Feedback field control improves the accuracy of $T_2^*$ mapping at 7T

Michael Wyss¹, Yolanda Duerst¹, Bertram Wilm¹, David Brunner¹, Benjamin Dietrich¹, Thomas Schmid¹, Christoph Barmet², and Klaas Pruessmann¹

¹Institute for Biomedical Engineering, University of Zurich and ETH, Zurich, Zurich, Switzerland, ²Skope Magnetic Resonance Technologies, Zurich, Switzerland

INTRODUCTION
At high field strength $T_2^*$ weighted imaging suffers from artifacts due to field fluctuations caused by breathing motion¹. Thereby the achievable accuracy of quantitative analysis such as for $T_2^*$ mapping can be heavily impacted. To correct for such fluctuations it has been proposed to use phase navigators² or magnetic field monitoring³. However such post-acquisition correction methods cannot restore inherent information loss, e.g. due to RF pulses being applied off-resonance or signal loss due to through-plane dephasing. Therefore we propose to employ real-time higher-order field control⁴ based on NMR field sensors and dynamic shim actuation providing full 3rd order real-time field compensation. The system has recently been demonstrated to stabilize the field during MRI at 7T⁵. Thereby breathing artifacts in $T_2^*$ weighted images could be effectively removed⁶. The aim of this work is to explore the utility of this approach for enhancing the accuracy of $T_2^*$ mapping.

MATERIAL & METHODS
All measurements were performed on a whole-body 7T MR system (Philips Healthcare, Cleveland, USA) using a quadrature transmit head coil together with a 32-channel receive array (NOVA Medical, Wilmington, USA). To test the benefit of the method, $T_2^*$ maps of a phantom (liquids doped with CuSO4 to typical in-vivo $T_2$ values) were acquired using a 2D multi-echo gradient echo sequence (10 echoes, $TE=3-33$ ms, $TR=400$ ms, matrix=260x250, FOV=130x130 mm²) with and without feedback field control. The field update rate was 10 Hz. Breathing related field perturbations were simulated by moving a water bottle (5 liters) periodically between 54 cm and 65 cm distance from the phantom along the z-direction. For reference the scan was repeated without field perturbations. The method was also tested in-vivo with a normally breathing subject. Five (in-vivo) and ten (in-vitro) repeated measurements with and without field feedback were recorded. In the in-vivo data the standard deviation of resulting $T_2^*$ estimates was analyzed for a selection of anatomical regions.

RESULTS
Without field control, breathing-type field fluctuations induced strong artifacts in the phantom data (Fig. 1b), especially at long TE. Feedback control removed these artifacts virtually entirely (Fig. 1c), achieving similar results as in the control experiment (Fig. 1a). The correction propagates to resulting $T_2^*$ maps (Fig. 1d-f). Analysis of these maps confirmed a strong decrease in the standard deviation of $T_2^*$ estimates from 2.28 ms to 0.48 ms (reference experiment: 0.38ms) by field control, which is also reflected in the box plots (Fig. 3). In the in-vivo experiment, field control likewise strongly reduced breathing artifacts in both the $T_2^*$ images and the $T_2^*$ maps (Fig 3a-d). The standard deviation of $T_2^*$ values over repeated measurements was reduced by 30% on average over the evaluated anatomical regions (Fig 4).

DISCUSSION/ CONCLUSION
The results of this study indicate that real-time higher-order field control significantly improves the accuracy of $T_2^*$ mapping in the head at 7T, as shown in phantom experiments and in-vivo. On this basis, it is anticipated that the control approach may be equally beneficial in susceptibility-weighted imaging (SWI) and quantitative susceptibility mapping (QSM). Addressing fields generated by motion of magnetized tissue, the utility of field control is expected to further increase with field strength beyond 7T.

REFERENCES
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Figure 1: Phantom images. $T_2^*$ weighted images (a-c) and calculated $T_2^*$ maps (d-f)

Figure 2: Without feedback ringing like artifacts in the $T_2^*$W image (a) and large intensity variations between corresponding structures (e.g. thalamus left/right) in the $T_2^*$ map (b), are apparent. These artifacts are effectively removed when turning on field feedback (c, d).

Figure 3: Variation over 10 measurements for liquid 3 (5.173g CuSO45H2O/L). Boxplots showing the median (red), 25th and 75th percentiles (blue box), and the whiskers indicates minimum and maximum values.

Figure 4: Variation over 5 measurements for different anatomical regions. Feedback field control significantly reduced the standard deviation of $T_2^*$ values in all but one region of interest.