7T Human in vivo Cardiac Imaging with an 8-Channel Transmit/Receive Array

S. Maderwald[1,2], S. Orzada[1,2], L. C. Schäfer[1,2], A. K. Bitz[1,2], I. Brote[1,2], O. Kraff[1,2], J. M. Theysohn[1,2], M. E. Ladd[1,2], S. C. Ladd[1,2], and H. H. Quick[1,2]

[1]Erwin L. Hahn Institute for MRI, Essen, Germany, [2]Department of Diagnostic and Interventional Radiology and Neuroradiology, University Hospital Essen, Essen, Germany

Introduction:

There are numerous reasons why cardiac MRI at high field strengths is a potentially challenging endeavor: the heart is subject to cardiac and breathing motion, necessitating peripheral pulse or preferably ECG-triggered sequences with breath holds or navigator sequences to capture the beating heart. Moreover, MRI signal generation is difficult due to inhomogeneous RF signal transmission [1] caused firstly by the heart's position deep within the body and the surrounding lung tissue, and secondly due to the reduced Larmor wavelength at 7 T of approximately 12 cm, which is shorter than the dimensions of the human body. This reduced wavelength causes B_1 inhomogeneities that can lead to destructive B_1 interference (signal voids). Another issue is the specific absorption rate (SAR): the maximum applicable energy often constrains the choice of imaging sequence parameters [2]. The purpose of this study was to transfer experiences in animal cardiac MRI at 7T [3] to human in vivo cardiac imaging using a flexible 8-channel transmit/receive body radiofrequency (RF) coil and to report on the potential benefits and limitations of high-field cardiac MRI.

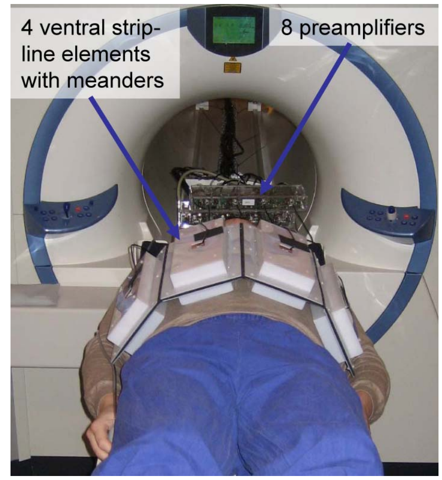

Fig. 1: Positioning of a healthy volunteer head-first supine with the chest encompassed by the 8-channel body coil.

Methods and Materials:

All examinations were performed on a 7-Tesla whole-body MRI system (Magnetom 7 T, Siemens Healthcare, Erlangen, Germany) equipped with a gradient system capable of 45 mT/m maximum amplitude and a slew rate of 220 mT/m/ms. A custom-built flexible 2x4-channel transmit/receive body RF coil for 7 T human imaging was used for RF signal transmission and reception. The coil was driven in the CP mode. For cardiac imaging four healthy volunteers (1 male, 3 female) were placed head-first supine with the chest at the isocenter of the magnet and within the sensitive region of the coil. Four coil elements are placed in the table to provide signal from the anterior of the subject while a second set of 4 elements is placed on top of the chest of the subject (Fig. 1). The imaging protocol encompassed cardiac function along standard views (short and long axis, 4-chamber, 2-chamber, LVOT) (Fig. 2) using peripheral pulse-triggered Cine FLASH sequences (TR/TE 62.5/3.73 ms; FOV 340 x 306 mm^2; matrix 240x216; slice 4 mm; BW 992 Hz/pixel; flip 40°, 20 phases per RR-interval, GRAPPA R = 2, TA 0:15 min). Additionally, a TrueFISP and a FLASH sequence with tagging pulses were evaluated. The image quality was visually assessed for signal homogeneity and myocardium-to-blood contrast.

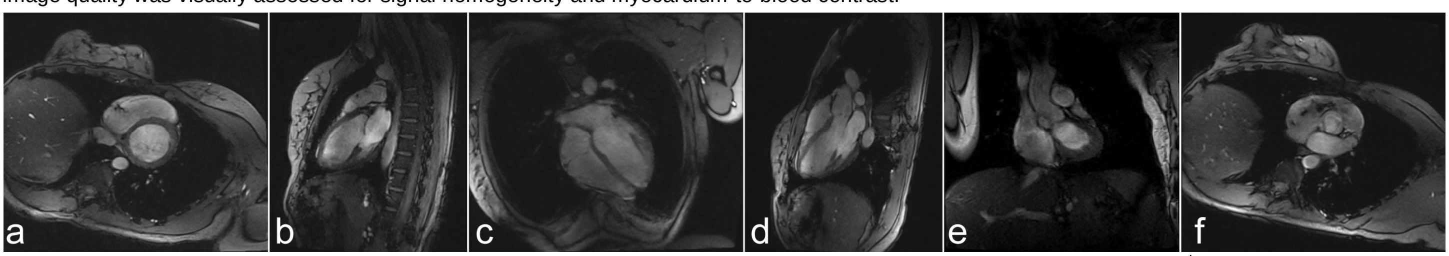

Fig. 2: Cine FLASH images of the human heart in vivo at 7T. a) short axis, b) 2-chamber, c) 4 chamber, d) LVOT, e) LVOT 2^{nd} plane, and f) aortic valve.

Results:

All four subjects tolerated the examination well and could be successfully examined. The positioning on the table including the anterior coil placement was considered comfortable. The coil, driven in CP mode, qualitatively provided relatively homogeneous B_1 signal over the sensitive body volume. Some regions in the images, however, showed mild destructive interference with associated signal voids. The Cine FLASH sequence provided satisfactory imaging quality with good signal homogeneity over almost the entire cardiac volume and with good myocardium-to-blood contrast. The achieved spatial resolution was 1.4 x 1.4 x 4 mm^3. Cardiac MRI with TrueFISP sequences in the tested setup was severely degraded by contrast loss (myocardium-to-blood), dark banding artifacts, and the resulting signal inhomogeneities (Fig. 3).

Discussion:

These initial results can be considered as a first step towards human in vivo cardiac imaging at 7 Tesla high-field MRI. The standard CP mode as B_1 shimming parameters was already sufficient to obtain relatively high signal homogeneity. Further improvements in image quality are expected by using improved RF shim parameters based on B1 maps or Transmit SENSE approaches. Parallel imaging in conjunction with breath hold scanning will allow higher temporal and spatial resolution. For perfectly timed and triggered cardiac images, however, ECG triggering seems mandatory. Peripheral pulse gating, as used in this study, in part was associated with imprecise triggering leading to mild motion artifacts in the Cine acquisitions. While TrueFISP images were susceptible to B_0 inhomogeneities and thus were severely degraded by artifacts, the FLASH sequence provided excellent image quality, contrast, and spatial resolution for evaluation of cardiac function; this also mirrors earlier experiences with animal cardiac high field imaging in mini-pigs [3]. Subsequent studies in patients will further assess these sequences in high-field cardiac imaging and additional cardiac protocols including late enhancement.

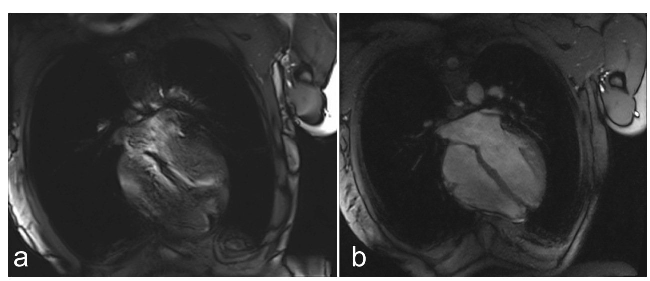

Fig. 3: 4-chamber views: a) TrueFISP, b) FLASH, both mid-diastolic phase. Note: The TrueFISP image is degraded by artifacts while the FLASH image shows good signal homogeneity and contrast over the cardiac volume.

References:

[1] DalaBarre et al.; ISMRM2007, p. 3867

[2] Maderwald et al.; ISMRM 2008, p. 2716.

[3] Quick et al.; ISMRM 2008, p. 1023.