Whole heart coronary angiography using self-navigated "paddle-wheel" balanced SSFP

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Introduction:

In conventional navigator echo technique which uses 1D navigator echo(es), the amount of information about respiratory motion is limited. 2D navigators are desirable, but it is difficult to acquire them within the limited amount of time. A novel 3D data sampling and image reconstruction scheme was developed and implemented, which uses image data itself for navigation. It uses combination of radial and recti-linear data sampling, and extracts 2D navigator images from the acquired 3D raw data set.

Methods:

The sequence uses segmented balanced-SSFP with fat suppression, similar to those used in navigator echo techniques. Following the trigger delay, a spectrally selective inversion pulse is applied to invert fat signal, and balanced SSFP data acquisition follows. A 5-pulse linear ramp startup sequence was used to stabilize the transient signal before SSFP acquisition. Navigator echoes were not used, and all of the raw data acquired were used for image reconstruction. The 3D k-space trajectory is illustrated in fig 1. After each R-wave trigger, a full 2D data set for a plane going through the kz-axis is acquired using a recti-linear trajectory. This is repeated with the sampling plane rotated around kz-axis slightly to cover the 3D k-space (paddle-wheel configuration). Typical imaging parameters were: 224 readout points, 400 projections, 64 slices, TR/TE = 4.0/2.0 msec. Readout length per trigger was 256msec, and imaging time was 400 heart-beats, or approximately 7 minutes. The image reconstruction / correction process is illustrated in the flow-chart (fig 3). By applying 2D FT to each plane, 2D projection images are obtained (fig 2). From these images, displacements caused by respiratory motion are estimated. The projection images are shifted to cancel these errors, and final images are reconstructed using these corrected projection images (fig 4). The pulse sequence was implemented on a 1.5T clinical scanner (GE Signa Excite, ver11.0), and image reconstruction was done offline on a workstation.

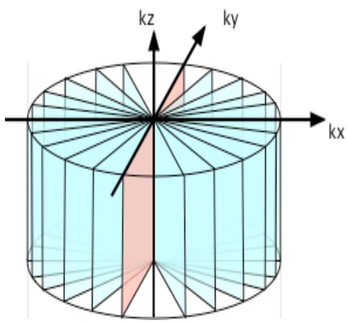

Fig. 1 k-trajectory

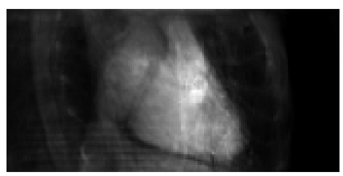

Fig. 2 Projection image

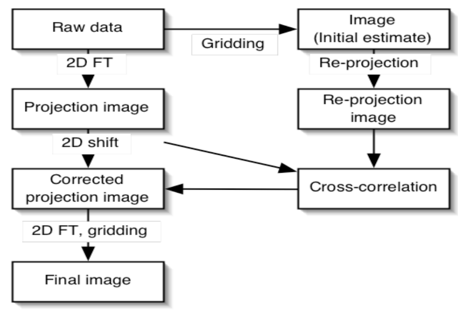

Fig. 3 Reconstruction flow-chart

Results and Discussion:

Reconstructed images are shown in fig 4. Even without respiratory correction, image quality was fairly good, but the coronary artery was blurred (fig 4 a). The image became much sharper after correction was applied for the respiratory motion (fig 4b).

Radial sampling is said to be resistant to motion artifacts, but this notion is somewhat misleading. Although less ghosts are recognizable due to the shape of ghost point spread function, there are more blurring since the center of k-space is always sampled. This redundant sampling near the center of k-space adversely affect both cardiac gating, and fat saturation in SSFP dada acquisition. It is advantageous to use recti-linear sampling during data acquisition block within each R-R period, since the center of k-space is sampled only for a short duration. On the other hand, radial sampling is more desirable for respiratory motion, since it is difficult to remove motion effects completely by navigator techniques, and image quality is not much degraded even if small error is remaining. By combining recti-linear and radial sampling in "paddle wheel" configuration where each plane is acquired during a single R-R period, it becomes recti-linear for cardiac motion, and radial for respiratory motion.

The 2D projection images do not contain information on positional error along projection direction, but it does not affect the reconstruction results anyway. Although a simple translation assuming rigid-body was used for correction as an initial implementation, it is possible to use more sophisticated correction methods like affine transform, which will further improve the final image quality.

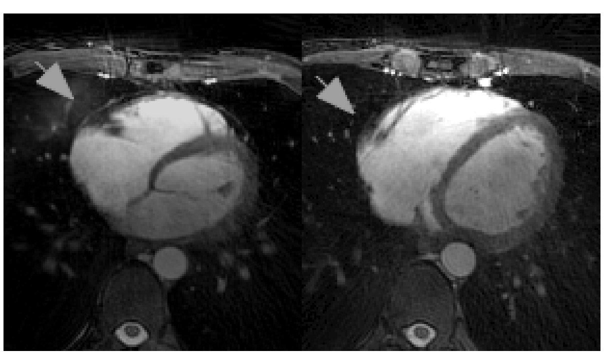

Fig. 4a Before correction

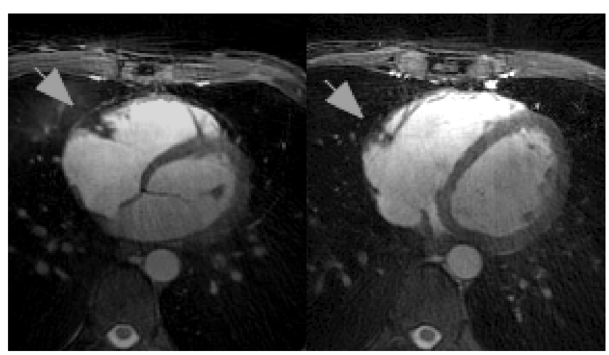

Fig. 4b After correction