Tailored and Universal pTx of the Human Heart at 7T: Open-source tool with 76 thoracic channel-wise 3D in-vivo B_1^+ datasets acquired during shallow and deep breathing

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Introduction: *MRI in the human body at ultra-high fields (>7T) is typically limited by motion and strong inter-subject variations of the spatial flip-angle (FA) patterns caused by varying body shapes and dimensions.[1] Multiple B_1^+-maps were acquired under free-breathing during shallow breathing (SB) and deep breathing (DB) in the human body[2] to analyse the impact of body shape and respiration on the spatial FA patterns and to develop dedicated parallel transmission[3] (pTx) pulses that produce homogeneous FAs in the heart volume. A set of 76 thoracic channel-wise 3D B_1^+ datasets of an 8-Tx-channel body array was used to design tailored[1] and universal pulses[4] (UP) to achieve homogeneous FA distributions throughout the heart for SB and DB[5]. Code for the pulse design and all 76 thoracic 3D B_1^+ datasets (26M/20F, 21-66 years, BMI = 19-35 kg/m^2) are provided under an open-source licence and could serve as a basis for new projects without the need to have access to a 7T scanner.*

Methods: *MRI was performed on a Siemens Magnetom 7T scanner using an 8-channel transmit array and a whole-body gradient system according to an approved IRB protocol in a total of 46 healthy volunteers (26M/20F, 21-66 years, BMI = 19-35 kg/m^2). The scans were performed with a 32-element body array (MRI-Tools, Berlin) driven in 8Tx/32Rx mode. Safety limits and coil placements are described in previous works.[1,2,4,5] Relative 3D non-respiration resolved (NRR) and respiration resolved (RR) thoracic B_1^+-maps were acquired under free-breathing in 3min25s for SB (256 radial-phase encoded (RPE) lines and in 6min50s for DB (512 RPE lines).[2] Common parameters were: nominal FA = 20°, TE/TR = 2.02/40 ms, FOV = 250x312x312 mm^3, resolution = 4x4x4 mm^3. The SB data was reconstructed NRR whereas the DB data was reconstructed RR into five respiration states using self-navigation. The kT-point pulse design problem to excite a 10° target flip-angle within the heart volume was solved using the small-tip-angle approximation with an interleaved greedy and local optimization.[6,7] Respiration robustness (RRob) was achieved using multiple B_1^+-maps of different respiration states for DB. The performance of different pulses was analysed using the coefficient-of-variation (CV) in the heart volumes. The used parameters, the source code, and the B_1^+-maps can be downloaded from https://github.com/chaigner/UP_body and https://github.com/chaigner/tailored-RRob.*

Results: *As depicted in Figure 1 and 2, all optimized pTx pulses performed well for SB. For DB, however, respiration specific tailored-RSpec pulses resulted in a higher FA variation and only the respiration robust UP-SBDB and tailored-RRob pulses achieved homogeneous FAs in all subjects and across all respiration states. The pre-computed UP-SBDB resulted in a mean CV in across all predicted FA maps of 12.8% compared to 8.2% achieved by subject-specific tailored-RRob pulses.*

Discussion: *Tailored and universal (calibration-free) pTx pulses were computed and evaluated with a large library of B_1^+ datasets. Respiration robust pulses (tailored-RRob and UP-SBDB) resulted in a negligible overall decrease of the FA homogeneity with clear benefits of achieving homogeneous 3D FA across all respiration states when volunteers perform DB.*

Conclusion: *The proposed open-source tool and the large B_1^+ library (26M/20F, 21-66years, BMI=19-35kg/m2) could serve as a solid basis for new projects without the need to have access to a 7T with a dedicated pTx coil or the need to acquire B_1^+-maps in a large set of volunteers.*

References: *1:) Aigner et al., 2020, NMR Biomed., 10.1002/nbm.4450 2) Dietrich et al., 2021, MRM, 10.1002/mrm.28602 3) Padormo et al., NMR Biomed., 2016, 10.1002/nbm.3313 4) Aigner et al., 2021, MRM, 10.1002/mrm.28952 5) Aigner et al., 2021, submitted to MRM. 6) Grissom et al., 2012, MRM, 10.1002/mrm.24165 7) Cao et al., 2016, MRM, 10.1002/mrm.26020*

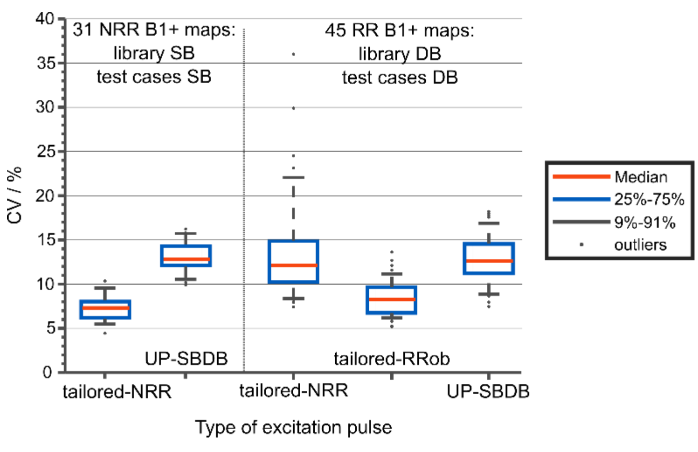

Figure 1. FA homogeneity of the 3D heart in terms of the coefficient of variation (CV) for different pulses for 31 NRR-SB and 45 RR-DB B_1^+-maps.

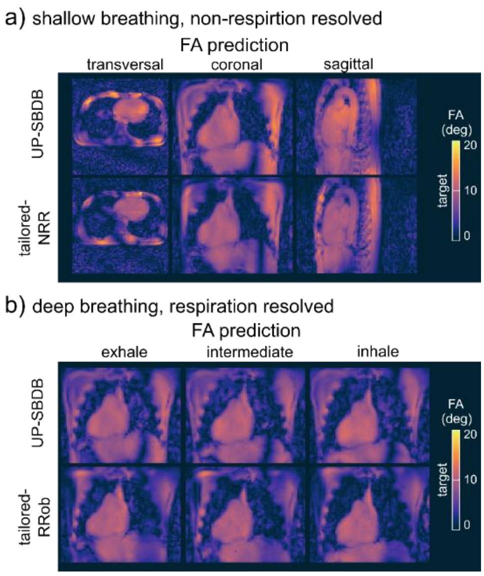

Figure 2. FA predictions for one of the volunteers. Shallow breathing is shown in a) and deep breathing is shown in b) for respiration robust tailored and universal pulse. The 3D images are free of breathing artifacts and demonstrate the feasibility to achieve a homogeneous calibration-free FA (UP) of the whole heart for SB and DB.