A New Respiratory Gating Technique for Whole Heart cine MRI.

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Introduction: Whole heart cine imaging has become increasingly interesting as a way to simplify cardiac imaging. However, a fundamental problem with 3D cine techniques is the attendant difficulties with respiratory compensation. The application of navigator beams in cine imaging is complicated [1] since they are time consuming and perturb the steady state [2]. To overcome this limitation different self respiratory navigation approaches have been proposed, e.g. the respiratory signal can either be derived from center *k*-space (k_0 point) [3] or from a k_0 projection [4]. However, these techniques could be less successful in heavy patients, since both types of data can be highly contaminated by strong fat signal, which make the projection data less sensitive to diaphragm motion. Here, we present a new and robust technique to obtain respiratory motion during whole heart cine imaging. In this approach, we integrate the acquisition of an extra "slice navigator" within the b-SSFP sequence, i.e without disturbing the steady state, and use a specific coil element to read the navigator signal.

Method: ***MR Sequence***: Breathing motion was detected by integrating (e.g. every 70 ms) the acquisition of an extra slice navigator (Slice Nav) while maintaining the normal steady state of the magnetization in the imaging volume (Ima Vol). This was done by modifying a balanced SSFP sequence (figure 2) so that in two consecutive TRs an extra slice was exited (first TR) and readout for gating (second TR). The position and orientation of the slice navigator can be determined arbitrarily (fig.1). In order to restrict the signal reception to the slice navigator location, one specific coil element from a 32 channel coil was used (blue coil in Fig 1). Moreover, the crosss-talk from the normal imaging volume (Ima Vol) to the projection signal was reduced by performing additional dephasing gradients [5] (dephasing gradients in fig 2). The amplitude of the dephasing gradients was set to produce a small effect of the navigator slice, but producing a stronger dephasing of the larger imaging volume (180° over Ima Vol). Finally a pairing of the slice navigator was applied to reduce eddy current artifacts [6]. ***Respiratory signal***: The breathing motion was calculated by cross correlation of a "slice navigator kernel" with slice projections obtained in real time. This signal was used to gate the sequence, i.e. the *k*-space data was accepted or rejected, using an acceptance-window in millimeter. If the efficiency of the scan was below 25%, the position of the acceptance windows was recalculated based on a histogram of the positions over the last 30 seconds (drift correction). ***Experiments:*** The MR sequence and the algorithms were implemented in a 1.5 Philips clinical scanner using pulse programming software. An isotropic non-angulated volume covering the whole heart was acquired in 5 volunteers during a non respiratory gated and a respiratory gated scan (15 cardiac phases, res 2.5 mm^3, 50-60 slices, TR/TE = 3.1/1.5). The slice navigator (40mm, 45°flip angle) was positioned over the diaphragm parallel to the imaging volume. Moreover, projections from a k_0-profile from the same imaging volume were acquired for comparison.

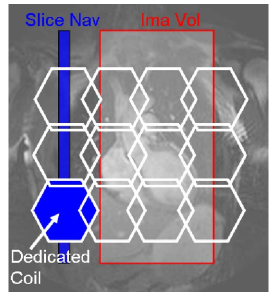

Figure 1. The imaging volume covers the heart, whereas an extra slice is exited to extract the position of the diaphragm

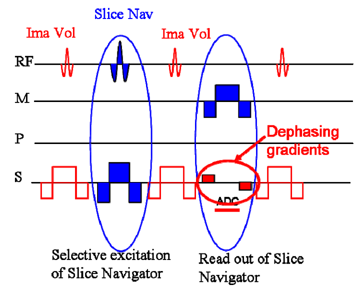

Figure 2. MR sequence diagram. Extra RF and gradients pulses are integrating into a b-SSFP sequence to excite an extra

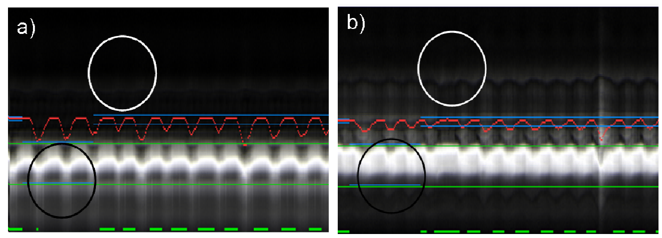

Figure 3. a) Projection of an excited slab positioned over the diaphragm and b) projection obtained from a k_0 profile.

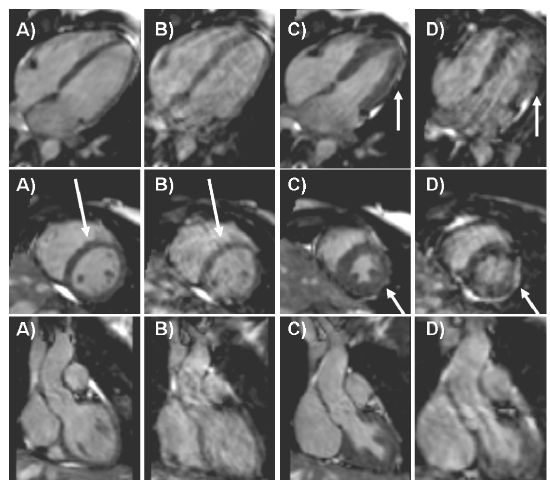

Figure 4. Reformatted slices of the gated (a,c) and non gated (b,d) scan during diastole (a,b) and systole (c,d) of the four chamber (top row), Short axis (middle row) and left ventricular output (bottom row) view of the heart.

Results: In all volunteers a robust respiratory signal was obtained. An example of the slice projections with time is shown in figure 3a, notice the clear borders of the projection and how the cross correlation accurately follows the breathing motion. An acceptance window of 6mm resulted in a gating efficiency of approx 45%. For comparison projections from a k_0 profile are shown in figure 3b), notice the different background contrast of the projections between 3a and 3b, especially in the black and white circle areas, which mark a better delineation of the diaphragm (black circle) and a "cleaner" projection using the proposed approach. Reformatted end diastolic and systolic views of the heart from the gated and non respiratory gated scan are shown in figure 4. Notice the improvement of the delineation of myocardium and papillary muscles in the gated scan.

Conclusion: We have proposed a new and robust method to derive breathing motion for whole heart cine imaging. An isotropic non angulated sagittal volume minimizes scan planning and allowed us to reformat the data at any view of the heart. The integration of an extra slice excitation and its readout into the steady state requires a careful design and some considerations have to be taken into account. (A) The phase introduced by the extra gradients has to be zero (balanced gradients). (B) Phase effects due to eddy currents of these additional gradients can be reduced by pairing them in consecutive TRs [6]. This method has a series of advantages in comparison with other self navigated techniques. Using a single k_0 point approach as proposed in ref. 3 the breathing signal is obtained from intensity modulations alone, which is less sensitive in 3D imaging. Using a complete profile as proposed in ref.4 improves respiratory detection, but the projection data could be contaminated with cardiac motion and could be less sensitive to breathing motion in heavy patients. Using the proposed method the slice projections are more sensitive to respiratory motion (as shown in fig 3a-3b). Moreover, rotating the slice navigator around the FH axis (fig 5) in conjunction with a dedicated coil, the contamination of projection by fat signal will be avoid and the navigator signal will become more similar to a normal navigator beam (fig 5). Furthermore we were able to obtain the diaphragm displacement in mm, which is not possible from an intensity modulation signal using a k_0 point and less robust using a k_0 profile. In conclusion, this new technique represents an easier and robust method for a whole heart examination, since it reduces time for scan planning and provides patient-friendly free-breathing examination.

References: 1 Peters D et al ISMRM 2006; 2 Scheffler K et al, Eur radiol 2003; 3 Brau et al MRM 2006;4 Uribe et al, MRM 2007, 5 Dixon et al, MRM 1986 ; 6 Bieri et al MRM 2005.

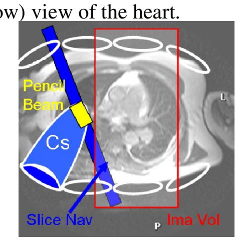

Figure 5. Rotating the Slice Nav in conjunction with a specific Coil Sensitivity (CS) will avoid the fat