Free Breathing Real-Time Functional Cardiac Imaging at 3 Tesla

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Introduction: Functional cardiac imaging is the current gold standard for the determination of parameters related to left ventricular (LV) function such as the end-diastolic volume (EDV), end-systolic volume (ESV) and the ejection fraction (EF). However, in cases of arrhythmia or when patients do not tolerate breath holds, the standard ECG-triggered segmented read out cannot be used and it becomes necessary to use a single-shot real-time (ss-rt) protocol [1,2,3] instead. In order to obtain the necessary temporal resolution of T_{res} = 50 ms [4], special care needs to be placed on the use of parallel imaging and the available SNR. So far, clinical studies of ss-rt protocols exist only at 1.5 Tesla; thus, this work investigates protocols for the use at 3 Tesla and presents the results of a volunteer study.

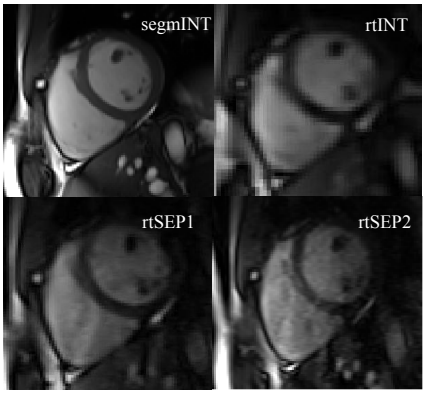

Fig. 1 Qualitative comparison of all protocols

Materials: 20 healthy volunteers underwent imaging on a clinical 3 Tesla scanner (Magnetom Verio, Siemens, Erlangen, Germany) using a dedicated 32-channel cardiac array (Rapid Biomedical, Rimpar, Germany). Three different rt-ss protocols with Grappa reconstruction were designed, namely I) rtINT: with integrated reference scan (voxel size *ds*= 2.5×5.0×8 mm³, GRAPPA acceleration factor *R*=3, T_{res}=51.3 ms); II) rtSEP1: with separate reference scan (*ds*=1.9×3.1×8 mm³, *R*=5, T_{res}=48.8 ms); and III) rtSEP2: with separate reference scan (*ds*=1.6×2.6×8 mm³, *R*=6, T_{res}=48.3 ms). Standard of reference was an ECG-triggered segmented readout cine protocol (segmINT), with ds=1.6×1.6×8 mm³ *R*=2 and T_{res}=30.4 ms. By using the ss-rt protocols the total acquisition time could be reduced from 5-7 minutes to less than 30 seconds for whole-heart coverage. Additionally, phantom measurements were performed at 3 Tesla and on a clinical 1.5 Tesla scanner (Magnetom Avanto, Siemens) on a phantom consisting of 3 bottles containing $NiSO_4$_6(H_2O) and NaCl using rtSEP1 with a slightly modified FoV (*ds*=2.1×2.3×8 mm³), and SNR maps were calculated on a pixel by pixel basis as proposed in [5].

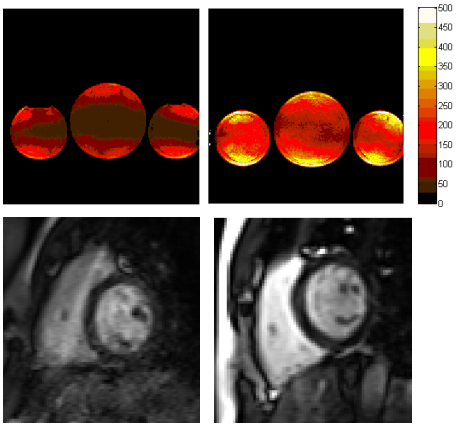

Fig. 3 Pixel by pixel comparison of the SNR values at 1.5 Tesla (top left) and 3 Tesla (top right) for *R*=5. The signal gain at 3T is essentially 2, resulting in a much better in vivo image quality (using rtSEP1) at 3T (bottom right) compared to 1.5 T (bottom left)

Results: All protocols showed sufficient image quality for all volunteers. Specifically, motion artifacts due to the use of the separate reference scan did not impede image analysis, but the visually best image compromise of SNR and spatial resolution is obtained from rtSEP1. A quantitative comparison of the results for EF (Fig. 2) shows that all protocol yield results that are consistent with the gold standard. Average values for the ejection fractions were segmINT = 60.6±5.8 %, rtINT = 55.9±5.3 %, rtSEP1 = 58.9±5.5 %, and rtSEP2 = 57.2±6.6 % respectively. The quantitative results in Fig. 2 also prefer the protocol rtSEP1, while rtINT reveals a larger bias towards large EFs and rtSEP2 a larger variation of EF. Results for the SNR measurements are shown in Fig. 3, comparing the results at 3 T to those at 1.5 for an acceleration factor of *R*=5. Signal inhomogeneities exist in the surface regions of the phantom, but no "folding artifacts" due to image reconstruction from parallel imaging are observed in this particular setup and the signal gain at 3 T is therefore indeed the expected factor of 2; in vivo image quality is improved accordingly as demonstrated in an additional volunteer measurement (Fig. 3, bottom).

Conclusions: With the help of a separate reference scan, single-shot real-time cine MRI offers the possibility to perform a complete functional analysis of the left ventricle even in cases of arrhythmia and under free breathing in a very short time. This work presents several protocols that yield results compatible with the gold standard (mean bias of the EF less than 5 %) and are thus suitable for clinical application.

References: [1] Barkhausen, J et al, AJR Am J Roentgenol. 2002;178(3):731-5. [2] Lee, VS et al, Radiology. 2002;222(3):835-42. [3] Wintersperger, B et al, Eur. Radiol. 2003;13(8):1931-6. [4] Miller, S et al, Radiology. 2002;223(1):263-9. [5] Reeder, SB, et al, Magn Reson Med. 2005;54(3):748-54.

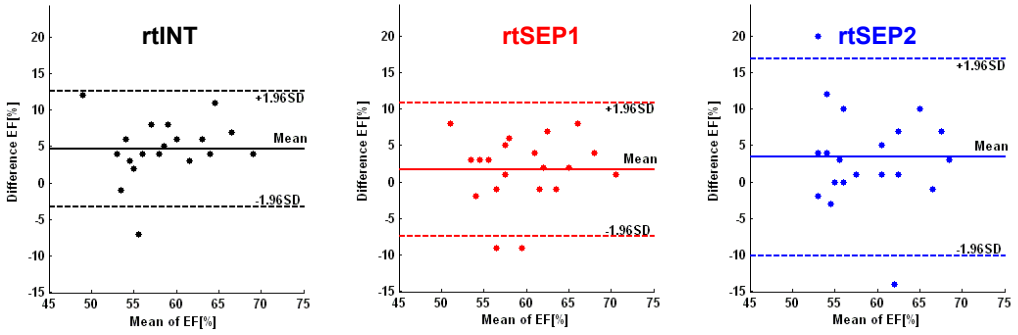

Fig. 2 Quantitative comparison of the EF values for all protocols (black = rtINT, red = rtSEP1, blue = rtSEP2) with the segmented cine protocol segmINT in a Bland Altman plot. Solid lines correspond to mean values, dashed to standard deviations. The difference refers to segmINT-rtXXX, for all rt protocols.