Lessons Learned from Cardiac MRI at 7.0 T: LV Function Assessment at 3.0 T Using Local Multi-Channel Transceiver Coil Arrays

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Introduction:

Cardiac MR (CMR) is of proven clinical value but also an area of vigorous ongoing research since image quality is not always exclusively defined by signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). Recent developments of CMR at 7.0 T have been driven by pioneering explorations into novel multichannel transmit and receive coil array technology to tackle the challenges B_{1+}-field inhomogeneities, to offset specific-absorption rate (SAR) constraints and to reduce banding artifacts in SSFP imaging [1-4]. For this study, recognition of the benefits and performance of local surface Tx/Rx-array structures recently established at 7.0 T inspired migration to 3.0 T, where RF inhomogeneities and SAR limitations encountered in routine clinical CMR, though somewhat reduced versus the 7.0 T situation, remain significant. For all these reasons, this study was designed to build and examine the feasibility of a local four channel Tx/Rx cardiac coil array for anatomical and functional cardiac imaging at 3.0 T. For comparison, a homebuilt 4 channel Rx cardiac coil array exhibiting the same geometry as the Tx/Rx coil and a Rx surface coil array were used.

Method:

Volunteer studies were performed on a 3.0 T whole body MR system (Verio, Siemens Medical Solution, Germany). The 4 channel transceive and the four channel Rx array are comprised of 2 anterior and 2 posterior elements (S-I: 20 cm, L-R: 26 cm). The 4 channel coils were built using loop elements as shown in Fig. 1. The RF power values were derived based on numerical SAR simulations using the Finite Integration Technique (CST MWS, Germany) for the Tx/Rx coil. Noise correlation between the coil elements was estimated for the transceive coil design. For comparison, a commercial 8 channel Rx body array in combination with a spine array were used (Bodymatrix, Siemens, Erlangen, Germany) was used. Volume selective B_0 shimming was performed with the shim volume encompassing the heart. A fixed B_1-phase shim setting was estimated and applied to all subjects. Single-breath-hold 2D CINE SSFP imaging was performed using: slice thickness=6 mm, TE=1.39 ms, TR=3.28 ms, pixel size=(1.3x1.3) mm^2, receiver bandwidth=698 Hz/Px, 30 cardiac phases, 6 views per segment. Acoustic cardiac gating (EasyACT, MRI.TOOLS GmbH, Berlin, Germany) was used for retrospective gating. Standard short axis views and 4-chamber views were acquired for all coils to examine image quality. 3D-B1 maps were acquired in phantom for bodycoil transmission and 4ch Tx/Rx using ϕFA CUP [5].

Results:

SAR values derived from the EM simulations are 19.1 W/kg local SAR and 0.91 W/kg global SAR for the Tx/Rx coil. These values are well below the limits given by the IEC guidelines for an average power of 30 W over 6 minutes (Fig. 2). B_1^+ maps were determined in phantoms including the body coil transmission configuration and the setup using the 4ch Tx/Rx excitation coil as shown in Figure 3. The RF transmitter power adjustments showed the B_1^+-efficiency advantage of the local Tx/Rx coil vs the body coil approach. While the local Tx/Rx coil required only 187 V for the transmitter output a voltage of 348 V was needed for the body coil to achieve the same flip angle. Consequently, the shortest TR (TR_{min}=4.24 ms) supported by the body coil approach for a flip angle of 65 degree used for 2D CINE SSFP imaging were dictated by SAR constraints (SAR value of 100%). In contrast, the local Tx/Rx coil did not reach the SAR limits (SAR=43%) for the same imaging parameters and flip angles because of its B_1-efficiency. Here the shortest TR (TR_{min}=2.97 ms) were given by the acquisition window length. The acquired *in vivo* images exhibited a rather uniform signal intensity across the heart for the Tx/Rx coil as demonstrated in Fig. 4 for four chamber views and short axis views of the heart. The blood/myocardium contrast obtained with the local Tx/Rx coil is clinically acceptable and matches that found for the body coil excitation.

Discussion and Conclusions:

Our results suggest that local Tx/Rx arrays are conceptually appealing for anatomic and functional CMR at 3.0 T. The improved B_1 efficiency of local Tx/Rx coil arrays bears the potential to address SAR constraints frequently encountered in current clinical practice at 3.0 T when using the body coil for excitation. This B_1 efficiency advantage can be translated into a shortening of RF pulses which is balanced against an increased RF peak power. This approach would afford a reduction in TE and TR. A decrease in TR increases the frequency spectrum of the pass bands in SSFP imaging, the gold standard for cardiac chamber quantification and LV assessment. This would be helpful for LV assessment at 3.0 T where the use of SSFP is limited by susceptibility-induced off-resonance effects, resulting in either SSFP banding artifacts across the heart or the need to use a short TRs that limit the readout matrix size and hence the spatial resolution achievable in current clinical practice. To this end our findings demonstrate that a larger number of transceive elements would be helpful to improve SNR, CNR, signal uniformity, anatomic coverage and parallel imaging performance for CMR at 3.0 T. A recognized limitation of this feasibility study is its assessment in a limited number of healthy subjects, but this mandatory precursor was essential before extra variances due to gender and/or pathophysiological conditions are introduced. Therefore, efficacy of the described local Tx/Rx coil approach for LV function assessment in the clinical routine environment awaits further study. Also, the implementation of transceive arrays with more than 4 channels might be anticipated to further improve the overall image quality for anatomic and functional CMR at 3.0 T without sacrificing patient comfort requirements or exceeding clinical RF power deposition limits.

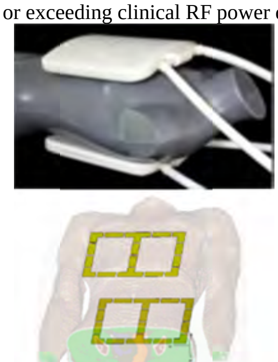

Figure 1: Photography (top) and basic design (bottom) of the four channel Tx/Rx and four channel Rx configurations. A professional housing and cable isolation ensure patient safety. The anterior and posterior sections of the coil arrays consist each of two loop elements.

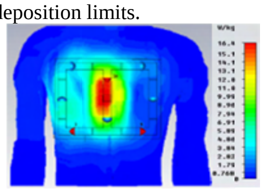

Figure 2: Color maps of SAR simulations scaled to first level SAR 20W/kg. The coronary slice with the highest local SAR values inside the voxel model "Duke" is shown.

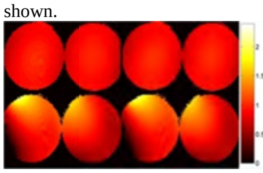

Figure 3: Two central partitions of a 3D-B1-maps of the bodycoil (top) compared with B1 map of the Tx/Rx coil (bottom).

8ch body coil | 4ch Rx only | 4ch Tx/Rx

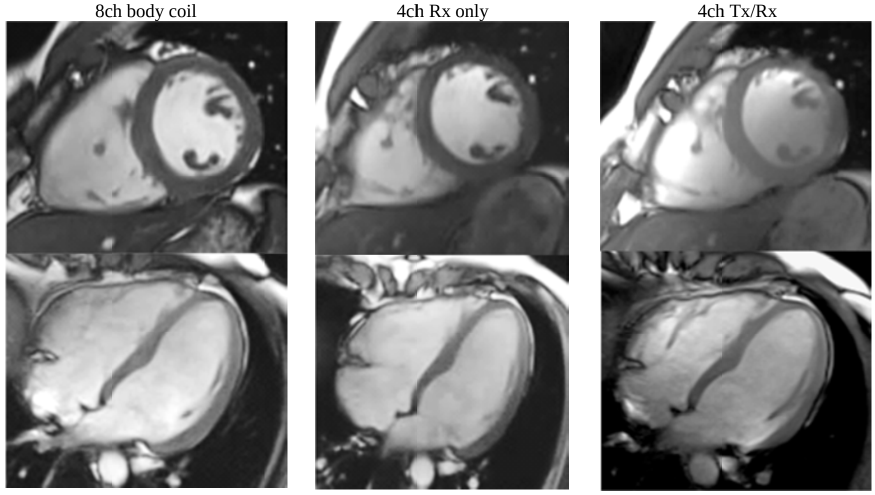

Figure 4: Short axis views **(top)** and four chamber views **(bottom)** derived from 2D SSFP of the heart using an 8 channel Rx coil **(left)**, a 4 channel receive coil **(center)** and a four channel Tx/Rx coil **(right)**.(TE/TR = 1.4/3.3 ms).

References:

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