A method for updating the aterial input function each cardiac cycle with flow compensation

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Introduction Dynamic contrast enhanced magnetic resonance imaging, or DCE-MRI, is a technique for non-invasively probing the vascular state of tissue, which is affected by many diseases. Quantification of these processes relies upon relating the concentration of a contrast agent in blood to the uptake in tissue via a parametric model. Measurement of the concentration in tissue is relatively straightforward, while the measurement of blood plasma concentration, also called an arterial input function (AIF), entails several special considerations.

First, it must be possible to isolate a blood vessel in which to measure the concentration, which may require high spatial resolution to identify a blood vessel surrounded by tissue. Second, it must be sufficiently high in temporal resolution to be resistant to motion. Third, the T_1 of the blood during uptake must be quantified accurately, because the calculation of contrast agent concentration depends crucially on T_1; in particular, flow effects can shorten the measured value of T_1 by introducing unsaturated spins into the tissue being imaged. This may confound estimates of the tissue concentration of the contrast agent.

We propose addressing the first issue by a modification of the technique proposed by Pickup, et al[1]. Rather than requiring that the heart be in the same slice as the tumor, we instead acquire a separate slice through the short axis of the heart. No phase encoding is performed on this slice, permitting measurement of the AIF every TR. This enables resolution of individual heartbeats and we may sample the AIF at a regular position in the cardiac cycle. To suppress through-plane flow effects through the heart, we propose a technique that involves surrounding the slice with spatial suppression bands. This will allow the incoming fluid to come closer to steady state, reducing artifacts. This technique is demonstrated both in phantom and in vivo.

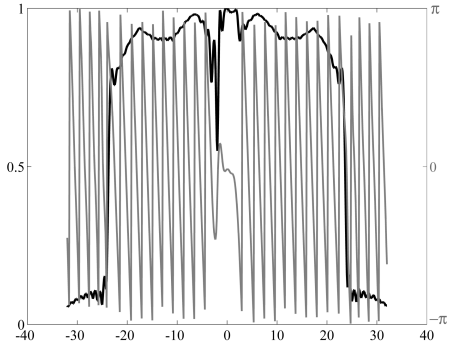

Figure 1: Slice profile of the composite pulse

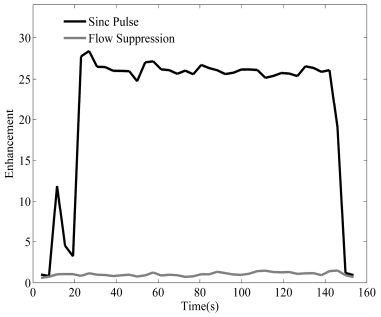

Figure 2:Relative enhancement of the two pulses

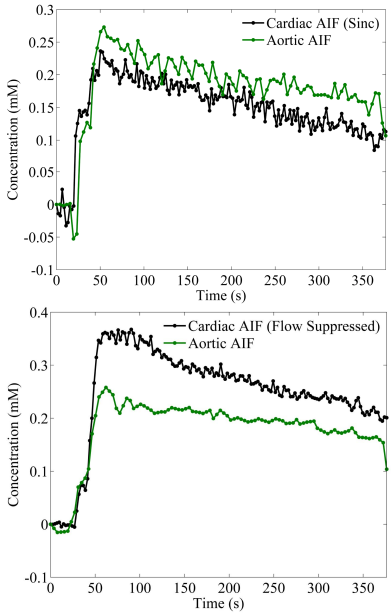

Figure 3: Measured AIFs

Methods All experiments used an RF-spoiled gradient echo sequence, modified to allow the acquisition of one slice out of many without phase encoding and to allow the use of different excitation pulses for one slice. The pulse for flow suppression consisted of the arithmetic sum of two waveforms. One was a 3-lobes sinc which excites the central portion of the slice; the other was a sine-modulated sinc pulse, shifted in time to create a phase modulation across the sidebands of the slice even after gradient refocusing. This both suppressed signal from regions outside the slice during excitation, and caused flowing blood to be closer to steady state, reducing flow effects. A slice profile, calculated by numerically integrating the Bloch equation, is shown in Figure 1. Each sideband of the full slice was five times the width of the non-suppressed region.

Validation of the flow suppression was performed in phantom. A phantom was constructed from a 30 mL sample tube with a 1 mm diameter catheter inserted. The tube was filled with tap water, and water was forced through the catheter with a 10 mL syringe over two minutes for a mean flow velocity of 0.1mm/ms. Images were acquired during injection with the gradient echo sequence. Two slices were acquired, one with the flow suppression pulse, the other with a 3-lobe sinc pulse. Acquisition parameters were: TE/TR = 1.8/30 ms, matrix size = 128x128, slice thickness = 1.5 mm (the suppression width was 7.5 mm each side), flip angle = 90°. The slices were placed as far apart as possible in the slice to avoid interference between the two slices.

In vivo measurements were performed on a single mouse. It was positioned in the scanner after catheterization and kept under anesthesia and at a constant temperature. Anatomical reference images were acquired using a self-gated cardiac technique. Two slices were chosen; one through the heart and the other through the aorta. Imaging was begun just before injection with gadopentetate dimeglumine, and repeated a total of 100 times. The acquisition parameters were: TE/TR = 1.8/40 ms, flip angle = 30°, matrix size = 128x96, FOV = 4 x 3 cm, slice thickness = 1 mm. A sinc excitation pulse was used to excite both the aortic slice and cardiac slice. The animal was allowed to rest for 45 minutes. The same sequence, using a sinc excitation for the aorta but the composite pulse for exciting the cardiac slice, was repeated with another injection of contrast agent. The slices were chosen so that there would be no overlap between the aorta slice and the sidelobes of the cardiac slice.

From these images, AIFs were created. The aortic AIFs were filtered to remove changes in signal caused by heartbeats through linear interpolation between time points surrounding the dip. Heartbeats were identified on the cardiac AIF and the signal was retrospectively gated by choosing timepoints midway between consecutive heartbeats. Signal was converted to concentration through the equation for the signal of a two-point spoiled gradient echo sequence, an assumed blood T1 value of 1500 ms, and an assumed relaxivity of 2.7 s/mM for Gd-DTPA.

All experiments and procedures were approved by our Institutional Animal Care and Use Committee, which is accredited by the Association for the Assessment and Accreditation of Laboratory Animal Care International.

Results The ratio of the catheter signal time course to the surrounding water is shown in Figure 2. Substantial flow suppression is evident.

The in vivo AIFs are shown in figure 3. There is close agreement between the two AIFs measured in the aortas, which are also both similar to the cardiac AIF measured with the sinc pulse. The cardiac AIF measured with flow suppression shows substantial differences compared to the other three AIFs.

Discussion The AIF was sampled at the repetition time of the sequence; this was higher than the Nyquist frequency of the heartbeat. This permitted us to retrospectively choose time points to represent the AIF that were at a constant phase of the cardiac cycle and did not suffer from heart-motion related artifacts.

The close match between the two aortic AIFs indicates that the difference between the two injections was relatively small. The similarity between the cardiac AIF measured with a sinc pulse and the aortic AIF from that same injection shows that the cardiac measurement compares well to our previous methodology. The substantially different behavior of the flow suppressed cardiac AIF from its matching aortic AIF implies that contrast agent concentrations may be underestimated in the absence of flow suppression.

References

1. Pickup, S., R. Zhou and J. Glickson. Academic Radiology, 2003. **10**(9): p. 963-8.