Retrospective respiratory triggering for 2D abdominal perfusion MRI

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Background Renal blood flow and glomerular filtration rate can both be quantified from DCE-MRI measurements [1,2,3], provided data are acquired at a high temporal resolution and an acquisition time of several minutes [4]. This implies that acquistions cannot be performed under breathold condition, so that an alternative strategy is require to eliminate the effect of respiratory motion. One alternative is to distribute the acquisition over mutliple breatholds [2], but this creates a risk of misregistration and may be problematic in critically ill patients. An alternative approach is to measure during free breathing, and use a triggering approach to select data measured in end-expiration [5]. When triggering is applied prospectively, measurements are not always performed in every individual breathing cycle, which may reduce the temporal resolution in the first pass to unacceptably low values [4]. The aim of this study is to propose an approach for retrospective respiratory triggering [6], using a reference signal measured at the interface between tissue and air on an axial slice. A first evaluation of the method is performed using patient data.

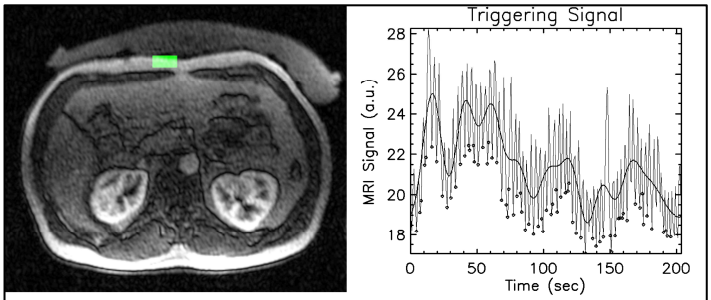

Figure 1. On the left, an image of the axial slice during cortical enhancement, showing the placement of the triggering ROI (green rectangle). In this case, the measurement was performed with a dielectic pad, and the ROI was chosen at the tissue-pad interface. On the right, the signal obtained from this ROI (thin line), and the low-pass filtered signal (thick line). The time-points selected to trigger the kidney curves are indicated with (◊).

Material and Methods 9 consecutive patients (4 women, 5 men; mean age 59) underwent renal perfusion measurements after intravenous injection of 7 ml Gd-BOPTA (Multihance®, Bracco) at 4 ml/s at 3.0T (Magnetom Tim Trio; Siemens Medical Solutions, Erlangen, Germany). Data were acquired with a 2D Saturation-recovery TurboFLASH sequence measuring 5 slices (4 coronal, 1 axial) with a temporal resolution of 0.9s and a pixel size of 2.3 mm (slice thickness 8mm, FA 8°, TI 71ms, TR 177ms, TE 0.93ms, matrix 192x176). Post-processing was performed off-line using the in-house built software PMI 0.3 written in IDL 6.4 (ITT Visual Information Solutions, Boulder, CO). A 4-pixel region-of-interest (ROI) was drawn manually in the lumen of the aorta to measure the Arterial Input Function (AIF). For the measurement of the triggering signal, a rectangular triggering ROI was placed at the interface between tissue and air on the axial slice (Figure 1, left). The signal-time curves of the triggering ROI were filtered with a low-pass filter with frequency cut-off 0.05 Hz. The signals in the kidney pixels or ROIs were triggered by disregarding in the calculations all time points where the triggering signal has a value above that of the filtered curve (Figure 1, right). Since the aorta does not move during breathing the AIF was not triggered, thus exploiting the full temporal resolution in the rapidly changing signal of the arterial blood. In a first step, the triggered curves of all kidney pixels and the untriggered AIF were converted to signal enhancement and fitted to a separable two-compartment model, producing a map of the plasma flow F_P, the plasma volume V_P, tubular flow F_T (the local glomerular filtration rate) and mean transit time T_T of the tubular compartment. A cortical ROI was segmented automatically on these maps by selecting those pixels with plasma volume V_P > 5 ml/100ml. The cortical ROI curve was triggered in the same manner as the pixel curves, all signals were converted to relative signal enhancement and the model fit was repeated on a ROI basis to produce the averages for the selected cortex region. In order to test the dependence of the results on the precise choice of the triggering ROI, the analysis was repeated for three widely differing ROIs at the tissue-to-air interface. On the ROI-level, a delay between artery and tissue was fitted as an additional parameter.

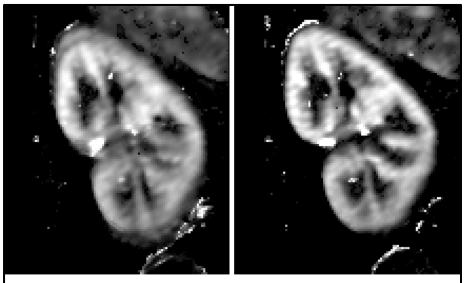

Figure 2. A renal blood flow map calculated without (left) and with (right) retrospective motion triggering. Both images are represented in equal grey scales.

Results: Triggering was succesfully applied in all cases, producing realistic values for the model parameters. Figure 2 shows a result of plasma flow calculation on the pixel level. Without triggering (left) the image is blurred due to the combined influence of data measured during in- and expiration. After triggering (right), the contours are sharper and the image has a stronger contrast. Figure 3 shows the result of a two-compartment model fit superposed on a triggered cortex curve. The temporal resolution is reduced due to the triggering process, but sufficient data points remain to fully resolve the rapid rise during the first pass. The mean values of the functional parameters of all patients were between 49.47 and 246.97 ml/100ml/min for F_P, 11.2 and 20 ml/100ml for V_P, 4.4 and 13.6 s for T_P, 9.77 and 41.4 ml/100ml/min for F_T, 86.23 and 150 s for T_T. The standard deviation (SD) of the values determined with three different respiratory triggering regions defined for every patient was between 0.81% and 9.87% for F_P, 1.45% and 8.19% for V_P, 0% and 9.63% for T_P, 2.15% and 12.23% for T_F and 1.97% and 12.87% for T_T. There were two outliers: in one patient SD was 23.2% (F_P), 18.7% (V_P) and 20.49% (F_T); in another patient SD were 18.23% (V_P) and 26.6 (T_P).

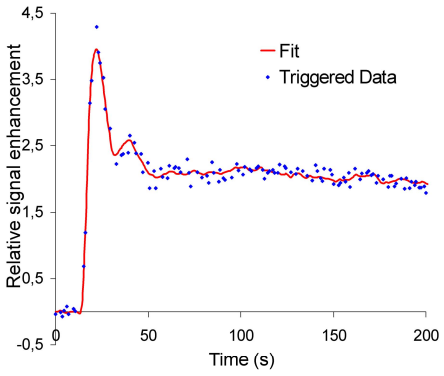

Figure 3. A plot of the triggered data and the two-compartment model fit for a single cortex curve. The plot shows that the temporal resolution after triggering is adequate to resolve the first pass of the bolus.

Conclusion: The results show that retrospective respiratory triggering is a feasible approach to correct for breathing motion in the quantification of renal functional parameters using a two-compartment model. The method does not require a modification of the measurement protocol, and can be implemented with minimal user interaction. Since triggered model fitting is feasible on the pixel level, it allows for automatic definition of cortex ROIs based on physical criteria, which may eliminate the need to perform additional segmentation on the dynamic curves. A limitation of the method is that it requires measurements at high temporal resolution, so that it may not be feasible for 3D acquisition.The effect of choosing widely different regions for triggering is small, but the larger deviations near 20% in two cases indicate that a (semi)automated approach for the selection of the regions is desirable to minimize the user dependence of the results.

References: [1] Dujardin et al *Magn Reson Med* 2005; 54: pp 841-849 [2] Bokacheva et al *Magn Reson Med* 2007; 57:pp 1012-1018. [3] Sourbron et al *Proc ISMRM* 2007, 403 [4] Michaely et al *Proc ISMRM* 2007, 401. [5] Michaely et al. *Radiology* 2006;2(238):586-596. [6] Bishop, et al. *Magn Reson Med* 2006; 35:pp 472-477.