On the feasibility of accelerating self-gated cine cardiac imaging in rodents using SENSE

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INTRODUCTION In recent reports, self-gated cardiac imaging has been demonstrated to be a useful tool for cine cardiac MR imaging in small rodents [1]. This approach simplifies animal preparation as neither external cardiac nor external respiratory triggering or gating is required. However, the method suffers from long acquisition times as a sufficient number of repetitions needs to be acquired to allow for a retrospective reconstruction of an entire cardiac cycle during at least one respiratory state. For this reason accelerating self-gated cardiac imaging is of high interest as has been demonstrated in humans [2]. This work aims at investigating the feasibility of and the requirements for accelerating self-gated cardiac imaging in rodents using the parallel imaging method SENSE (SENSitivity Encoding) [3]. For this purpose fully sampled data of the rat heart were acquired using the IntraGate technique. Cardiac cine images were retrospectively reconstructed using different percentages of the respiratory cycle. In computer simulations the effect of residual artifacts caused by respiration and blood pulsation on the SENSE reconstructions were investigated by calculating artifact levels and reconstruction errors.

METHODS All experiments were carried out on a Bruker BioSpec 94/30 (Bruker BioSpin MRI, Ettlingen, Germany) small animal MR system operating at 400 MHz. A linear polarized volume resonator was used for excitation and a four element (2x2) phased array surface coil for signal reception.

In vivo experiments were carried out on male Lewis rats in strict adherence with the Swiss law for animal protection. The animals were anesthesized using 2.0% Isoflurane in an oxygen/air (20%/80%) mixture. Animals were freely breathing and carefully positioned with the heart resting on the center of the phased array.

Initially, scout images of the heart anatomy were acquired for accurate planning of the subsequent cine cardiac scans. Short axis images covering the entire left ventricle were acquired using the self-gating technique IntraGate (Bruker BioSpin MRI, Ettlingen, Germany) with the following parameters: field-of-view (FOV)=60x35mm², 9 contiguous slices of 1.0mm thickness, matrix dimension=300x175, spatial resolution=(200x200)µm², pulse angle=10°, echo/repetition time (TE/TR)=1.9/78.7ms, number of repetitions (NR)=200, total acquisition time: 23min. Inflowing blood was saturated in a slice of 4.2mm thickness parallel to the imaging stack.

Reconstruction: In post processing the acquired navigator information was used within the IntraGate software to assign the acquired k-space lines to ten cardiac frames and one respiratory frame. This assignment was repeated using 10 to 70 percent of the respiratory cycle.

Two-fold accelerated SENSE acquisitions were simulated by discarding every second k-space line. Coil sensitivities were estimated by dividing the time-averaged single coil images by the corresponding reference images. Reference images were calculated as the sum-of-squares (SOS) combination of the single coil images, whereas the phase of the reference images was estimated according to the approach proposed by de Zwart et al. [4]. For coil sensitivity estimation a signal mask was calculated using a noise level adapted threshold (mean(noise)+5*SD(noise)). Reconstruction was performed using in-house software written in IDL (RSI, Boulder, USA).

Data analysis: Analysis of the artifact level with respect to the percentage of the respiratory cycle used in IntraGate was performed on one mid-ventricular slice most severely affected by respiratory motion artifacts. The artifact level in the images was estimated from two regions-of-interest (Fig. 1b) reflecting artifact signal ($S_{Artifact}$) and tissue signal (S_{Tissue}), respectively, according to the following equation:

$$Artifact\ level = \frac{S_{Artifact} - S_{Tissue}}{S_{Tissue}} * 100 \qquad [1]$$

Reconstruction quality was estimated by calculating the relative root-mean-square (RMS) error of the reconstructed images (*acc*) compared to the reference images (*ref*) when using 30% of the respiratory cycle:

$$E_{RMS} = \sqrt{\sum_{x,y,z,t} |acc - ref|^2 \Big/ \sum_{x,y,z,t} |ref|^2} \qquad [2]$$

RESULTS Increasing the percentage of the respiratory cycle used during the assignment of the raw data to the cardiac and respiratory frames leads to enhanced residual respiratory motion artifacts (Fig. 1c). Accordingly this increased artifact level severely degrades the estimated coil sensitivities (Fig. 2) as artifact and tissue signal are of comparable magnitude. Two-fold SENSE accelerated images show excellent image quality when using 30% of the respiratory cycle, while severe fold-over artifacts in addition to respiration artifacts occur when using 70% of the respiratory cycle. A significant increase of the RMS error was found for two-fold SENSE accelerated images using more than 50% of the respiratory cycle.

DISCUSSION Accelerating self-gated cine cardiac imaging in rodents using SENSE seems to be feasible. However, in contrast to human applications where coil senstivities are usually estimated using separate scans acquired during short breath-hold periods, the coil sensitivities in small animal MRI have to be estimated from the cine cardiac data directly acquired following a self-calibrated sampling pattern. In this case, self-gated cine cardiac imaging accelerated using SENSE puts higher demands on the compensation of respiratory motion compared to full k-space sampling which might still yield acceptable image quality. For the accurate estimation of the coil sensitivities only minimal artifact levels can be tolerated. Nevertheless, assuming proper control of respiration artifacts SENSE holds potential to speeding up self-gated cine cardiac imaging in rodents.

REFERENCES [1] Hiba, B, et al., MRM; 58:745-753, 2007; **[2]** Uribe, S, et al., MRM; 57:606-613, 2007; **[3]** Pruessmann, KP, et al., MRM; 42:952-962, 1999; **[4]** de Zwart, JA, et al., MRM; 48:1011-1020, 2002;

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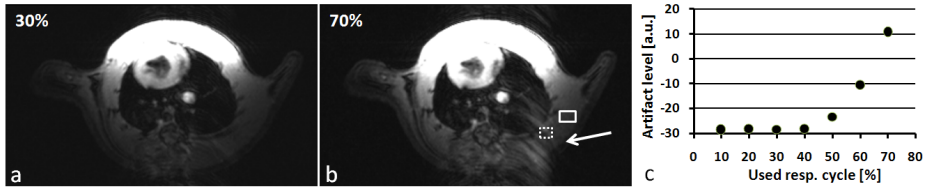

Figure 1: Short axis view of the rat left ventricle SOS reconstructed from fully sampled k-space data using 30% (a) and 70% (b) of the respiratory cycle. Severe respiration artifacts (arrow) are visible when using 70% of the respiratory cycle. (c) Artifact levels (Eq. 1) in images reconstructed using different percentages of the respiratory cycle. Signal and artifact were estimated in the solid and the dashed rectangular region-of-interest, respectively.

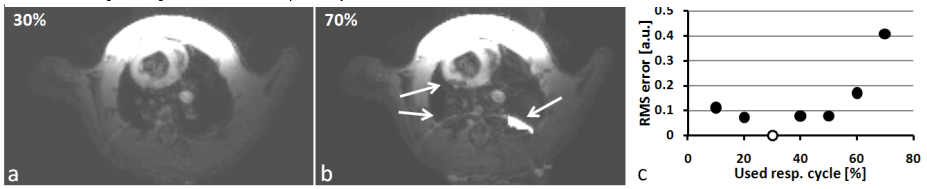

Figure 3: Simulation of two-fold SENSE accelerated acquisitions using data reconstructed from 30% (**a**) and 70% (**b**) of the respiratory cycle, respectively. Using 70% of the respiratory cycle severe residual fold-over artifacts (arrows) are visible (Fig. 2). (**c**) Relative RMS error (Eq. 2) of the SENSE accelerated images for data reconstructed from increasing percentages of the respiratory cycle. Data using 30% of the respiratory cycle (open circle) served as reference.

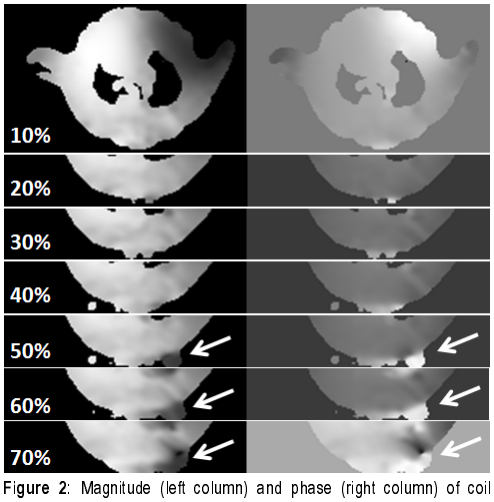

Figure 2: Magnitude (left column) and phase (right column) of coil sensitivities estimated from time-averaged data using 10-70% of the respiratory cycle. Degradation of the coil sensitivities (arrows) increases for larger percentages of the respiratory cycle.