CONTRAST ENHANCED FLOW QUANTIFICATION USING BREATH HOLD AND CONVENTIONAL GRADIENT ECHO MAGNETIC RESONANCE TECHNIQUES

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INTRODUCTION

Two important areas of clinical flow imaging such as stenotic flows and small vessels were investigated to assess the influence of contrast agents on Magnetic Resonance flow measurements. Blood flow measurements using MR imaging have a significant drawback in areas where turbulence downstream of stenotic orifices can adversely effect the quality of phase velocity measurements. Either the use of low echo time (TE) or the small imaging voxel size can minimise the effects of turbulence however the latter case reduces significantly the MR signal [1]. The first hypothesis of this study relies on the paramagnetic effectiveness of contrast agents to improve the accuracy of MR flow measurements by improving the signal from the flowing blood in these areas. Our aim was to assess the potential influence of contrast agents a) on the accuracy of conventional gradient echo techniques using small voxel imaging and b) on the standard Breath-hold imaging in turbulent flows.

Small vessel flow measurements with limited spatial resolution are subject to systematic errors due to partial volume effect and the selection of the vessel pixels [2]. The non-linear relationship that exists between MR signal and velocity when using phase contrast technique indicates their dependence on accurate flow measurements. High-resolution imaging increases the number of pixels required to minimise the partial volume error but the drop of the signal to noise ratio affects the flow quantification. Based on the same hypothesis of paramagnetic effectiveness of contrast agents, our aim was to assess the influence of contrast agents on the accuracy of high resolution flow imaging techniques by improving the MR signal in small vessels.

METHODS

MRI was performed on a 1.5 T whole-body imaging system (Gyroscan, Philips, Netherlands) using a five-element synergy cardiac surface coil. Single Breath-hold (BH), turbo field echo (turbo factor 7) and conventional gradient echo (FFE) velocity encoded sequences were used in-vitro to image steady flows through an axisymmetric stenosis, simulating severe aortic stenosis (fig.1) and two small vessels with diameters 2 and 4mm, simulating cerebral sized arteries. The working fluid was an aqueous glycerine solution with similar relaxation properties to those of blood, doped with concentrations of Gd-DTPA (Magnevist) to reach bolus concentration of 7 mmol/l for stenotic flows and 5mmol/l for small vessels.

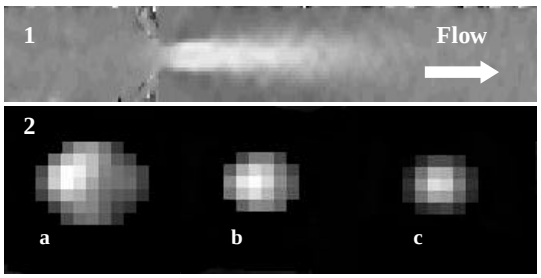

Figure 1. BH flow imaging of a stenotic phantom
Figure 2. Effective FOV of a 2mm vessel diameter a) 80, b) 100 and c) 128 mm.

Transverse images of the stenotic flow were obtained upstream, at and downstream of the orifice. The imaging parameters were for BH TR=4.9ms, TE=2.8ms, 300mm FOV, 128x128 matrix reconstructed at 256x256, 6mm slice thickness and for FFE sequences a) with low resolution (LR) TR=18.4ms, TE=4.9ms, 300mm FOV, 256x256 matrix, 6mm slice thickness and b) with high resolution (HR) TR=20ms, TE=6ms, 256mm FOV, 256x256 matrix, 2mm slice thickness. Small vessel imaging was achieved by varying the field of view and keeping constant the repetition time (TR), echo time (TE), matrix, slice thickness and bandwidth for both sequences. For BH imaging three resolutions were used, low, medium and high corresponding to FOV of 128, 100 and 80mm (fig.2), (TR=15ms, TE=8.8ms, matrix 128x128 reconstructed to 256x256, slice thickness 4mm). For FFE techniques four resolutions were used corresponding to FOV of 256, 200, 150 and 100mm (TR=38ms, TE=7ms, matrix

256x256, slice thickness 4m). In both studies through plane MR mean flow was measured by superimposing circular regions of interest (ROI) over the lumen and corrected using a parabolic background correction algorithm. Imaging was k-space segmented and triggered at 70 bpm. True flow rates were measured manually. Mean flow and standard deviation values were calculated over the number of individual phase images acquired.

RESULTS / DISCUSSION

Figure 3 shows a typical result for the calculation of flow as a function of distance from the orifice (+ is downstream) after the application of contrast agents. The FFE sequences could not accurately quantify the flow immediately downstream of the orifice although they produced accurate measurements upstream. The combination of contrast agents and small voxel imaging could not improve flow measurements as the MR signal was vanished by the high resolution imaging, the turbulence related signal loss and the time of flight effects due to the low slice thickness. Conversely, the BH sequence produced a good quantification of flow even at the highest flow rates (fig.3 and fig.4). The accuracy of this technique in stenotic flows is mainly based on the low TE < 4ms, however the temporal variation in flow is large in turbulent region indicating that turbulence is affecting the individual phases. In pulsatile flow where a temporal mean is not taken, individual measurements may be inaccurate. The reduction of the phase variations after the administration of gadolinium (fig.4) increases the applicability of this technique in quantifying real arterial flows.

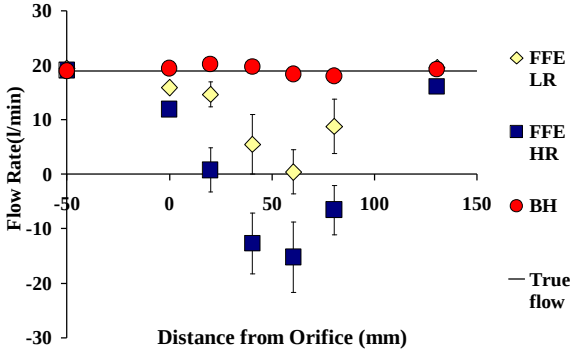

Figure 3. Contrast enhanced flow calculation as a function of position from the orifice for low and high resolution FFE and BH imaging.

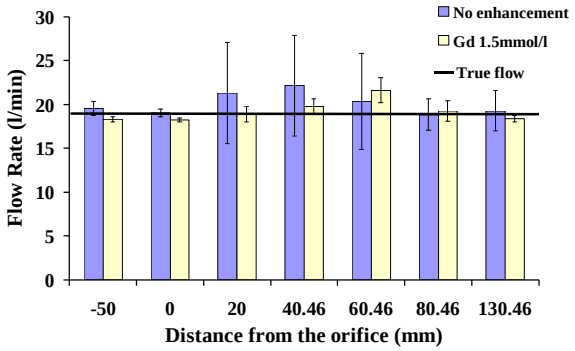

Figure 4. The effect of gadolinium on BH flow imaging.

Figure 5 illustrates a comparison of different resolutions for BH flow imaging as functions of contrast administration. Low resolution flow imaging did not perform well because the small number of pixels available increased the errors due to the partial volume effect. High-resolution imaging was not affected by the drop of the signal (67%), keeping the flow error less than 5%, even before the administration of gadolinium. The addition of contrast agents improved low and medium resolution sequences indicating that an accurate small vessel flow measurement relies mostly on the improvement of the vascular lumen delineation. The flow error dropped significantly as the number of pixels increased and was kept minimum (less than 5%) for measurements using more than 20 pixels for lumen area without being affected by any addition of gadolinium. FFE sequences quantified flow measurements accurately when 150 and 100mm FOVs were used however measurements were strongly affected by partial volume errors. BH was superior to FFE in terms of the imaging time, the signal to noise ratio and the flow measurement accuracy but the small number of individual phases (5 phases) may seen inadequate in pulsatile flow measurements.

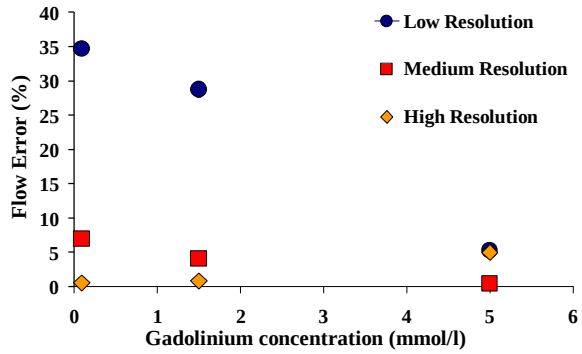

Figure 5. The percentage of flow error as a function of contrast administration for different BH resolutions in a 2mm diameter small vessel.

CONCLUSION

This in vitro study investigates how contrast agents influence the accuracy of MR flow measurements examining two important areas of clinical imaging a) aortic stenosis and b) small vessel imaging. The combination of contrast agents and high resolution FFE imaging was proved inaccurate to quantify post-stenotic flows, however contrast agents improved BH measurements by reducing the temporal variation in turbulent regions. The key tool for high post-stenotic flow quantification is the low echo time (<4ms). High resolution BH imaging provides accurate flow quantification in small vessels reducing the effect of partial volume. The use of contrast agents in small vessels imaging can improve only low-resolution measurements because they can define better the number of pixels required for a correct result. BH is fast and accurate technique that has not been validated yet in flow imaging. Upon the results produced, BH imaging could be used clinically for flow quantification.

AKNOWLEDGMENTS

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