Interleaved Spiral Cine Coronary Artery Velocity Mapping

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INTRODUCTION

Breath-hold segmented FLASH phase velocity mapping techniques have recently been validated in the coronary arteries of both open chest dogs (1,2) and humans (3). However, the number of cine frames acquired is limited by poor temporal resolution which is largely determined by the sequence echo and repeat times and the number of view pairs acquired per cardiac cycle, the latter being relatively high so as to acquire all of the data within a single breath-hold. This, in turn, limits the accuracy of the technique for assessing pulsatile flow waveforms and also results in motion blurring of the arteries as they move during the data acquisition window. Retrospective respiratory gating has been implemented as an alternative means of respiratory control and has generated high quality images with good temporal resolution (4) but at the expense of prolonged acquisition times (typically 17minutes for a 256 view study). Although potentially usable for resting coronary blood flow studies, maintaining a state of maximum vasodilation by means of pharmacological stress or exercise for such periods is not feasible and the assessment of coronary flow reserve with this method is therefore not possible.

Interleaved spiral cine velocity mapping techniques have the advantages of rapid k-space coverage and good temporal resolution and have been successfully implemented in the descending aorta, in the carotid arteries, in the heart (with breath-holding) and in the renal arteries, both with breath-holding and, very recently, with navigator controlled respiratory gating (5). The purpose of this study is to investigate the potential for using navigator-echo controlled free breathing interleaved spiral cine velocity mapping to provide a rapid measure of the phasic blood flow velocity in the coronary arteries where such a technique could be instrumental in assessing both coronary blood flow and coronary flow reserve.

METHODS

The spiral readout gradients of the sequence are of 18.6ms duration and are designed to give a minimum field of view of 224mm with 256 pixel resolution in a 20 interleaf acquisition. A 2ms delay between the bi-polar velocity encoding gradient and the start of the spiral readout period removes the effects of any short term eddy currents originating from the bi-polar gradient pulse which may otherwise be active at the time of sampling the centre of k-space. The resulting echo time is 12.3ms and the minimum repeat time is 35.8ms. The sequence is preceded by a chemical shift fat suppression pulse and by a navigator echo passing through the dome of the right hemi-diaphragm. One navigator echo and one fat suppression pulse are output per cardiac cycle with data being accepted for processing only if the diaphragm position is within a 5mm window centred on the end expiratory pause position. A velocity sensitivity of 50cm/s is achieved by alternating the velocity sensitivity of the interleaf with each accepted navigator-echo trace. Eight – 12 frame through-plane interleaved spiral cine velocity maps were acquired in the right coronary arteries of 6 healthy volunteers. The flip angle used was 50°, the in-plane resolution 1.1mm x 1.1mm and the slice thickness 7mm. Prior to imaging, the magnet was carefully shimmed so as to improve the efficacy of fat suppression, to minimise the blurring effects of static field inhomogeneities and to reduce the likelihood of generating direction sensitive implosion/explosion flow artefacts.

RESULTS

Good quality magnitude images and velocity maps were achieved in all 6 subjects with the mean acquisition duration being 94s (range 69 – 123s, SD = 20s). There was considerable inter-subject variability in both the flow velocity profiles observed and in the degree of motion of the coronary vessels. The mean peak coronary artery blood flow velocity in the 6 subjects was 138mm/s (range 90 – 171mm/s, SD = 29mm/s) and occurred at a mean gating delay of 383ms (range 360 – 420ms, SD = 27ms). In four subjects, unsuppressed fat surrounding the coronary artery was visible and used as a marker for the through-plane velocity of the vessel itself. In these subjects, the corrected mean peak flow velocity was 120mm/s (range 88 – 149mm/s) occurring at a mean gating delay of 370ms (range 320ms – 400ms). An example of an oblique transverse study acquired in 112s is shown in Figure 1 below where the magnitude images and velocity maps at times of minimum and maximum flow velocities (gating delays of 320ms and 400ms respectively) are presented together with the measured velocity-time curve, both before and after correction for the through-plane motion of the vessel.

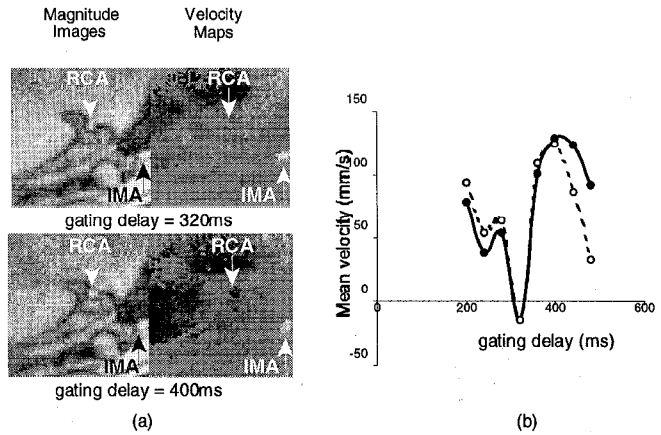

Figure 1: (a) Right coronary artery (RCA) magnitude images and velocity maps at times of minimum and maximum flow velocity. Note flow in the internal mammary artery (IMA) also. (b) Phasic velocity profile showing minimum and maximum coronary artery velocities at gating delays 320ms and 400ms respectively. Profiles are shown both before (solid line) and after (dotted line) correction for the through-plane velocity of the vessel itself, as determined from adjacent unsuppressed fat.

DISCUSSION

The phasic nature of coronary artery blood flow has been clearly demonstrated and considerable inter-subject variation in the timing and magnitude of the peak flow velocity observed. The rapid coverage of k-space and good temporal resolution of interleaved spiral cine coronary artery velocity mapping potentially enables the acquisition of a large number of frames per cardiac cycle with minimal motion blurring in reasonable acquisition times, without the need for breath-holding. These factors make the assessment of coronary artery flow reserve by magnetic resonance techniques a practical possibility.

REFERENCES

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