Feasibility of MR-thermometry with blood suppression on the human heart at 3T

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Introduction

Ventricular tachycardia and atrial fibrillation can be treated in a minimally invasive fashion with localized catheter radio-frequency ablation of the myocardium [1]. For cardiac ablation, PRFS-based MR thermometry [2] may provide intra-procedural feedback, helping with the determination of the therapy endpoint and to avoid damage to adjacent vital structures such as the esophagus. However, MR thermometry of the heart is challenging due to the continuous contraction and respiratory movement. In addition, blood suppression is preferable to avoid artifacts in the myocardium and may improve the robustness of motion correction algorithms. In this work, we explore three options for blood suppression, namely double inversion recovery (DIR), motion-sensitized driven equilibrium (MSDE) [3], and inflow saturation (IS). The effectiveness of the blood suppression and its effect on the temperature stability in the septum is evaluated in eight healthy volunteers over a period of 50s of free-breathing using VCG cardiac triggering and navigator respiratory compensation.

Materials and Methods

MR-Imaging:Imaging was performed on a 3T Philips Achieva MR system (Philips Healthcare, The Netherlands) using a 6-channel cardiac coil. Respiratory motion was compensated during the acquisition by placing a pencil-beam navigator on the diaphragm and on the heart for the IS sequence. All acquisitions were VCG-triggered, with a trigger delay set to longest. For effective fat suppression in the presence of B1 inhomogeneities, spectral adiabatic inversion recovery (SPAIR, inversion time 90ms) was applied before each slice acquisition. As a compromise between acquisition speed, sufficient echo time length, and image quality, a RF-spoiled TFE-EPI (transient field echo) sequence (TR/TE = 11/6ms , flip angle = 26-30°, FOV = 350x350x8mm³, matrix = 100x100) with an echo train length of 3 and a SENSE factor of 3 was used. Echo train lengths of 5 or more were tested, but, despite the use of a localized volume shim on the heart, led to significant image quality degradation at 3T and were not further used. The sequence was tested a) without flow suppression, b) with multi-slice DIR (inversion delay 320ms), c) with MSDE (2 inversion pulses, duration 9ms, velocity encoding = 20cms^{-1} to 40cms^{-1}) and d) with IS (1 rest slab between the imaged slices and the base of the heart, thickness 60mm-80mm, gap 5-15mm). Three slices per cardiac cycle were acquired dynamically over 100 cardiac cyles (dynamic scan time 0.75 -1.2s).
Postprocessing: Residual motion and susceptibility effects were corrected with a multi-baseline approach [4], using an affine motion model and assuming a linear dependence between the registered phase images and the displacement [5]. For this purpose, the first 50 images (learning phase) were used to correct the following 50 images (50s of free-breathing), which were then used to calculate the baseline temperature variation at each pixel with the PRFS method [2]. Finally, the temperature stability was evaluated as the temporal standard deviation of the temperature in a voxel.

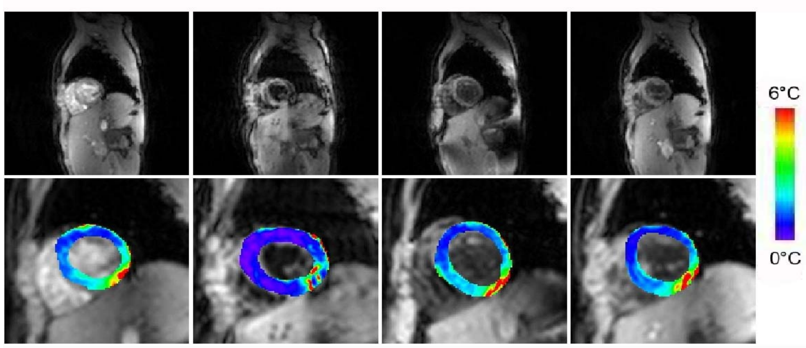

Figure 1: Magnitude images (top row) and maps of the temperature stability (bottom row) for the acquisitions without blood suppression, DIR, MSDE, and IS (from left to right).

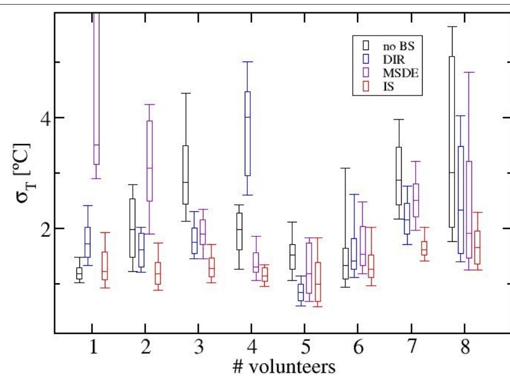

Figure 2: Box-Whisker plot of the temperature stability in a ROI in the septum without blood suppression (no BS), DIR, MSDE, and IS. Shown are the values of the temperature stability that are exceeded by 10%, 25%, 50%, 75% and 90% of the voxels in the ROI.

Results and Discussion

The magnitude images and maps of the temperature stability in the myocardium are displayed in Fig. 1 for a representative case. In terms of image quality, the acquisitions using IS represent the best compromise between blood suppression, myocardial SNR, and artifact reduction in the presence of motion and magnetic field inhomogeneities. For this particular case, MSDE shows a comparable image quality to IS. However, in the presence of B0 and B1 inhomogeneities signal loss in the myocardium or incomplete blood suppression occur, leading to a reduced temperature stability. The acquisitions using DIR blood suppression suffered from motion artifacts when combined with EPI readout. Without EPI acceleration, however, the acquisition time would be prolonged which poses problems for multi-slice imaging and could introduce intra-scan motion artifacts. The statistical analysis of the temperature stability in the septum for the different blood suppression techniques is shown in Fig. 2 for all volunteers. A statistically significant (paired t-test with a significance of $p=0.05$) improvement of the mean temperature stability in the septum in comparison to the acquisition without blood suppression can be observed in 5 of 8 cases for DIR and MSDE and in 7 of 8 cases for IS. With the same type of analysis, we found that out of the three blood suppression methods IS performs better than DIR and MSDE in 7 of 8 cases, leading to a temperature stability of 2°C or better for 75% of the voxels in the septum. As expected, the motion correction algorithm was more robust in acquisitions with higher image quality (SNR, effectiveness of blood suppression as evaluated by CNR between myocardium and blood), leading to an improved temperature stability.

Conclusion

The application of blood suppression improves the robustness of the applied motion correction technique and the temperature stability of PRFS-based thermometry in the myocardium. PRFS-based MR-thermometry on the heart is feasible at 3T yielding an average temperature stability of 2°C or better when combined with cardiac triggering, navigator respiratory compensation, inflow suppression, and a multi-baseline motion and phase correction algorithm.

References
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