Three-dimensional time-resolved flow quantification with balanced SSFP

F. Santini[1], S. G. Wetzel[2], and K. Scheffler[1]

[1]MR-Physics, Institute of Medical Radiology, University of Basel/University Hospital, Basel, BS, Switzerland, [2]Dept. of Neuroradiology, Institute of Medical Radiology, Basel University Hospital, Basel, BS, Switzerland

Introduction. The analysis of three-dimensional flow patterns is becoming an important tool for investigating hemodynamics and flow patterns of body fluids in general. The existing methods for three-dimensional time-resolved flow quantification [1] are based on radiofrequency spoiled gradient echo sequences that give very low signal from fluids because of spin saturation effects when TR << T_1. Here, we show the feasibility of a three-dimensional, three-directional flow sensitive phase-contrast balanced SSFP (bSSFP) sequence, which overcomes the problem of saturation and enables imaging of tissues with long relaxation times and little or no inflow enhancement effect, like cerebro-spinal fluid. In order to maintain the very sensitive steady-state of the bSSFP sequence, flow compensation at the end of TR was implemented, and k-space pairing [2] was adopted as a method for reducing artifacts due to eddy currents.

Material and methods.

Sequence development. A prospectively triggered 3D bSSFP sequence was implemented, with constant flow sensitivity at TE and flow compensation at TR. To achieve this, a custom iterative algorithm that calculates the optimum gradient parameters was developed. This algorithm finds the shortest bipolar gradient shape with given zeroth and first moments, taking into account the hardware constraints (discrete gradient event timing, slew rate and amplitude limitations). Zeroth moment relates to k-space location and SSFP balancing conditions, and first moment relates to flow sensitivity and compensation. The used flow encoding scheme is the "balanced four-points" phase-contrast method as described in [1], for optimal efficiency. To apply the "k-space pairing" principle, two adjacent k-space lines are acquired consecutively, as shown in figure 1.

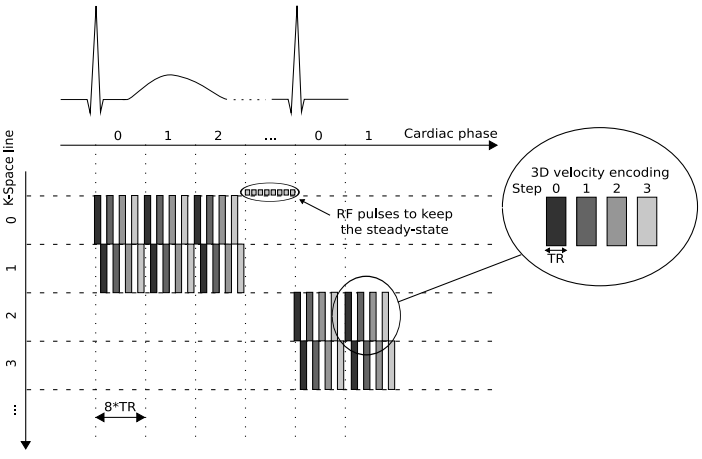

Fig. 1: Flow encoding scheme. The four different gray levels correspond to the flow encoding steps.

Experimental setup. To prove the applicability *in vivo*, the sequence was used to acquire datasets of cerebral vessels and of CSF circulation in the neck in four different healthy volunteers. The scanning parameters for blood vessels were the following: Venc 100cm/s, TE 4.8 ms, TR 9.6 ms, flip angle 70°, matrix size 128x128x10, spatial resolution 2.3x2.3x3 mm^3, temporal resolution 76.8 ms; and for CSF the following: Venc 10cm/s, TE 6ms, TR 12ms, flip angle 70°, matrix size 128x128x22, spatial resolution 1.1x1.1x2mm^3, temporal resolution 86ms. All the scans were performed on a 1.5T whole-body scanner (Avanto, Siemens Medical Solutions, Germany). The flow patterns were reconstructed using commercial 3D visualization software (Ensight, CEI, NC).

Results. The images obtained with the sequence did not show any significant artifact contamination, and the reconstructed flow images showed a very high accuracy in representing the flow patterns, and the measured flow velocities were within the physiological ranges. In detail, CSF flow patterns are shown as vector fields in fig. 2. These images clearly show the dependency of the flow intensity and direction from the cardiac phase, showing backflow in the last acquired phase, and also depicting in-plane flow components that present a non-constant behavior during the cardiac cycle.

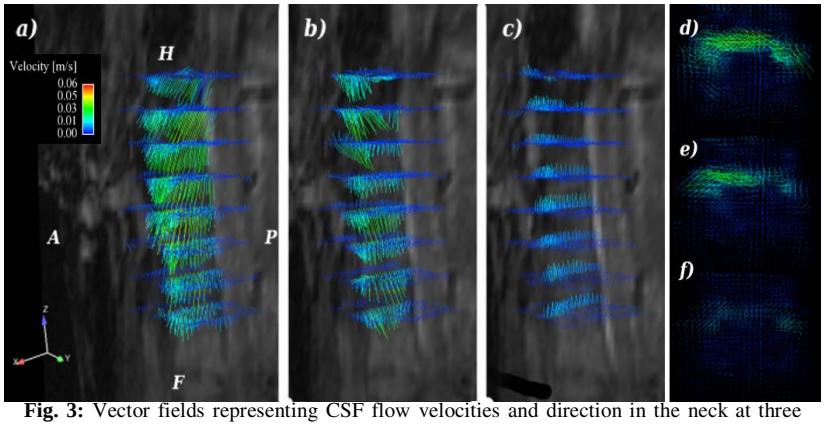

Fig. 3: Vector fields representing CSF flow velocities and direction in the neck at three different cardiac phases, in oblique coronal view (*a, b* and *c*) and axial view (*d*, *e* and *f*).

Discussion. Three dimensional time-resolved phase contrast bSSFP can be effectively used for the imaging of tissues with long T1 relaxation times, when there is no inflow enhancement effect and contrast agent injection is not possible or not desirable. In particular, it resulted especially useful in the imaging of CSF. The drawbacks of this technique include the possible appearance of bSSFP-specific artifacts like banding, especially because of the long TR that are necessary for the complete gradient compensation. The time resolution is also affected by the longer TR and by the "pairing" implementation.

References. [1] Markl M. *et al*., J Magn Reson Imaging 2003;17(4):499-506. [2] Bieri O *et al.*, Magn Reson Med 2005;54(1):129-137.