Highly Accelerated Contrast-Enhanced MR Angiography using Ghost Imaging

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Introduction: Contrast-enhanced MRA (CE-MRA) is a well-established methodology that accurately depicts vessel morphology in multiple vascular territories. In order to minimize the signal contribution from background tissues, a pre-contrast data set is typically subtracted from the post-contrast data set. Parallel acceleration techniques such as GRAPPA and SENSE are routinely used to improve spatial resolution and reduce scan times. However, severe image artifacts and noise are introduced if large parallel acceleration factors (PAF) are applied with standard phased array coils.

Ghost MRA represents a fundamentally new approach for vascular imaging with potential applications for both non-contrast and contrast-enhanced angiography. The method involves the creation of a ghost image which displays the vasculature with little or no signal contribution from background tissues. We compared conventional subtraction CE-MRA with Ghost CE-MRA in a series of healthy subjects using comparable image acquisition parameters. We also tested the hypothesis that the near perfect background suppression with Ghost imaging enables the use of much higher parallel acceleration factors (PAF) than are feasible with standard phased array coils using the conventional CE-MRA approach.

Subjects and Methods: For Ghost CE-MRA in its most basic implementation, the even k_z lines of a 3D data set are populated with pre-contrast data and the odd k_z lines with post-contrast data. The modulation of the signal intensity along the k_z direction produces a ghost image of the contrast-enhanced blood vessels which can be processed using a maximum intensity projection and rotated in three dimensions as with a conventional CE-MRA.

Six healthy subjects (6 male, ages 21-31) were imaged on a 1.5 Tesla Avanto MRI system with 32 channels (Siemens Medical Solutions, Erlangen). The standard peripheral and body array coils were used for signal acquisition. Two sequential contrast agent infusions (gadopentetate dimeglumine, Bayer Pharmaceuticals, Berlin, 0.1 mmol/kg per infusion at 2 cc/sec) were performed in each subject, separated by at least 15 minutes. In three subjects the conventional CE-MRA was performed first, and in the other three subjects the Ghost CE-MRA was performed first. The field of view spanned from the renal arteries through the upper thighs. Typical pulse sequence parameters included TR/TE/flip angle = 2.4 ms/0.8 ms/23°, field of view = 500 x 500 mm, matrix = 320 x 320, acquired slice thickness = 2 mm, PAF (ipat) = 4, scan time = 17 sec. Vessel-to-background contrast-to-noise ratios (CNR) were computed using region-of-interest measurements. In addition to these six subjects, three subjects were imaged using Ghost CE-MRA with a PAF of 8 or 13 and single contrast agent infusion.

Results: Figure 1 shows a representative comparison of image quality using conventional subtraction and Ghost CE-MRA. Vessel conspicuity and background suppression were superior with Ghost imaging. The visual impression was supported by the quantitative image analysis, which showed an approximately two-fold improvement in vessel-to-background CNR using Ghost compared with conventional subtraction CE-MRA for the pooled data [mean (s.d.) of 36.9 (13.1) vs. 18.9 (9.5)]. Moreover, with a PAF of 4, conventional subtraction CE-MRA showed substantial PA artifact which was absent from the Ghost MRA. Even with a PAF of 13, no PA artifact was observed in the Ghost MRA.

Conclusion: Ghost imaging enables highly accelerated CE-MRA with excellent vessel conspicuity, higher vessel-background CNR than conventional subtraction CE-MRA, and no PA artifact. Much higher PAF can be used than with standard MRA techniques without any obvious penalty in image quality. For instance, at 1.5 Tesla the peripheral array coil we used at most supports a PAF of 3. Remarkably, Ghost CE-MRA showed no PA artifact using a PAF of 13, whereas conventional CE-MRA was markedly degraded with a PAF of only 4. Even larger PAF may be feasible. Similar benefits might accrue using Ghost imaging for non-Cartesian techniques such as undersampled stack of stars radial MRA. Given the improved background suppression and accelerated scanning, Ghost imaging might prove beneficial not just for CE-MRA but for a range of applications such as dynamic contrast-enhanced breast MRI and perfusion imaging.

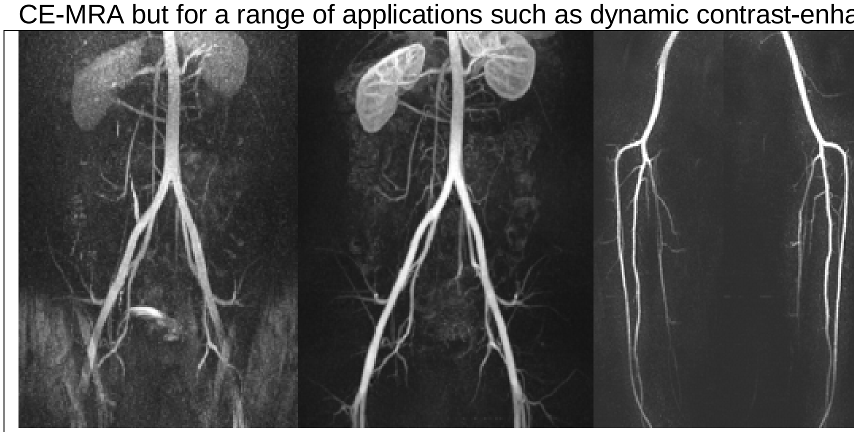

Figure 1. Comparison of conventional subtraction CE-MRA (left) and Ghost CE-MRA (middle) in one subject using a PAF of 4. Whereas the conventional CE-MRA shows severe PA artifact in the lower pelvis, Ghost CE-MRA shows no such artifact. In addition, Ghost CE-MRA shows superior background suppression and small vessel conspicuity. In another subject, Ghost CE-MRA of the calf vessels using a PAF of 13 (right) shows excellent image quality and no PA artifact.