Design, Evaluation and Application of a Modular 32 Channel Transmit/Receive Surface Coil Array for Cardiac MRI at 7T

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Introduction: Cardiac MR (CMR) at ultrahigh (≥7.0 T) fields is regarded as one of the most challenging MRI applications. At 7.0 T image quality is not always exclusively defined by signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). Detrimental effects bear the potential to spoil the signal-to-noise (SNR) and contrast-to-noise (CNR) benefits of cardiac MR (CMR) at 7.0 T (1, 2). B_1^+- inhomogeneities and signal voids represent the main challenges. Various pioneering coil concepts have been proposed to tackle these issues, enabling cardiac MRI at 7.0 T (3, 4). This includes a trend towards an ever larger number of transmit and receive channels. This approach affords multi-dimensional B_1^+ modulations to improve B1+ shimming performance and to enhance RF efficiency (5). Also, parallel imaging benefits from a high number of receive channels enabling two-dimensional acceleration. Realizing the limitations of existing coil designs tailored for UHF CMR and recognizing the opportunities of a many element TX/RX channel architecture this work proposes a modular, two dimensional 32-channel transmit and receive array using loop elements and examines its efficacy for enhanced B_1^+ homogeneity and improved parallel imaging performance.

Methods: The coil array consists of planar (posterior section) and bend (anterior section) modules. Each module comprises 4 independent transceiver loop elements (2 x 2 array) with a rectangular size of 6 cm x 6 cm each (Fig. 1a, b) and a conductor width of 1 cm. Both rows are arranged in an interleaved fashion so that the elements are shifted from each other by a half element size. Adjacent elements share a common conductor with an integrated, adjustable capacitor for decoupling of neighboring elements. For the proposed 32 channel TX/RX design four planar modules and four bend modules are realized. Inter module decoupling is suppressed by a distance of 3 cm between neighboring loop structures. To reduce the radiation losses of the array, an RF shield, made of patches of slotted copper foil, was placed at a distance of 2 cm to the conductors. Unbalanced currents on the coaxial cables were minimized by cable traps. All 32 elements were connected to multipurpose transmit/receive switch boxes with integrated low-noise preamplifiers. The MR experiments were conducted on a 7 T scanner (Siemens Healthcare, Erlangen, Germany), equipped with an RF amplifier providing a peak power of 8 kW. The amplifier output was split into 32 equal-intensity signals by means of home-built power splitters. Phase adjustments of sections, modules and single channels were implemented by phase-shifting coaxial cables in the appropriate position in the power splitting network. Electro-magnetic (EM) field and SAR simulations were performed using CST Studio Suite 2011 (CST AG, Darmstadt, Germany) together with voxel models from the Virtual Family (7). The RF characteristics were measured using an 8-channel network analyzer (Rohde & Schwarz, Munich, Germany). Cardiac MR was performed in healthy subjects using single breath-hold 2D CINE FLASH in conjunction with retrospective acoustic cardiac gating (MRI Tools GmbH, Berlin, Germany). Imaging and RF measurements were done on three different subjects without subject-specific tuning and matching.

Results: The modules are lightweight (m< 400 g) and conform to a broad range of upper torso geometries. The loop elements have an average Q_U/Q_L of 2.14. Reflection coefficients of -21± 7 dB were observed. Element coupling was below -10 dB for all elements and subjects. Noise correlation was 0.46 or well below for all elements and subjects (Fig. 1c). SAR values, derived from the EM simulations incorporating the phase settings of the *in vivo* study, were well below the limits permitted by the IEC guidelines (8) for an average power of 30 W over 6 minutes (Fig. 1d). The acquired images exhibit a rather uniform intensity over a deep lying region in the torso encompassing the heart with a high myocardium/blood contrast as demonstrated in Fig. 2 for various long axis and short axis standard cardiac views. The overall image quality and the high spatial resolution of (1x1x4) mm3 enabled the visualization of subtle anatomic structures such as pericardium, mitral and tricuspid valves and their associated papillary muscles and trabeculae. Parallel imaging with 2D CINE FLASH provided excellent image quality for acceleration factors up to R=4. Mean geometry factors for a ROI covering the heart in a short axis view were found to be g=1.07 for R=2, g=1.24 for R=3 and g=1.72 for R=4. (Fig. 2e), (9)

Discussion: Our results demonstrate that the proposed modular, two-dimensional 32 channel coil array supports the acquisition of rather uniform images of the heart at 7.0 T. Combining a large number of surface coil elements yielded an excellent SNR and CNR and facilitated the depiction of subtle anatomical cardiac details. The parallel imaging performance enabled the acquisition of high resolution images with satisfactory SNR within one breath-hold (Fig. 2). Since the proposed approach is modular it is conceptionally appealing to move towards 64 and more TX/RX channels. We anticipate further improvement in image quality by using more advanced B_1^+ shimming and an assessment of different element distributions over the anterior and posterior torso.

References: 1) Niendorf T. et al. Eur. Radiol. 2010; 1-11. 2) von Knobelsdorff-Brenkenhoff et al. Eur. Radiol. 2010; 1-9. 3) Snyder CJ. et al. MRM 2009; 61:517-524. 4)Renz W. et al. ESMRMB 2009, p. 476. 5) Adriany G. et al. ISMRM 2010, p. 3831. 7) Christ A. et al. Physics in Medicine and Biology 2010; 55:N23-N38. 8) IEC 60601-2-33 Part 2-33, Ed. 3.0 2010 9) Kellman P. et al. MRM 2007; 58:211-212.

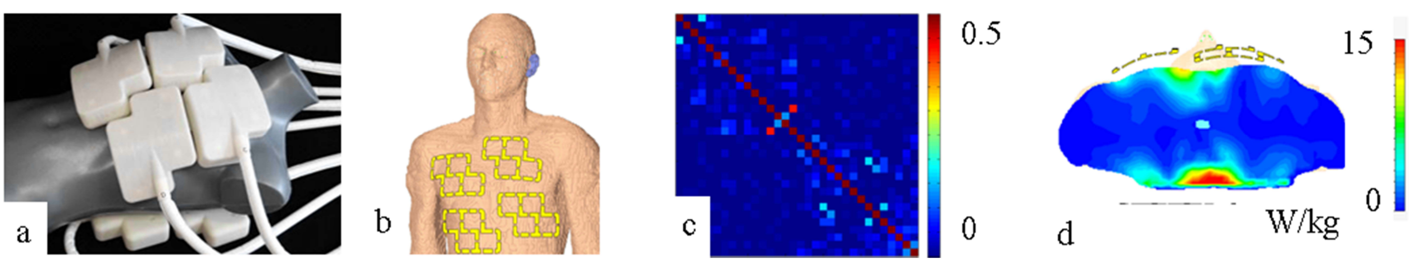

Fig. 1: a) The coil placed on a mannequin. b) Basic scheme of the coil design and positioning on the anterior chest. c) SAR distribution derived from EMF simulations for transversal slice including the overall SAR maximum. d) 32 x 32 noise correlation matrix obtained for the proposed coil design.

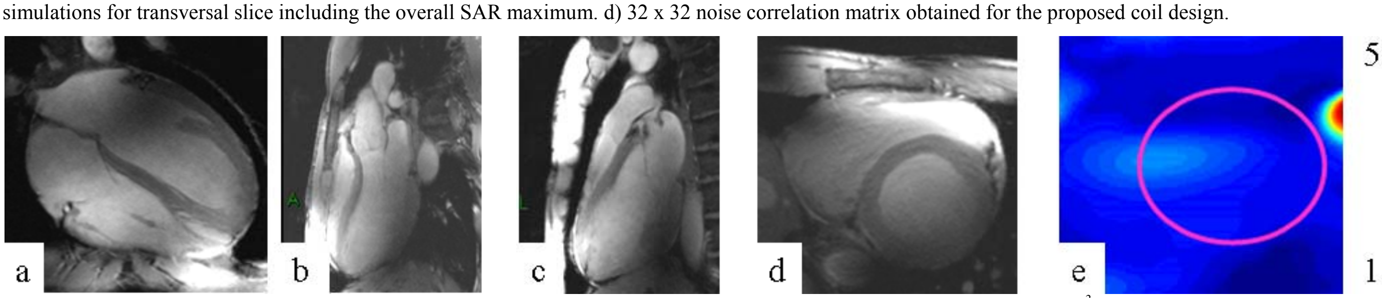

Fig. 2: a-d) Images of the heart derived from 2D CINE FLASH imaging using the proposed coil design (voxel size 1x1x4 mm^3, TE/TR=2.65/5.6 ms, BW=454 Hz): 4-chamber view, 3-chamber view, 2-chamber view, short axis view(R=2). e) GRAPPA g-factor map for short axis view and R=4.