

# Conjugate symmetry for improved parallel imaging with GRAPPA

M. Blaimer<sup>1</sup>, H. Köstler<sup>2</sup>, P. Kellman<sup>3</sup>, and M. A. Griswold<sup>1</sup>

<sup>1</sup>Department of Radiology, University Hospitals of Cleveland and Case Western Reserve University, Cleveland, Ohio, United States, <sup>2</sup>Experimentelle MR Tomographie, Institut für Röntgendiagnostik, Universität Würzburg, Würzburg, Germany, <sup>3</sup>Laboratory of Cardiac Energetics, National Institutes of Health, National Heart, Lung and Blood Institute, Bethesda, Maryland, United States

**Introduction:** Several approaches for combining parallel imaging with conjugate k-space symmetry have been presented previously (1,2,3). Here, we present a practical implementation for GRAPPA by generating virtual coils with conjugate sensitivity profiles. In contrast to image domain approaches, no phase maps or coil sensitivity maps have to be calculated since they are inherent in the GRAPPA reconstruction when using variable-density (VD) or time-interleaved acquisition schemes. In combination with symmetric trajectories, this approach results in improved image quality exhibiting less noise enhancement.

**Methods:** The conjugate symmetry relation can be written as  $S(k) = S(-k)^*$ . Here,  $S(k)$  is an acquired signal at position  $k$  in k-space and  $*$  denotes the complex conjugate. The basic idea for improving the performance of GRAPPA is to create virtual coil elements containing conjugate sensitivity profiles. Using a coil array with  $N_C$  elements signals from virtual coil elements are generated in the following way:

$$S(j+N_C, k) = S(j, -k)^*, \quad j = 1, \dots, N_C. \quad [1]$$

In that way, the encoding capabilities of the coil array are improved resulting in a reduced geometry factor and better image quality. Conventional GRAPPA reconstructions are then performed using fully sampled auto-calibration signal (ACS) lines acquired with the same sequence parameters. The ACS can either be obtained by using a VD acquisition scheme or in dynamic imaging by using a time-interleaved phase-encoding (PE) scheme as in TSENSE (4), TGRAPPA (5) or Auto-SENSE (6). Equation [1] can also be applied to symmetric non-Cartesian trajectories, for example in projection reconstruction MRI.

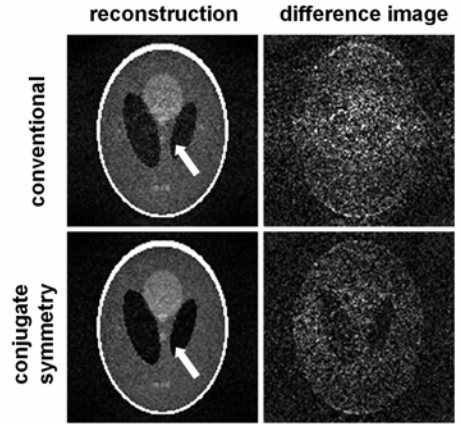


Fig 1: Simulation results (R=3, 4 chan) showing reconstructed images (left side) and difference from fully sampled reference image (right side).

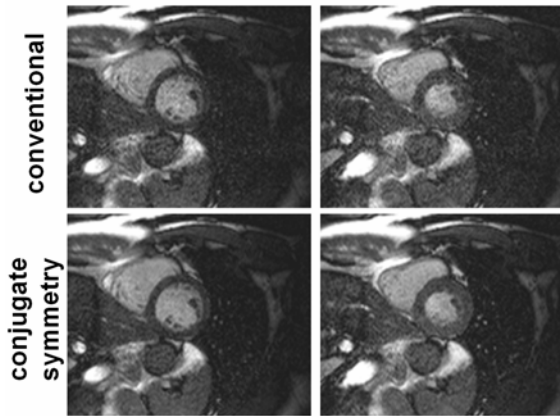


Fig 2: Dynamic cardiac imaging results (R=4, 8 chan) reconstructed with conventional TGRAPPA (top row) and conjugate-symmetry TGRAPPA (bottom row).

conjugate symmetry approach. Fig 2 shows two time frames from the cardiac TrueFISP study. Compared to conventional TGRAPPA, the conjugate-symmetry results exhibits significantly reduced noise revealing more details of the heart and the lung tissue. Results from the radial acquisition are presented in Fig 3. In all presented examples, the reconstructions employing conjugate symmetry exhibit less noise enhancement and reduced artifacts. The presented approach works with all symmetric trajectories (Cartesian and non-Cartesian) allowing improved GRAPPA reconstructions. The cost is an increased reconstruction time due to an increased number of channels.

**References:** (1) Willig-Onwuachi, JD, et al. Proc ISMRM 2003, #19. (2) Bydder M, Robson MD. MRM 53 (2005) (3) Heidemann RM, et al. MRM 49 (2003) (4) Kellman P, et al. MRM 45 (2001) (5) Breuer FA, et al. MRM 53 (2005) (6) Köstler H, et al. JMIRI 18 (2003) (7) Griswold MA, et al. Proc ISMRM 2003, #2349.

Computer simulations were performed using a Shepp-Logan phantom with a linear phase-roll over the FOV. A four-channel linear array was simulated and GRAPPA reconstructions (R=3) were performed employing 11 ACS lines (not integrated into final reconstruction). Accelerated (R=4) dynamic cardiac images were acquired on a clinical 1.5 T scanner with an 8-channel coil array and a time-interleaved PE scheme. A phantom experiment was performed using an accelerated (R=4) radial TrueFISP acquisition and a 12-channel head coil for signal reception. Radial GRAPPA (7) reconstructions were performed using a separate pre-scan as ACS data (256 projections).

**Results and Discussion:** The simulation results are presented in Fig 1. Reconstructed images and their subtraction from the fully sampled reference image are shown. One should note the reduced noise using the

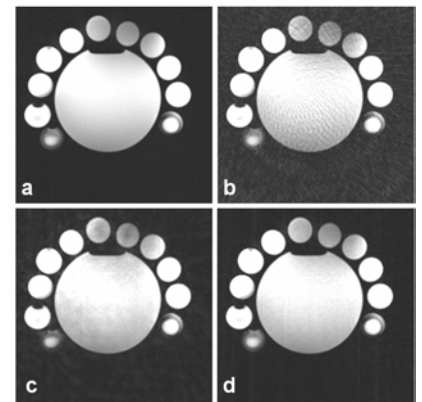


Fig 3: Radial GRAPPA results (R=4, 12 chan) showing the fully sampled pre-scan (a) and the undersampled acquisition (b), reconstructed with conventional radial GRAPPA (c) and conjugate symmetry radial GRAPPA (d).