A general dual-bolus approach for high resolution quantitative DCE-MRI

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Introduction: Accurate measurement of the arterial input function (AIF), essential for quantitative dynamic contrast-enhanced (DCE) MRI, is challenging due to the rapidly-changing high concentration of contrast agent during a bolus injection, particularly during the first pass peak. Temporal undersampling, inflow of unsaturated spins and signal saturation all have the potential to corrupt the measurement. Furthermore, imaging both the tissue of interest and a feeding vessel in the same volume constrains how well the different requirements for the AIF (high temporal resolution) and tissue uptake curve (high spatial resolution) are met. In this study, a dual-bolus technique is presented for accurate AIF measurement, applicable to high-resolution DCE-MRI of tissue uptake in any organ. A low-dose prebolus was used for AIF measurement, a technique first proposed to reduce signal saturation in quantitative myocardial perfusion imaging [1] that has also been applied in the lung [2]. The prebolus was scaled to estimate the AIF for a second, high-dose injection, for which the protocol can be tailored for monitoring tissue uptake only. A 3D TRICKS (Time Resolved Imaging of Contrast Kinetics) sequence [3] was incorporated for rapid sampling of the relatively low spatial frequencies present in an AIF. Results presented here demonstrate that the proposed technique can capture even the rapid circulation kinetics of a rabbit, and that the scaled prebolus AIF is equivalent to the AIF from a high-dose injection

Methods: MR imaging was performed at 1.5 T (Signa EXCITE TwinSpeed; GE Healthcare, Milwaukee, WI, USA) on 5 New Zealand white rabbits (2.9-3.4 kg) using a transmit/receive knee coil. Anaesthesia was induced and maintained with 5 % and 2 ± 0.2 % isoflurane, respectively, in 100 % oxygen using a face mask. Contrast agent (Gd-DTPA – Magnevist, Berlex Canada, Lachine, Canada) was administered through the ear vein using a power injector (Spectris Solaris, Medrad, Warrendale, PA), adapted for use with rabbits. A double dose of contrast agent was used (0.2 mmol kg^{-1}), split into 20 % for the prebolus and 80 % for the main bolus. In each case Gd-DTPA was diluted with saline to the same volume as the original double dose (0.4 ml kg^{-1}). Contrast was injected at a rate of 0.5 ml s^{-1}, followed by a 2 ml saline chaser. The study was approved by our institutional animal care committee.

The aorta was imaged in the sagittal plane, with the volume positioned to have one slice running down the centre of the caudal portion of the vessel, using an oblique volume if necessary. Acquisitions were location-matched for the two injections. For both the prebolus and main bolus, a 3D TRICKS acquisition was used with the following parameters: FOV 18 cm, 70 % phase FOV, 10 reconstructed slices (overcontiguous), 3 mm slice thickness, in-plane matrix 90 x 90, 0.75 NEX. The prebolus acquisition used a 20° flip angle to increase signal to noise ratio for the low dose, whilst the main bolus used 40° to increase signal-to-noise ratio and avoid signal saturation. Repetition and echo times were TR / TE = 2.94-3.14 / 1.33-1.36 ms, depending on slice obliquing. Temporal resolution was ~0.4 s. Baseline signal intensities were acquired before the prebolus injection for both the 20° and 40° sequences, (56 phases). The passage of each bolus was imaged by acquiring the TRICKS sequence twice in quick succession (112 phases total). A period of 15 min elapsed between the prebolus and main bolus injection.

AIFs were extracted from the image slice that lay in the centre of the aorta (to minimise partial volume effects), in the caudal portion of the vessel (to minimise inflow effects). For the main bolus images, signal intensity-time curves were plotted for a grid of 9 x 9 voxels centred over the vessel, and converted to ΔR_1-time curves using an assumed baseline T_1 for rabbit blood of 1270 ms [4], the standard spoiled gradient echo signal equation, and a linear relationship between ΔR_1 and contrast agent concentration. Voxels were selected from the grid for inclusion in the AIF if the baseline signal intensity and peak height were similar to that in the centre of the vessel. The same voxels were chosen for the prebolus AIF so that any partial volume effects would be consistent between the two curves. Chosen voxels were averaged together to form the prebolus and main bolus AIFs, and the prebolus AIF was scaled by a factor of four for comparison with the main bolus.

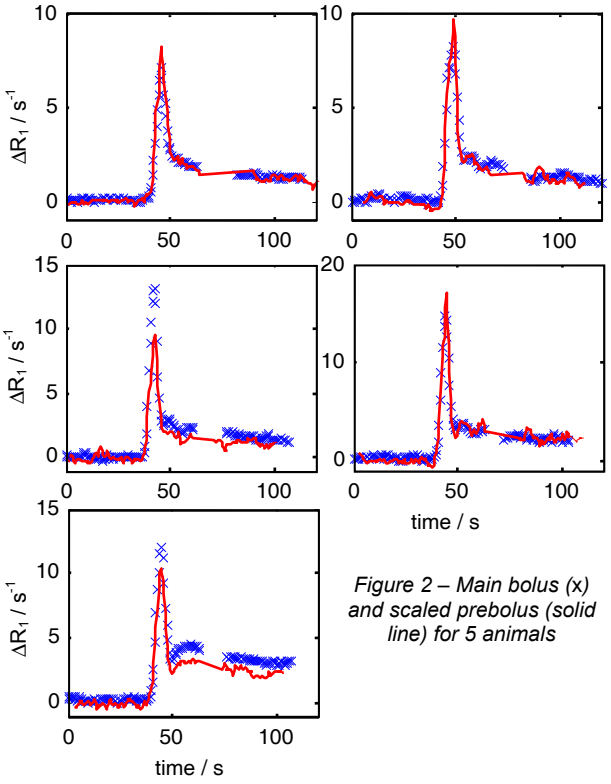

Figure 2 – Main bolus (x) and scaled prebolus (solid line) for 5 animals

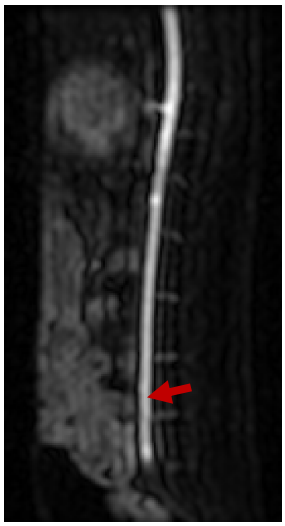

Figure 1 – TRICKS image at the main bolus peak. Arrow shows level of ROI

Results: A sample TRICKS image is shown in Fig. 1, clearly demonstrating the aorta during passage of the main bolus peak. The arrow shows the position of the region of interest for the AIF. Fig. 2 shows the agreement between the scaled prebolus and main bolus AIFs for each animal.

Discussion: This study shows that the AIF measured from the prebolus is equivalent to that measured during the main bolus injection. Using the prebolus to estimate the AIF allows the protocols for the two injections to be tailored to the unique requirements of the AIF and tissue uptake curve. The AIF can be imaged in-plane (reducing inflow effects), without signal saturation and with good definition of the first-pass peak due to rapid temporal sampling. For the main bolus injection used to monitor tissue uptake, sampling can be slower [5] to allow high spatial resolution, a higher contrast dose could be employed if necessary to achieve adequate signal, and the feeding vessel need not be included in the field of view.

Conclusion: The dual-bolus protocol described here allows measurement of a high temporal resolution AIF, free from signal saturation effects and with minimised inflow and partial volume effects. Separate acquisition of the AIF allows the contrast agent uptake in the tissue of interest to be imaged at high spatial resolution without inclusion of a feeding vessel.

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References: [1] Kostler *et al* MRM 2004;52:296. [2] Oeschner *et al* JMRI 2009;30:104. [3] Korosec *et al* MRM 1996;36:345. [4] Cheng JMRI 2007;25:1073. [5] Henderson *et al* MRI 1998;16:1057