Highly accelerated non-contrast-enhanced MR angiography of the renal arteries featuring sparse, incoherent sampling and L1-regularized iterative SENSE

Michaela Schmidt[1], Stefan Haneder[2], Ulrike I. Attenberger[2], Melissa M. Ong[2], Mariappan Nadar[3], Peter Schmitt[1], Xiaoming Bi[4], Stefan O. Schoenberg[2], and Michael O. Zenge[1]

[1]Siemens AG Healthcare Sector, Erlangen, Germany, [2]University Medical Centre Mannheim, Institute of Clinical Radiology and Nuclear Medicine, Germany, [3]Siemens Corporate Technology, Princeton, NJ, United States, [4]Siemens Healthcare, LA, CA, United States

INTRODUCTION: Inversion-prepared b-SSFP imaging is a suitable approach to perform non-contrast-enhanced (non-CE) MR angiography (MRA) of the renal arteries. This technique uses a slab-selective inversion of the volume of interest followed by a time delay before data acquisition [1]. A general limitation of non-enhanced MR angiography, however, is its long data acquisition time compared to contrast-enhanced methods. However, novel iterative image reconstruction methods promise to radically accelerate the data acquisition [2]. While preliminary results of retrospectively sub-sampled data were very promising [3], imaging contrast could be different if such under-sampling is done in a prospective manner. The current study aims at combining highly accelerated data acquisition with L1-regularized iterative SENSE. Image quality of acquisitions with increasing sub-sampling rates was investigated in a volunteer study.

METHODS: 20 healthy subjects (11 f, age range 25-68 y, mean age 39 y) were included in the study with informed consent. Data acquisition was performed on two identical clinical 3T MRI systems (MAGNETOM Skyra, Siemens AG, Healthcare Sector, Erlangen, Germany). The standard Body 18 and Spine 32 Tim 4G coils of the system were used for signal reception. A variable-density spiral phyllotaxis trajectory [4] was implemented to support sparse, incoherent sampling in an inversion-prepared 3D b-SSFP prototype sequence. Image reconstruction was performed on the MR scanner with a prototype implementation of an L1-regularized iterative SENSE algorithm [5]. The data acquisition was triggered using an external respiratory belt. The slice orientation was transversal and two transverse inversion slabs (IR1: TI 1300ms, 150mm thickness; IR2: positioned below, TI 850ms, 100 mm thickness) were used for spin-labeling of both kidneys and to suppress venous inflow (Fig 1). Each acquisition, preceded by a fat sat module, was performed with the following parameters: Voxel size 1.1 mm³ measured and reconstructed, 88 slices, flip angle = 38–55 deg, TE/TR=1.9/4.2ms, BW=783Hz/Pix. Sub-sampling was performed with rate 6.4, 9.0 and 11.5 with respect to the fully sampled matrix and was compared to a reference protocol with rate 2 GRAPPA acceleration. The image quality of the renal artery tree were graded according to a 5-point scale (1=excellent, 2=good, 3=moderate, 4=poor, 5=non-diagnostic) by two experienced radiologists for each subject. The right and left artery tree were divided into a proximal and distal part, and the mean result of both sides was assigned to the dataset. Furthermore the delineation of the right and left distal renal arteries and the overall diagnostic quality were rated.

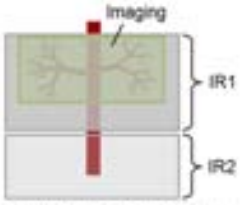

Figure 1: Labeling scheme: Inversion slabs (grey) and imaging volume (green)

RESULTS: Fig. 2 shows representative MIPs and transversal MPRs obtained with different sub-sampling rates in two volunteers. The image quality scores obtained in all volunteer datasets are shown in waterfall plots (Fig. 3) for the 4 acceleration factors. The mean scan times were
08:07±1:41min (Acc2);
02:12min±0:25 (Acc6.4);
01:33min±0:18 (Acc9);
01:12min±0:16 (Acc11.5). The image quality was rated as non-diagnostic for 1 volunteer with Acc2, for 2 volunteers with Acc6.4 and Acc9 and for 6 volunteers with Acc11.5. Delineation of the distal renal arteries was not possible with Acc2 and Acc6.4 in 4 (1 left , 3 right), with Acc9 in 6 (3 left, 3 right) and with Acc11.5 in 11 (5 left, 6 right) cases. The iterative image reconstruction times were less than 5 minutes in all cases.

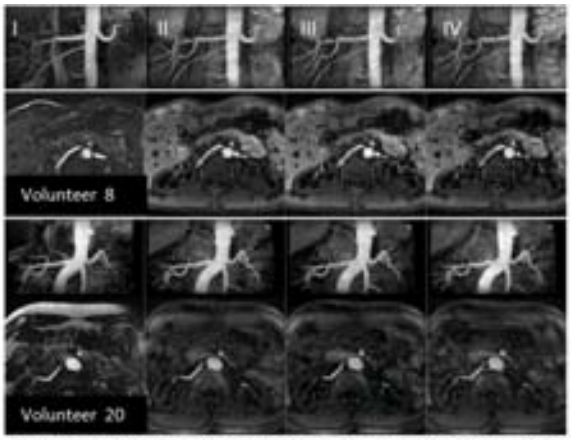

Fig 2: MIP and transversal slice for I) Acc2; II) Acc6.4 III) Acc9 and IV) Acc11.5 for volunteer 8 and 20

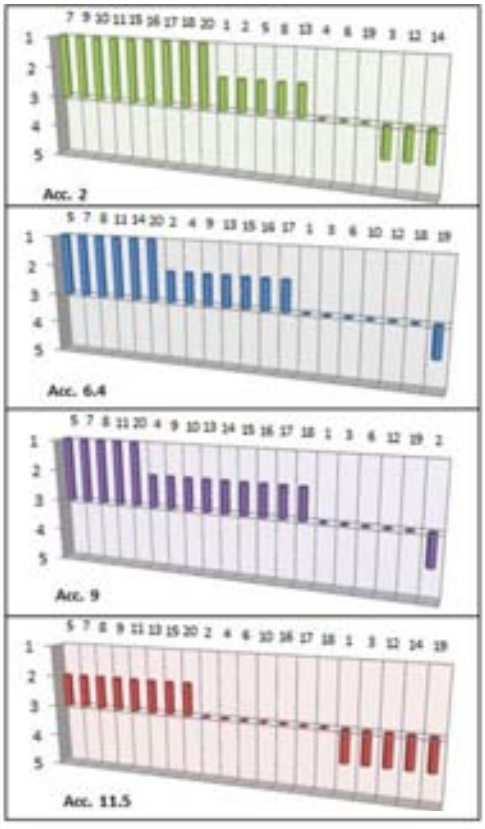

Fig. 3: Image quality scores for Acc. 2, 6.4, 9 and 11.5 displayed for each volunteer individually

DISCUSSION: In comparison to the reference protocol, the proposed highly accelerated imaging method performed very competitively with acceleration rates up to 9. In particular, if the radical savings of the data acquisition time are taken into account, then small deficits in image quality might be tolerable. Nonetheless, the artifact characteristics of the featured incoherent sampling pattern have to be investigated very carefully. In contrast to the conventional linear reordering, data close to the k-space center and the periphery were acquired with every trigger event. While this is optimal from fat-saturation perspective, an increased sensitivity to data inconsistencies is to be expected and, indeed, cases with impaired image quality correlated well with irregular breathing and other triggering problems. Finally, respiratory motion and uncompensated sub-sampling artifacts manifest very similarly in the images which renders the interpretation of such effects difficult.

CONCLUSION: The current work proves that a radical reduction of the scan time for non-ce MRA of the renal arteries is practically possible. Ultimately, incoherent sampling strategies have to be developed which are less sensitive to uncompensated motion artifacts. Primarily the achieved image quality, but also the smooth integration of the current prototype into the system architectures motivate additional experiments in volunteers and patients.

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