Does Temporal Regularization Lead to Systematic Underestimation of Ejection Fraction?

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Introduction: Ejection fraction (EF) is the volumetric fraction of blood that is pumped out of the ventricle in each cardiac cycle. One way to assess the EF, is the segmentation of the end-diastolic volume (EDV) and the end-systolic volume (ESV) from cardiovascular MR images (CMR). In clinical practice breath-hold ECG-synchronized cine protocols remain the preferred method. Recent research aims for real-time free-breathing CMR by combining fast imaging sequences with parallel imaging and compressed sensing (CS). Recent results of Voit et al. [1] report a 10% lower ejection fraction for their nonlinear inverse reconstruction method. In this work, we reproduce these results with k-t radial SPARSE SENSE (k-t RASPS) [2] and show that the underestimation might be explained by the strong temporal regularization that is needed to reconstruct the highly undersampled CMR images.

Methods:

Acquisition: Short-axis cardiac datasets from a total of 8 healthy volunteers were acquired under free breathing on a Philips 3T Achieva (Philips Healthcare, Best, The Netherlands) using a 32 channel coil array and a radial golden angle trajectory [3]. Written informed consent was obtained in all cases. The parameters for the spoiled gradient echo sequence were TE/TR = 1.3 / 3.4 ms, flip angle = 15°, pixel bandwidth = 857.8 Hz, FOV = 400 x 400 mm², and spatial resolution = 2 x 2 x 8 mm³. Additionally, for each volunteer a fully sampled breath hold ECG triggered dataset was acquired.

	ECG Triggered[1)]	k-t RASPS [2)]
End-diastolic vol. [ml]	14.2 ± 1.8	14.3 ± 1.8
End-systolic vol. [ml]	4.7 ± 0.9	5.4 ± 1.4

Table 1: Summary of the left-ventricular volumes and its standard deviations. The values were calculated from a single 8mm thick short-axis slice. [1)] breath hold [2)] free breathing

Reconstruction: The images were reconstructed using k-t RASPS [2] with 13 radial profiles per time frame and spatiotemporal adaptive total variation regularization. The images were reconstructed multiple times with increasing regularization strength λ.

Analysis: A quantitative analysis of the left ventricular volumes was done using standard software (Segment, Medviso, Lund, Sweden [4]). The regularization strength was set to λ = 0.1 which eliminated most aliasing artifacts. For simplicity, a single short-axis slice was used. The chambers in end-diastolic and end-systolic state were segmented blinded by two experienced medical imaging experts.

Results: Table 1 summarizes the quantitative analysis. No statistically significant differences (Wilcoxon signed rank test) were found for the end-diastolic volumes. However, a statistical significance (one-sided rank test) for a general over estimation of the end-systolic volume by k-t STARR compared to ECG Triggered was found (p = 0.022). Figure 1 shows that the increasing temporal regularization blurs the end-systolic peaks, which leads to an underestimation of the ESV.

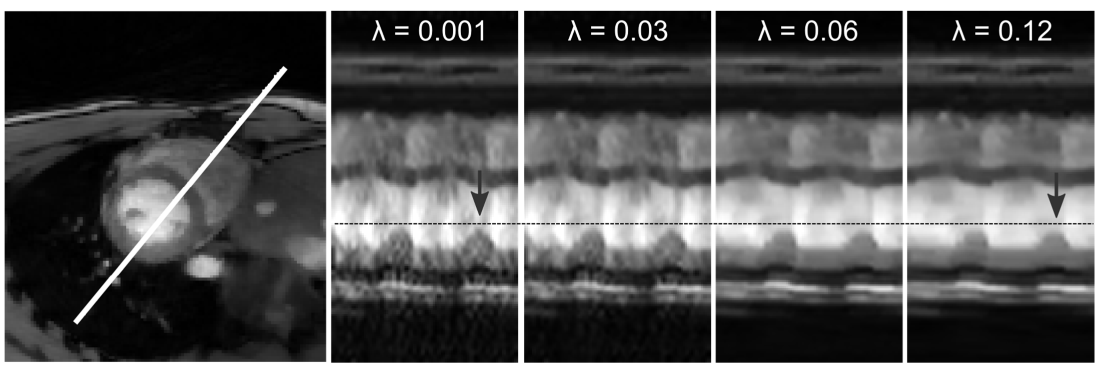

Figure 1: Reconstruction results using an increasing temporal regularization strength λ.

Conclusion: The results of the increased end-systolic volumes are in line with the 10% lower EF reported by Voit et al. [1]. In contrast to the end-diastolic state, the resting phase of the heart in end-systole is limited to only a few milliseconds, which leads to a sharp peak in the temporal signal profile of some voxels that is blurred by the strong temporal regularization. This blurring increases the chamber volume in end-systolic state and leads to a general under estimation of the EF.

References:

[1] Voit D, et. al. J. Cardiovasc. Magn. Reson., vol. 15, no. 1, p. 79, Sep. 2013. [2] Feng L, et al. Proc. Intl. Soc. Mag. Reson. Med., 2011. [3] Winkelmann S, et. al. IEEE Trans. Med. Imaging, vol. 26, no. 1, pp. 68–76, Jan. 2007. [4] Heiberg E, et al. BMC Med. Imaging, vol. 10, no. 1, pp. 1–13, 2010.