Flow Quantification by Dual Echo Phase Contrast SSFP

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Introduction: Phase contrast flow quantification with balanced SSFP (PC-SSFP) is still in development phase. At the moment there are three main approaches to phase contrast measurements with SSFP [1,2,3,4]. One of the approaches is the dual-echo technique, presented by Pai et al. [4]. This method uses a flyback gradient between two echoes during which velocity encoding is performed. The main advantages of this approach are the preservation of the steady state for single direction velocity measurements and the time efficiency of a phase difference measurement in one TR. The main disadvantage is that the TR is considerably prolonged. This abstract assesses image quality and accuracy of flow quantification with dual echo PC-SSFP for the application of cardiac output measurements.

Method: The dual echo PC-SSFP sequence was implemented on a 1.5T scanner (Sonata, Siemens, Erlangen). Cardiac output was measured in seven healthy volunteers by through plane velocity measurements in the ascending aorta at the level of truncation of the pulmonary artery. The same measurement was also performed using a conventional phase contrast spoiled gradient echo (PC-GE) sequence for comparison. Every measurement was performed twice to assess the influence of physiological differences. Imaging parameters were: spatial resolution 1.25x1.25x8 mm^3, matrix 256x205, 30 reconstructed phases, V_{enc} 150 cm/s through plane. PC-SSFP: TR 5.8 ms, TE 1.75/4.0 ms, 5 segments, flip angle 70º, duration ~50 s. PC-GE: TR 11 ms, TE 4.8 ms, flip angle 15º, duration ~3½ min. For the PC-SSFP a locally adjusted shim was used. Images were analyzed with commercial software (Flow, Medis, Leiden). To correct for an offset in the velocity map, end-diastolic velocity was set to zero.

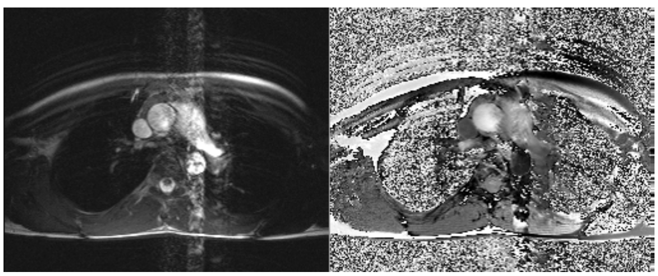

Figure 1: Typical dual echo phase contrast images (trigger delay 185 ms). Left: Magnitude image of first echo. Flow artefacts due to the long TR of 5.8 ms are visible. Right: Phase difference image. Most striking is the large water-fat difference.

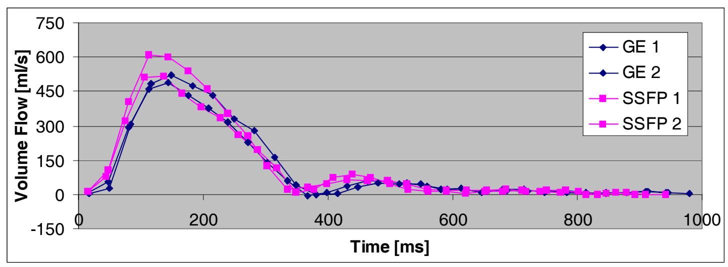

Figure 2: Typical flow curves from PC-SSFP and PC-GE in one healthy subject. Flow curves show good agreement between the two sequences.

Results: PC-SSFP images showed better SNR than PC-GE. There were considerable artifacts during systole (fig. 1), due to through plane flow in combination with the long TR (5.8 ms). Shimming reduced artifacts but could not completely remove them. Artifacts within the ascending aorta remained in four cases and some overlapping artifacts from other large vessels remained in five cases. In the phase difference images water-fat differences due to the different TE's were observed. The TE difference of 2.3 ms maximized the water-fat difference at 1.5 Tesla. Also, there was a large phase offset over the image. Flow curves from PC-SSFP showed agreement with the PC-GE curves (fig. 2). PC-SSFP measurements tended to overestimate flow during systole, due to the artifacts from through plane flow. Cardiac output correlated between the two techniques (R 0.85), with a significant RMS error of 1.0 liter per minute. Especially in those cases where artifacts originated from multiple vessels, cardiac output was significantly higher in PC-SSFP measurements (fig. 3).

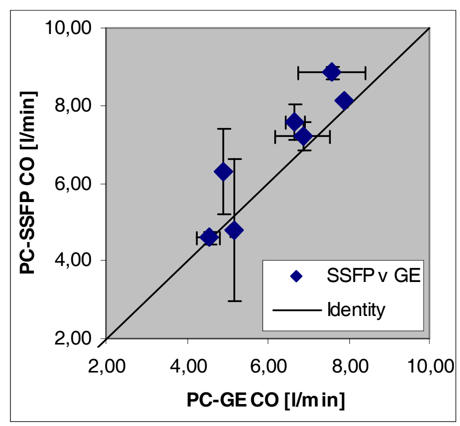

Figure 3: Cardiac output measurements. Data points are averages of two measurements, error bars show the standard deviation.

Discussion: Dual echo PC-SSFP has advantages over PC-GE: it is faster or has a better temporal resolution, and image contrast is improved. On the other hand there were considerable artifacts due to the long TR in combination with through plane flow [5]. A locally adjusted shim reduced artifacts to an acceptable level in most cases. Rotation of the image plane might further reduce overlap of artifacts from other vessels onto the aorta. Offset correction is necessary, as besides uncompensated eddy currents and Maxwell concomitant terms, off-resonance effects also result into velocity offsets. Offset correction is problematic, the water-fat phase difference prevents correction from the images themselves [6]. To remove water-fat effects, the TE difference should be increased to 4.7 ms, creating a too long TR. However, at 3T this effect can be compensated without TR penalty.

References: 1. Bieri O et al. MRM 2005;54:901-907. 2. Markl M et al. MRM 2003;49:945-952. 3. Overall WR et al. MRM 2002;48:890-898. 4. Pai VM et al. Proc ISMRM 2006;14:1899. 5. Markl M et al. JMRI 2004;20:697-705. 6. Hofman MBM et al. Proc ISMRM 2005;13:1733.