Application of a Novel Motion Resistant Phase Ordering Technique to Segmented 2D Imaging of the Heart

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Introduction
Prospective navigator-echo controlled scans are a widely used as an alternative to breath-hold acquisitions, generating respiratory motion free images with minimal patient co-operation. Such acquisitions require the setting of a navigator acceptance window (typically 5mm), usually about the end expiratory pause position, resulting in a scan efficiency during steady free-breathing of typically around 40 - 45%. Phase ordering and weighting techniques have been shown to improve image quality for a given acceptance window (2,3) and these have been used for conventional 2D and segmented (multiple k, 3D acquisitions. Changes in the breathing pattern during the scanning period however are common and may result in unacceptable reductions in the scan efficiency, resulting in the need to abort the scan and reposition the acceptance window. This is a considerable drawback of any navigator technique relying on the definition of an acceptance window. The aim of this work is to investigate the application of a novel phase ordering technique to segmented (multiple k,) 2D acquisitions. The proposed technique does not require the setting of an acceptance window and is resistant to changes in the breathing pattern over the scan duration.

Method
The order of k, line acquisition within a data segment is generally interleaved to avoid signal discontinuities in k-space and the resulting artefacts. However, this interleaving precludes the use of phase ordering techniques and the k, lines are here acquired sequentially. The proposed technique, Phase-ordering with Automatic Window Selection (PAWS), uses a multi-level approach where no acceptance window is specified. Instead, the initial position of the diaphragm is taken as the reference and all further diaphragm positions are given an index position which is equal to the displacement from this reference. Each index position is allotted a starting position in a region of k-space and data segments fill k-space in an order determined by the diaphragm position. The phase ordering limits motion between successive data segments and motion artefacts are therefore minimised. A 2-1-2 weighting scheme is implemented which allows the edges of k-space to be filled with a 2mm range of motion whilst the centre of k-space is allowed only 1mm of motion. During an acquisition, all data segments are stored and the k-space coverage of those segments and the diaphragm positions at which they were acquired are continuously reviewed. As the acquisition proceeds, the stored data therefore consists of a number of partially completed k-spaces for a number of possible 5mm navigator acceptance windows. At any time, the k, lines acquired in the next data segment are then determined by how close to completion the k-space is for any possible 2-1-2 weighted 5mm range of diaphragm positions. The resulting image is completed in the fastest time possible for the breathing pattern prevailing at that time.

Transverse navigator-echo controlled segmented FLASH (8 views per segment) images were acquired in 4 healthy volunteers using a user defined navigator acceptance window about the end expiratory pause position and then when using the proposed Phase ordering with Automatic Window Selection (PAWS) technique. If the scan efficiency fell below 20% in any user defined window acquisition, the scan was aborted and the navigator acceptance window repositioned to take into account the respiratory drift that had occurred. The non-PAWS scans were performed with both sequential and non-sequential ordering of the k, lines within each data segment. In each subject, image quality was assessed by two independent observers.

Results and Discussion
The results showed no difference in image quality in the user defined navigator window acquisitions with sequential and non-sequential ordering of k, lines within each data segment. Similarly, there was no difference in image quality between the user defined navigator window acquisitions with sequential ordering of k, lines and those acquired with the PAWS technique. In two of the four subjects, the user defined navigator window needed to be reset to take into account respiratory drift and in one of these, the window was reset three times. One other subject narrowly missed redefinition of the navigator window when the scan efficiency in two consecutive scans fell from 59% to 24%. For all PAWS scans, a review of the respiratory trace data showed that the navigator window automatically selected during scanning was that which allowed the fastest completion of the scan for the breathing pattern at that time. As an example, the figure below shows the breathing patterns of 1 subject during the three data acquisitions. In this subject the navigator acceptance window was 295 - 300 and the scan efficiencies for the user defined window acquisitions ((a) and (b)) were 57% and 40%. The drift in the end expiratory pause position implicit in this reduction in scan efficiency continued for the PAWS scan (c) although in this case, the window selected automatically for respiratory motion control was 204 - 207. This enabled a high scan efficiency (67%) to be maintained despite the changing breathing pattern. If the predefined window of 295 - 300 had been used, only 8 out of 16 data segments would have been acquired over the same time period and the efficiency considerably reduced.

Conclusions
A method of respiratory motion control has been introduced which is resistant to changes in breathing patterns and allows images to be acquired in the shortest possible scan time for the breathing pattern prevailing at the time of acquisition. The need for a user defined navigator acceptance window has been removed with the PAWS technique automatically selecting the window enabling fastest completion of the scan. We believe this technique will aid in overcoming many of the current problems faced with navigator acceptance techniques, providing an ordering technique robust against changes in breathing which has previously not been possible.

References