Retrospectively gated CINE ^{23}Na imaging of the heart at 7.0 T using density-adapted 3D projection reconstruction

Ana Resetar[1], Stefan H. Hoffmann[1], Andreas Graessel[2], Helmar Waiczies[3], Thoralf Niendorf[2,4], and Armin M. Nagel[1]

[1]*Medical Physics in Radiology, German Cancer Research Center (DKFZ), Heidelberg, Germany,* [2]*Berlin Ultrahigh Field Facility, Max-Delbrueck-Center for Molecular Medicine, Berlin, Germany,* [3]*MRI.TOOLS GmbH, Berlin, Germany,* [4]*Experimental and Clinical Research Center (ECRC), Charité Campus Buch, Berlin, Germany*

INTRODUCTION

Sodium (^{23}Na) plays an important role in many biological processes, especially for ion homeostasis. Alterations of the vital ^{23}Na concentration gradient between intracellular (10-15 mM) and extracellular (~145 mM) sodium have been found in various disorders such as cancer and myocardial infarction [1]. ^{23}Na-MRI is especially suitable for the detection of acute and chronic myocardial infarction due to increased sodium signal intensity in the affected regions [2]. The low sodium concentration versus protons and the fast transverse relaxation manifest itself in in-vivo sensitivity constraints. To offset these constraints it is conceptually appealing to pursue dedicated pulse sequences for ^{23}Na MRI [3]. To meet this goal a retrospectively gated reconstruction routine was implemented and evaluated in conjunction with different 3D radial sampling schemes with the ultimate goal to support ^{23}Na CINE imaging of the heart at 7.0 T.

MATERIALS AND METHODS

^{23}Na MRI was performed on a healthy female volunteer using a 7 T whole body MRI system (Magnetom 7T, Siemens AG, Erlangen, Germany) with a custom-built four channel transceiver RF coil consisting of an anterior and a posterior section with two loop elements each [4]. A density-adapted 3D projection reconstruction sequence (3D-DAPR) was used with a standard (STD) [5] and a golden angle (GA) [6] projection acquisition scheme. The sequence parameters for both acquisition schemes were: TE/TR 0.4/11 ms, flip angle 18°, nominal spatial resolution (6x6x6) mm^3, readout duration 7.1 ms and RF pulse duration 0.7 ms. Cardiac activity logging was performed simultaneously with an acoustic cardiac gating device (easyACT, MRI Tools GmbH, Germany) which provides a digital trigger pulse with each phonocardiogram's first heart tone. MR data acquisition was performed w/o cardiac triggering and with free breathing. The golden angle acquisition was conducted with 50000 projections and 2 averages resulting in a scanning time of 18 min 34 s. In the standard projection acquisition scheme, the same number of projections was distributed over 10 acquisitions (10000 projections each) to provide a more uniform distribution of the projections in the retrospectively filled k-spaces. Reordering of the acquired projections was accomplished by filling the k-spaces for each cardiac phase using the trigger signal as a reference (cf. Fig. 1). The performance of the standard and the golden angle sampling was evaluated in phantom measurements by comparison of the SNR and the distribution of the projections in k-space.

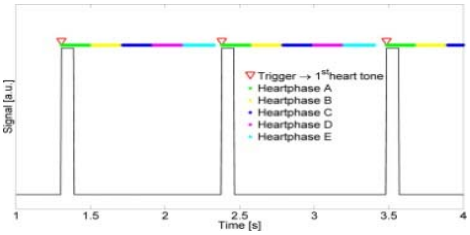


Fig. 1. *Pulse signal of the cardiac gating device with the trigger at the first heart tone. The colored spots represent the reconstructed heart phases of 0.2s temporal resolution.*

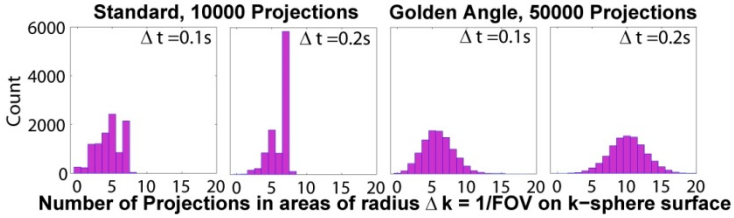
Table 1: *Percentages of Nyquist fulfilment and SNR*

Acquisition scheme, Δt	*% Nyquist*	*SNR (Hanning Filter)*
Standard, 0.1s	130	29
Standard, 0.2s	169	36
Golden angle, 0.1s	230	33
Golden angle, 0.2s	393	44

RESULTS

The 3D images of the cardiac cycle were reconstructed with temporal resolutions Δt of 0.1s (10 phases) and 0.2s (5 phases). The percentages of Nyquist fulfilment were calculated according to the expression $P_C/P_N \cdot 100\%$ with P_C being the number of collected projections and P_N the number of projections needed for 100% Nyquist sampling ($P_N = 4 \cdot \pi \cdot (FOV/2)^2$, FOV=40 pixel). The percentages of Nyquist fulfilment and the SNR of a ROI covering the heart reconstructed with the Hanning filter are shown in Table 1. The GA approach with Δt=0.2s (0.1s) yielded 18% (12%) higher SNR versus the STD technique. To determine the distribution of the projections in k-space (Fig. 2) the number of projections in an area with radius Δk = 1/FOV around each radial projection was investigated. The resulting histograms show a more uniform projection distribution for GA versus STD, resulting in a reduced propensity for artefact-producing holes on the surface of the k-space sphere.

Fig.2: *Distribution of the projections in k-space for STD and GA measurements with Δt=0.1s and 0.2s*



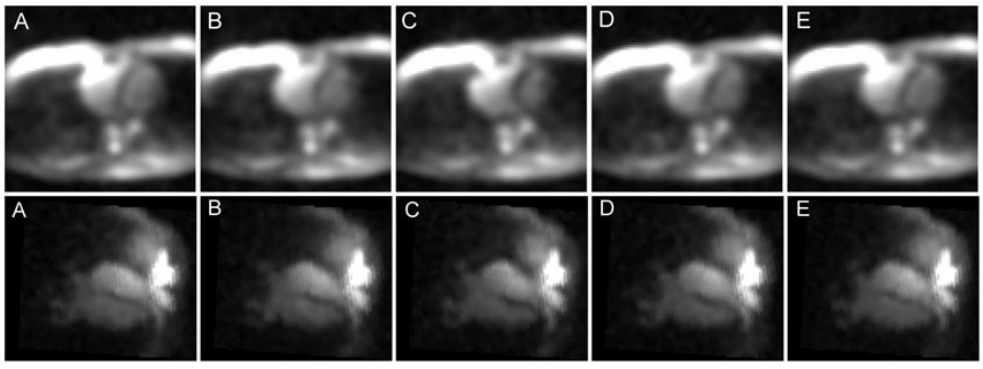


Fig 3: *Upper row: Five short axis views of the heart; bottom row: four chamber view. A temporal resolution of 0.2s was used to cover the entire cardiac cycle. For data acquisition and reconstruction nominal spatial resolution of 6x6x6mm^3, FOV (240 mm)^3, Hanning filter and a standard acquisition scheme were used. Figures A and B represent images of the heart acquired during systole, while C, D, E were recorded during diastole (cf. Fig 1.)*

CONCLUSION AND DISCUSSION

Our results demonstrate that retrospectively gated CINE ^{23}Na imaging of the heart at 7.0 T using density-adapted 3D projection reconstruction is feasible. The GA acquisition scheme is superior to the STD acquisition. GA sampling yields a more uniform distribution of projections in the reordered k-spaces, in particular if images of the heart are reconstructed with a high temporal resolution (0.1s; i.e. less collected projections per heart phase). This results in reduced image artefacts and higher SNR.

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