac and respiratory frequency peaks in the pre-water load cortex and medulla BOLD data (**A, C, E**). Post-water loading (**B, D, F**), however, the respiratory frequency was still distinctly present, however, the cardiac signal diminished significantly. To magnify this observation, a normalized PSD (to a value of one) was calculated (**Fig.2**), enhancing the spectral data around the subjects cardiac frequency (± 0.1 Hz) for both pre- (**A, C**) and post-water loading (**B, D**) in the renal cortex. To even further verify the strong influence of the cardiac signal on the pre-water loading, a correlation coefficient of 0.9127 (P<0.00001) was calculated between the PSD's of **Fig.1(A)** and **Fig.1(E),** using only data relevant to the cardiac frequency (0.8 ± 0.1 Hz). Alternately, the correlation coefficient was calculated to be 0.4487 (P<0.001) for the post-water loading cortex and cardiac PSD's.

Conclusions: Considering the vast amount of blood that is being perpetually shunted to the kidney, it is not surprising that the cardiac peak would be present in the renal BOLD signal. It makes even more sense that the respiratory frequency would appear in the BOLD signal, considering the immense amount of respiratory associated motion the kidney is influenced by. The respiratory peak is quite visible in both pre- and post-water loading scans, indicating the patient's breathing pattern did not significantly change. The decrease in the correlation coefficient post water loading may indicate a decrease in renal O_2 consumption. This approach may find utility in assessing kidney health non-invasively.

References: **[1]** Tumkur SM, *et al.* (2006) *Kidney Int.* 70:139-143. **[2]** Prasad PV, *et al.* (1999) *Kidney International* 55:294-298. **[3]** Han F, et al. (2008) *Nephrol Dial Transplant* 23:2666-2672. **[4]** Boyd BJ, et al. (2009) *ESMRMB-2009* 329. **[5]** Noseworthy *et al.* (2007) *JCAT* 31:193-197. **[6]** Cox RW. (1996) *Comp. Biomed. Res.* 29:162-173.