ANATOMIC AND FUNCTIONAL CARDIAC MR AT 7T: A COMPARISON OF 4, 8 AND 16 ELEMENT TRANSCEIVE RF COIL DESIGNS

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Introduction
Ultrahigh field cardiac MR (CMR) is an area of vigorous ongoing research [1-2] and is regarded as one of the most challenging MRI applications since image quality is not always exclusively defined by signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). A recent report demonstrated, that cardiac chamber quantification at 7T using 2D CINE FLASH is feasible and agrees close with left ventricular (LV) parameter derived from 2D CINE SSFP imaging at 1.5 T [3]. This progress in the field of LV assessment at 7.0 T has been driven by pioneering explorations into hardware developments which focused on novel multichannel transmit and receive coil arrays technology to tackle the challenges of B_0- and B_1-field inhomogeneities [4]. Consequently, transmit-receive (TX/RX) structures are not a nicety but a necessity for ultrahigh field CMR including a trend towards a large number of transmit and receive channels. For all these reasons, this study was designed to compare the quality of anatomical and functional CMR at 7.0 T under clinical aspects using cardiac optimized transceive coils that use loop structures with the number of TX/RX elements ranging from 4-16.

Methods
Volunteer studies were performed on a 7T whole body MR system (Magnetom, Siemens Medical Solution, Germany). Three different TX/RX surface coil arrays have been used: **(i)** a 4-channel coil with 2 anterior and 2 posterior elements (S-I: 20 cm, L-R: 26 cm) [5], **(ii)** an 8-channel coil with 5 anterior and 3 posterior elements (S-I: 17 cm, L-R: 37 cm [6] and **(iii)** a 16-channel coil with 8 anterior and 8 posterior elements arranged in a 2x4 matrix (S-I: 28 cm, L-R: 29 cm). All coils were built using loop design technology as shown in Fig. 1a. The ratio of unloaded to loaded quality factors is Q_{UL_4ch}: 7 Q_{UL_8ch}: 4.7 Q_{UL_16ch}: 5. The power values have been adjusted in compliance with the IEC (60601-2-33, Ed.3, Status FDIS) based on numerical SAR simulations using the Finite Integration Technique (CST MWS, Germany) for all three coils as illustrated in Fig. 1b. Noise correlation between the coil elements was compared for all three coil designs. Volume selective B_0 shimming was performed with the shim volume aligned with the hearts position/geometry. A fixed B_1-phase shim setting was estimated beforehand and applied to all subjects. Single-breath-hold 2D CINE FLASH imaging together with acoustic cardiac gating (ACT, MRI Tools GmbH, Germany) was performed using: slice thickness = 4 mm, TE = 2.67 ms / 4,42 ms , TR = 5.43 / 8,66 ms, pixel size = (1.8 x 1.4) mm^2, receiver bandwidth = 444 Hz/Px, retrospective triggering, 30 cardiac phases, 6 views per segment, GRAPPA (R = 2). Standard short axis views and 4-chamber views were acquired to examine image quality. Also, tag band prepared 2D CINE FLASH and 2D CINE SSFP images were acquired for the same cardiac views. SNR and CNR measurements were performed according to Knobelsdorff et al. [3] and were averaged over 10 cardiac cycles.

Results
The mean noise correlation of the 4 channel coil was found to be superior to that of the 8 channel and 16 channel coil as illustrated in Fig. 1c. The largest noise correlation values were found to be 0.10 for the 4 channel coil,0.28 for the 8 channel coil and 0.3 for the 16 channel coil. All three coil designs produced 2D CINE images of the heart at 7.0 T with clinically acceptable image quality as demonstrated in Fig 1d,e. Consequently, fine subtle anatomic structures such as pericardium, mitral and tricuspid valves and their associated papillary muscles, and trabeculae were identifiable. For a nominal flip angle of 70 degree SNR and blood myocardium contrast derived from the 2D CINE FLASH images obtained with the 16 channel coil were superior to those values derived from 2D CINE FLASH using the 4- and 8-channel coil (SNR/CNR 4ch: 122/95; SNR/CNR 8ch: 175/124; SNR 16ch: 261/171). The myocardial signal intensity observed for the 16 channel coil was more uniform than that accomplished with the 4 channel or 8 channel coil as indicated by the relative mean standard deviation of the signal over the entire septum: RSD_{4ch_septum}=43%, RSD_{8ch_septum}=22%, RSD_{16ch_septum}= 17% and the lateral wall: $RSD_{4ch\_lateral}$=31%, $RSD_{8ch\_lateral}$=36%, $RSD_{16ch\_lateral}$=18%. A decrease in signal intensity between the septum and the lateral wall was observed (4ch coil: 44%, 8ch coil: 54%, 16ch coil: 44%). SSFP images (TE = 2.3 ms, TR = 4.6 ms) showed severe banding artifacts due to strong B_0-gradients across the heart which were found to range between (150 -200) Hz. The results derived from tagging were somewhat disheartening due to significant changes in the contrast between the tag bands and the surrounding tissue, which requires further subject optimized B_1^+-shimming efforts.

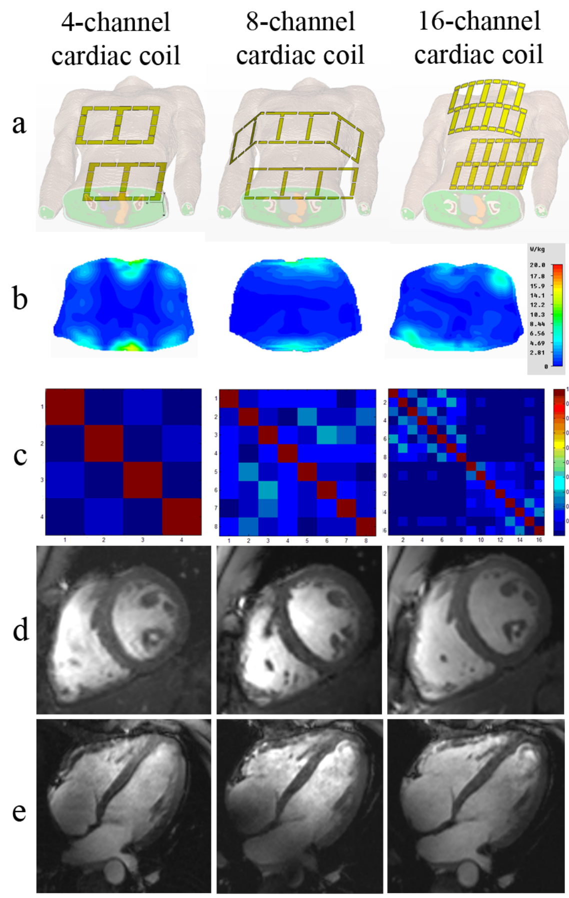

Figure 1: a) Geometries of the different coil setups **b)** Color maps of SAR simulations scaled to first level SAR 20W/kg. The axial slice with the highest local SAR values inside the voxelmodell "Duke" is shown. **c)** Normalized noise correlation matrices **d)** Short axis 2D FLASH cardiac images (TE/TR = 2.67/5.43 ms) **e)** Four chamber view 2D FLASH cardiac images (TE/TR = 2.67/5.43 ms)

Conclusion
Our results suggest that many element, cardiac optimized transceive arrays are beneficial for anatomic and functional MR at 7.0 T. This includes the translation of the baseline SNR advantage of ultrahigh fields into a reduction of the slice thickness or/and into an improved in-plane resolution. This helps to reduce partial volume effects in functional CMR, which may be particularly useful for visualizing small rapidly moving structures such as valve cusps, assessing subtle anatomical features such as trabeculae, or extending morphologic assessment to the right ventricle. To conclude, our findings demonstrate that a larger number of transceive elements helps to improve SNR, CNR, signal uniformity, anatomic coverage and parallel imaging performace for CMR at 7.0 T. Further functional CMR studies with larger samples including volunteers and patients of both sexes are required, but this mandatory precursor was essential before extra variances due to gender and/or pathophysiological conditions are introduced. An extension of this work towards patient tailored B_1-shimming is anticipated. Also, the implementation of transceive arrays with more than 16 channels is anticipated to further improve the overall image quality for anatomic and functional CMR at 7.0 T without sacrificing patient comfort requirements or exceeding clinical RF power deposition limits.

References
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