3D Cardiac Cine Imaging in a single Breathhold using Elliptically reordered 3D TrueFISP

Klaus SCHEFFLER

1Universität Freiburg, Radiologische Klinik, Freiburg, Germany;

Introduction
The TrueFISP sequence as proposed by Oppelt et. al. in 1986 (1) offers a high contrast between myocardium and intraventricular cavity, which is desirable for accurate assessment of ventricular function. A significant drawback of TrueFISP is its sensitivity to offresonance effects caused by an imperfect shim, chemical shifts, eddy currents, and Maxwell effects. An extension of the 2D TrueFISP sequence to an ecg-gated 3D TrueFISP sequence is thus not straightforward and requires a very carefully designed acquisition scheme. The current implementation of our gated 3D TrueFISP sequence allows to acquire the complete heart in its diastolic phase within about 20 heartbeats with a resolution of 2 x 2 x 3 mm. In addition, a 3D TrueFISP cine technique with a time resolution of 50 to 90 ms and a spatial resolution of 3 x 4 x 4 mm was implemented.

Methods
Besides offresonance effects generated by different susceptibilities and chemical shifts, eddy currents are a further source of signal insabilities for the TrueFISP sequence.

Linear phase encoding as used for 2D TrueFISP sequences generates a smooth variation of the phase gradient amplitudes, and the nearly balanced amplitudes of the phase encoding gradients before and after the RF pulse act as an intrinsic eddy current compensation. In conventional 3D sampling patterns, however, 3D k-space is scanned line by line for each linearly increasing partition step. As a result, after each completed line scan, the line position is rewinded from the outermost position to the starting position while increasing one step in partition direction. At this point the intrinsic eddy current compensation fails since here the line phase encoding gradients have same amplitudes before (rewinder) and after (prewinder) the RF pulse. An alternating or zigzag sampling trajectory through lines and partitions as shown in Fig. 1 is proposed that eliminates this effect. This sampling pattern provides a smooth and small variation of the k-space encoding position between any succesiv step of the encoding procedure.

Fig. 1: Elliptic, alternating k-space scan to reduce eddy currents

3D TrueFISP images acquired with this alternating scan show significantly reduced artifacts as compared to the conventional, line by line scanning method, see Fig. 2.

Fig. 2: Comparison of conventional and alternating k-space scan

An ecg-gated 3D TrueFISP technique was implemented on a Siemens Sonata system with a TR of 2.8 ms. The time resolution of successive 3D data sets was about 50 and 90 ms, depending on the required spatial resolution. The complete 3D+1D data set was measured within one breathhold (20 to 24 heart beats) which gives a total acquisition time of 1 to 2 seconds for each 3D data set. In order to speed up image acquisition an elliptical, alternating sampling pattern as shown in Fig. 1 was implemented. This scheme reduces the number of phase encodings by about 25% compared to rectangular sampling, with nearly the same image resolution.

Results
Figure 3 shows a comparison between a 2D and a single slice out of a 3D TrueFISP data set measured on the same patient. Besides an increased SNR the 3D slice shows a stronger contrast between blood and myocard (CNR = 38) as compared to 2D images (SNR = 9.6). The different contrast between single shot 2D and 3D TrueFISP is based on the T2/T-weighted signal intensity of steady-state TrueFISP whereas single shot 2D TrueFISP is more proton density weighted.

Fig. 3: Contrast of 2D versus 3D TrueFISP

Figure 4 shows some 3D images out of a 3D cine data set measured with a time resolution of 49 ms (every second 3D frame is depicted). The 3D resolution (3x4x4 mm³) seems to be sufficient to calculate myocard and blood volumes, and ejection rates.

Fig. 4: Short axis view (source images)

Fig. 5: MPRs along the long axis

Discussion
The presented 3D acquisition scheme allows to measure time resolved 3D data sets within a single breathhold. The high SNR and CNR between blood and myocard of 3D TrueFISP makes this technique to an ideal tool for the assessment of ventricular functions. The time resolution (or the spatial resolution) can be further increased by a factor of two using half Fourier or view sharing techniques. Further increase in time or spatial resolution may be possible with parallel imaging techniques such as PILS (2), SENSE, or SMASH.

References