Breath-hold signal loss sequence for the qualitative assessment of blood flow disturbances in cardiovascular MR

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Abstract

The development of a breath-hold segmented FLASH sequence for the visualisation of signal loss in areas of complex blood flow is described. Both velocity sensitised and acceleration sensitised sequences were developed and compared with a conventional non-segmented TE14 sequence (taking approximately 2 minutes to acquire) in 8 subjects with valvular heart disease. All three sequences resulted in similar degrees of signal loss but the image quality of the acceleration sensitised sequence was consistently best, with no respiratory motion artefacts being present.

Introduction

In cardiovascular MR, flow compensated gradient echo sequences with echo times of around 15ms have been shown to exhibit signal loss in areas of complex blood flow. Although not directly related to the severity of stenosis or to other pathology, the level of signal loss has proved to be a clinically useful indicator of valvular heart disease and can also aid in the positioning of further imaging planes for quantitative analysis with phase velocity mapping. Due to the requirement for a long echo time however, such a sequence cannot be segmented to allow breath-hold acquisition and studies typically take approximately 2 minutes to acquire with respiratory motion artefact being a frequent problem. Although signal loss has been observed with breath-hold TrueFISP imaging, it's extent does not correspond to the region of turbulent flow (1).

The purpose of this research is to develop a segmented gradient echo sequence which results in a degree of signal loss similar to that obtained with a conventional sequence whilst allowing the entire acquisition to be performed in the duration of a single breath-hold.

Methods

This work was carried out on a Siemens Sonata scanner equipped with gradients having a peak strength of 40mT/m and a peak slew rate of 200mT/m/ms. Two sequences were developed, based on a simple segmented gradient echo sequence with increased flow sensitivity and view-sharing, as shown in Figure 1. In the first (a), velocity sensitivity was introduced with the addition of a bi-polar gradient in both the slice-select and read directions. In phantom and initial patient studies, the velocity sensitivity in both directions was adjusted to give a similar extent and degree of signal loss as a conventional gradient echo sequence with an echo time of 14ms. In the second (b), the gradient waveforms in the slice-select and read directions were modified to give an acceleration sensitivity, whilst maintaining velocity compensation. This involved the addition of extra gradient lobes between the slice selection and signal readout. The timing and magnitude of these lobes were such that the phase shifts due to acceleration in both directions were equal to those introduced by the conventional TE14 sequence.

The sequences developed in (a) and (b) had echo times of 6.9ms and 8.2ms respectively. Breath-hold acquisitions with 7 views per segment and view-sharing enabled the acquisition of cine data with effective temporal resolutions of 45 and 50ms over 18 cardiac cycles.

Conventional TE14 and breath-hold velocity and acceleration sensitised acquisitions were performed in 6 subjects with valvular heart disease. The images obtained were compared in terms of extent of signal loss and the artefacts present.

Results and Discussion

For all subjects, the breath-hold velocity sensitised, the breath-hold acceleration sensitised and the conventional TE14 sequences produced similar degrees of signal loss. The image quality obtained with the 3 sequences however was very different.

Figure 2 is a representative example showing the results of using these sequences in a subject with aortic stenosis and regurgitation. Figure 2(a) shows a single cine frame from a conventional sequence acquired over approximately 2 minutes showing signal loss at the valve plane which extends into the left ventricle. Respiratory motion artefact is also present and the image is considerably degraded, this being particularly apparent at the level of the diaphragm edge. Figures 2(b) and (c) show the corresponding cine frames from the velocity and acceleration sensitised breath-hold sequences shown in Figures 1(a) and (b) respectively, both showing a similar degree and extent of signal loss as the TE14 sequence. The image quality in Figure 2(b) however, is considerably degraded by artefacts from constant velocity blood flow which smears out in the phase encode direction. In comparison, the acceleration sensitised acquisition shown in Figure 2(c), where constant velocity material is rephased at the centre of the echo readout, is of high quality and devoid of both respiratory and blood flow artefacts.

The appearances observed in Figure 2 were similar for all subjects studied. It is thought that variations in blood flow velocities from beat to beat can result in phase variations and associated artefacts when using the velocity sensitised sequence, resulting in poor image quality. High acceleration and other high orders of motion however are present in the region of highly complex flow where the related phase shifts tend to result in signal cancellation.

Figure 2: Single frames from the conventional TE14 (a), the breath-hold velocity sensitised (b) and the breath-hold acceleration sensitised cine acquisitions (c).

Conclusions

We have developed a segmented sequence which is able to generate similar degrees of signal loss to a conventional gradient echo sequence. By comparison, the acquisition duration is considerably reduced and breath-hold imaging is feasible, removing respiratory motion artefact. Although the most obvious approach to generating signal loss is to add velocity sensitivity to a previously compensated sequence, as in Figure 1(e), we have shown that artefact from flowing blood degrades the images obtained (Figure 2(b)). Signal loss is instead best generated by using the acceleration sensitised sequence shown in Figure 1(b) where both stationary and constant velocity blood signal are rephased at the centre of the echo readout.
