Morphing-SSFP: A new method for fast detection of strong magnetic field inhomogeneities and its application for tracking ferromagnetic devices

O. Bieri[1], S. Patil[1], and K. Scheffler[1]

[1]MR-Physics, Department of Medical Radiology, University of Basel / University Hospital, Basel, Switzerland

Introduction. There is increasing interest in methods that are able to guide endovascular devices in interventional MRI (1,2) or to visualize labeled cells with super paramagnetic iron oxides (SPIOs) (3). Here, we focus on the development of a passive method that is able to produce positive contrast from susceptibilities only. That is: (i) background signal is nulled and (ii) strong susceptibility changes, as either produced by SPIOs or iron-coated guide-wires for vascular interventions generate a positive signal. The proposed method bases on morphing steady state free precession (SSFP) sequences. Morphing SSFP is a chimera type of sequence, that is, in regions close to abrupt susceptibility changes, it will acquire a balanced echo (bSSFP: TrueFISP, balanced FFE, FIESTA), whereas in all other regions a spin-echo (SSFP-echo: PSIF, T2-FFE, CE-FAST) will be formed. In combination with low flip angles, morphing-SSFP is a promising new concept for fast generation of positive contrast from susceptibility effects.

Methods. Measurements were performed on a Siemens Avanto 1.5 T system. In Fig. 1, the concept of morphing-SSFP is displayed (left: balanced SSFP, non-alternating RF; middle: SSFP-echo). Susceptibility changes from SPIO's or guide-wires can locally generate strong gradients (ΔGx in Fig. 1). Thus, at the end of any repetition time (TR) susceptibilities may compensate the dephasing inherent to the SSFP-echo sequence to reach a balanced SSFP status, i.e. zero dephasing (right). However, at the time of echo formation (or echo readout), i.e. TE=TR/2, compensation for isochromats experiencing zero-dephasing within TR is only completed half (only 64% of the full signal amplitude is reached so far). Using very low flip angles in bSSFP, results in the full signal amplitude at on-resonance, whereas the signal from SSFP-echo is drastically reduced (up to two order in magnitude, see Fig. 2).

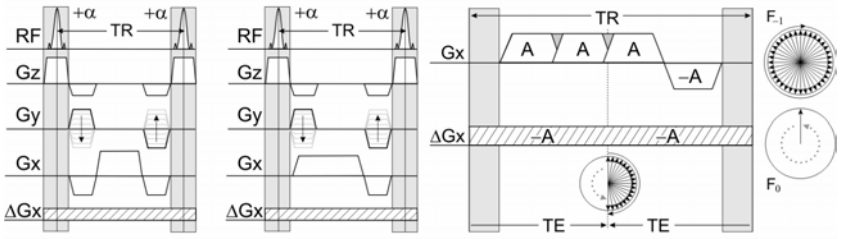

Fig.1: Balanced SSFP (left). SSFP-echo (middle). Any local gradient, ΔGx, may compensate for the inherent dephasing in SSFP-echo to produce a balanced SSFP type of sequence (right).

Results & Discussion. Morphing SSFP was tested on an iron-coated guide-wire using a custom-built phantom as shown in Fig. 3 (left). 11 mm diameter tubes model large vessels and were immersed in a gadolinium (Gd)-doped water. The outer container was filled with 2% agarose gel doped with 0.5 mM copper sulphate (CuSO4) concentration to closely resemble the relaxation times of muscle tissues. Coronal images were acquired with image encoding (Gx) along the main magnetic field (along the tubes). Low flip angles with SSFP result in a vanishing stimulated echo signal. Clearly, any signal, from any tissue is strongly suppressed. However, regions near the guidewire's iron-coating again appear as bright spots (Fig. 3, right). Thus local gradients near the marker compensate for the SSFP dephasing to produce a balanced SSFP type of echo. From 3D measurements, we reconstructed an isosurface and three projections (Fig. 4) from the optioned positive contrast signals (using α=1.5°). A simulation of the gradient produced by the guidewire is shown as inset. Calculations were done using Matlab 7.0 (The Mathworks Inc). The ring-like surface appears on one side of the coating, whereas the dot appears on the antipode. An inverted gradient readout (i.e. –Gx as compared to +Gx in Fig. 1) results in a flip of the intense signals with respect to the coating (not shown), in accordance with the expected symmetry.

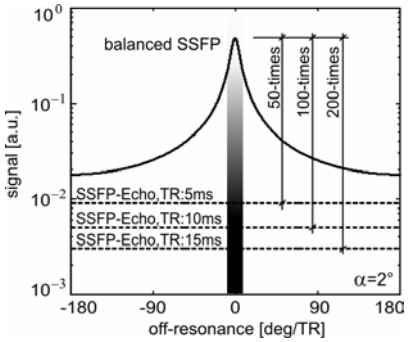

Fig.2: Balanced SSFP vs. SSFP-echo for low flip angles and different repetition times.

Conclusion. We have given evidence, that the proposed new method of SSFP morphing is able to produce positive contrast from susceptibilities, while keeping a vanishing background signal. Since positive signals relate to a balanced SSFP type of acquisition, morphing is flow insensitive. SSFP morphing is a promising new concept for fast detection of positive contrast from SPIOs or for passive tracking of interventional devices.

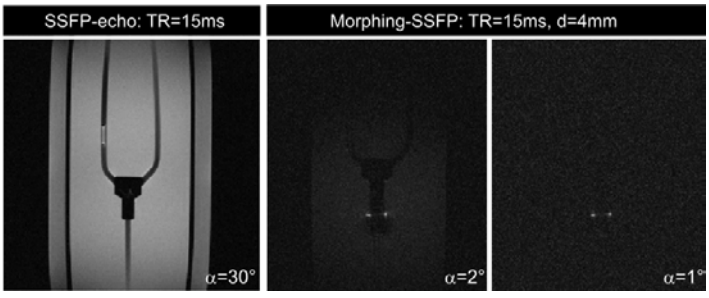

Fig.3: (left) Common SSFP-echo image of the phantom. (middle) Morphing SSFP clearly localizes the position of the guide-wire by positive contrast (bright spots). Residual background signals can be further reduced by decreasing the flip angle (right).

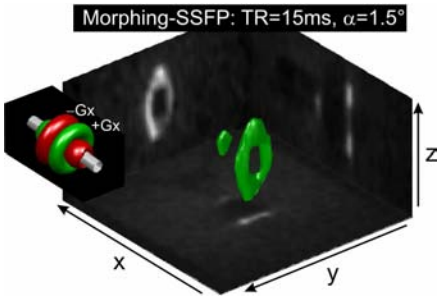

Fig.4: Isosurface reconstruction from positive contrast of 3D morphing SSFP measurements. Positive contrast forms in front (dot) and on the side (ring) of the coating (see sketch).

References. (1) Wacker FK et al. *Magn Reson Imaging Clin N Am* **13** (2005). (2) Mekle R et al. *JMRI* **2**3 (2006). (3) Bulte JW & Kraitchman DL, *NMR in Biomed* **17** (2004).