2D CINE SSFP Imaging At 7.0T Using 8-Channel Bowtie Antenna Transceiver Arrays: A Cardiac MR Feasibility Study

Oliver Kraus[1], Matthias Dieringer[1,2], Fabian Hezel[1], Lukas Winter[1], Andreas Graessl[1], Celal Oezerdem[1], and Thoralf Niendorf[1,2]

[1]*Berlin Ultrahigh Field Facility (B.U.F.F.), Max-Delbrueck Center for Molecular Medicine, Berlin, Germany,* [2]*Cardiovascular Magnetic Resonance, Experimental and Clinical Research Center, A joint cooperation between Charité Medical Faculty and Max-Delbrueck Center for Molecular Medicine, Berlin, Germany*

Target audience: This work is of interest for clinical scientists, basic researchers and engineers interested in cardiac MR imaging at ultra-high magnetic fields ($B_0 \geq 7.0T$).

Purpose:

Dynamic CINE imaging of the heart is of high clinical relevance for the assessment of cardiac morphology, myocardial contractile function and wall motion. Due to the excellent blood/myocardium contrast (BMC) steady state free precision (SSFP) imaging has become the gold standard for cardiac chamber quantification and left ventricular function assessment at 1.5T. Since SSFP "recycles" both longitudinal and transversal magnetization it provides very high signal intensity relative to the applied radiofrequency power [1]. But this recycling of the magnetization only works if the steady state is not corrupted by static magnetic field (B_0) inhomogeneities, transmission field (B_1^+) non-uniformities and/or cardiac motion artifacts. While the latter can be overcome by cardiac gating/triggering, B_0 and B_1^+-inhomogeneities present major obstacles for SSFP imaging free of off-resonance and banding artifacts at ultrahigh fields [2,3]. Realizing these challenges together with the gain of signal-to-noise ratio and blood/myocardium contrast-to-noise ratio inherent to UHF-MR this work examines the feasibility of *in vivo* 2D CINE SSFP of the heart at 7.0T. For this purpose an eight channel transceiver array tailored for cardiac MR that uses bowtie antenna elements was employed.

Methods:

All images were acquired on a 7.0T whole body scanner (Magnetom, Siemens Healthcare, Erlangen, Germany). A one-dimensional array of eight radiative bowtie antennas was used for Tx/Rx [4,5] with four elements placed anterior and four elements posterior of the subjects upper torso (Fig. 1 left). The eight bowtie antennas were fed by an RF power amplifier (RFPA) which can be driven in multiple or single feeding channel mode (peak power maximum=8kW). In the multiple feeding RFPA mode phases and amplitudes of all eight transmit channels can be adjusted individually. By handing over relative B_1^+-maps into an implemented optimization algorithm a homogeneous excitation pattern over the region of interest (ROI) was achieved as demonstrated by the uniform signal intensity observed for 2D CINE FLASH imaging (Fig. 1 right). For the single channel feeding mode the RF input power was equally split into the eight transceiver elements. The obtained transmit phase-setting from the multi-feeding mode was realized via extra cabling. To obey local SAR limits given by the IEC [6] electro-magnetic field simulations using CST Studio Suite 2012 (CST AG, Darmstadt, Germany) together with the voxel model "Duke" from the "Virtual Family" were performed. Volume selective B_0 shimming using shim volumes adjusted to cover the entire heart was conducted to reduce B_0 inhomogeneity. This approach reduced out-of-slice flow artifacts. A SSFP frequency scout was conducted ($\Delta f_0 = \pm 300$Hz, 50Hz increments) to shift the remaining SSFP banding artifacts outside the target region. Retrospective acoustic cardiac triggering (easyACT, MRI.TOOLS GmbH, Berlin, Germany) was used to acquire single breathhold 2D CINE SSFP images (matrix=256x256, spatial resolution=1.3x1.3x4mm³, 25 cardiac phases).

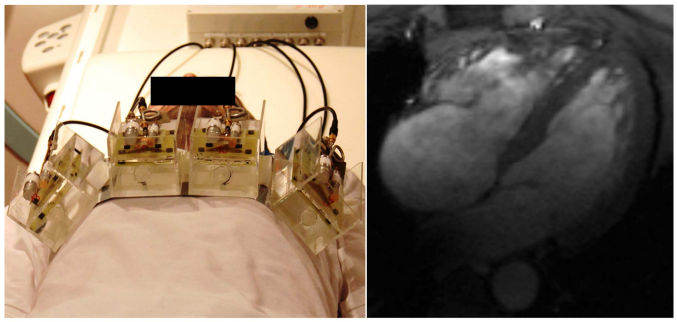

Fig. 1: left) *In vivo* Tx/Rx-array setup with four radiative bowtie antennas anterior. The remaining four elements are located posterior forming a ring around the upper torso. **right)** Four chamber view of the heart derived from 2D CINE FLASH at 7.0T showing a rather uniform signal intensity across the heart.

Results:

With the bowtie antenna approach the directional energy flux density of the electromagnetic field is oriented toward the heart. This ensures that the propagating wave is efficiently emitted toward the heart which results in a reduction of destructive B_1^+-interferences as shown in Fig. 1 (right) for 2D CINE FLASH (T_E/T_R=1.8/4.2ms, GRAPPA R=2, BW=444Hz/Pixel). The four chamber view (4CV) shows subtle anatomical structures such as the valves. For 2D CINE SSFP (Fig. 2) a uniform BMC was found for the left ventricle which indicates a rather homogeneous excitation of the heart (nominal flip angle=28°, T_E/T_R=1.4/3.2ms, BW=849/Pixel). However, SNR and CNR reduction was observed for deeper lying regions such as the right and left atrium. B_0-shimming and frequency scouting helped to increase the SSFP passband width and to shift banding artifacts. Peak-to-peak B_0-inhomogeneities across the heart were found to be approximately 600Hz and 500Hz for four chamber and short axis (SAX) views of the heart, with the B_0 gradient being most pronounced at the heart-lung interface. Within the heart the B_0-homogeneity was well below 300Hz for 4CV and SAX views. This afforded 2D CINE SSFP imaging of the heart (T_R=3.2ms) being either free of B_0-artifacts or showing only minor banding artifacts at 7.0T. For the left ventricle the peak-to-peak B_0-variation was 170Hz (4CV) and 240Hz (SAX).

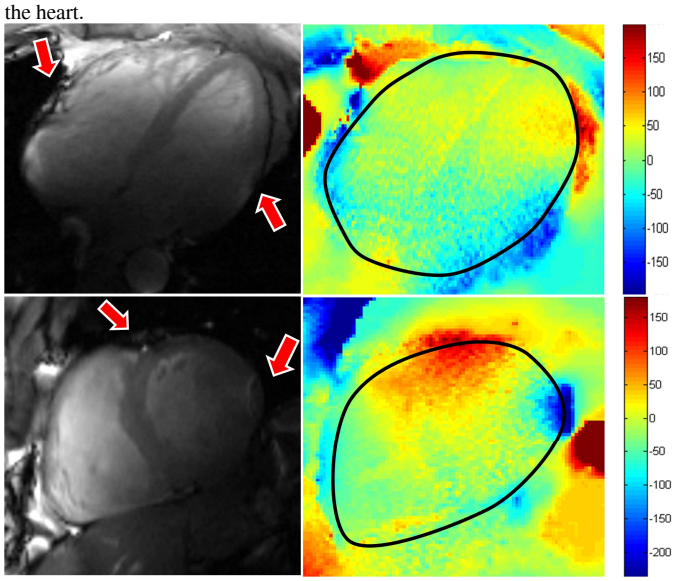

Fig. 2: 2D CINE SSFP images of the heart acquired at end diastole including **top left)** a four chamber view with minor banding artifacts only at the lung-heart interface of the lateral wall and **bottom left)** a short axis view with a minor banding artifact at the inferolateral myocardial segment (Segment 11 according to AHA convention). **right)** Relative B_0-maps showing a rather uniform B_0-field across the heart but major susceptibility gradients at the lung-heart interface

Discussion:

Our results demonstrate that an array of eight radiative bowtie antennas provides a rather uniform B_1^+ excitation field and presents a valuable alternative for parallel transmit at UHF-CMR. The homogeneous B_1^+-distribution obtained for 2D CINE SSFP imaging at 7.0T is heartening and the driving motivation to further offset RF power deposition constraints which prohibited a further increase in the nominal flip angle. For bandwidth truncated 2D excitation pulses our simulations predict an optimal BMC at a flip angle of 66° for SSFP imaging at 7.0T. The optimal BMC is expected to be 50% higher than in the images shown here.

Conclusion:

In conclusion we anticipate to implement more sophisticated approaches for SAR management including local SAR monitoring using virtual observation points (VOPs) [7] or specially tailored RF-pulses [8] to increase the excitation flip angle and thereby BMC. An implementation of a controlled spoiling mechanism for off-resonances holds the promise to compensate adverse effects of inevitable B_0-inhomogeneities [9].

References:

[1] Scheffler K, et al., Eur Radiol (2003) [2] Suttie J, et al., NMR in Biomed (2011) [3] DelaBarre L, et al., p. 596, ISMRM (2011) [4] Winter L, et al., p. 543, ISMRM (2012) [5] Oezerdem, C., et al., p. 2641, ISMRM (2012) [6] IEC 60601-2-33 Part 2-33, Ed. 3.0 (2010) [7] Eichfelder G, Gebhardt M, Magn Reson Med (2011) [8] Saekho S, et al., Magn Reson Med (2006) [9] Nielson JF, et al., Magn Reson Med (2012)