Inherent insensitivity to B1 field inhomogeneity using regularized nonlinear inversion reconstruction

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INTRODUCTION

Signal intensity variation that arises from inhomogeneous transmit and receive fields not only complicates the qualitative appearance of MR images but also presents the major source of error in quantitative MRI/S. Many current approaches address this problem by mapping the transmit field [1] and assuming the same transmit and receive field patterns during compensation [2]. However, this assumption becomes problematic at high field where the correction becomes more significant [3]. While work has also been done to simulate both fields numerically, these calculations are usually model-dependent and cannot account for field inhomogeneity due to non-RF field factors. Collins et al. observed that with known receptivity, some parallel imaging methods such as SENSE can remove the receptivity inhomogeneity [4]. However, the coil receptivity is generally unknown and needs to be estimated from additional acquisitions. Recently, Ying [5] and Uecker [6] each proposed a method to jointly reconstruct the images and estimate the coil sensitivity for parallel imaging. This work studies the effect of the latter regularized nonlinear inversion approach on image signal intensity. We demonstrate that not only receptivity inhomogeneity, but also transmit inhomogeneity may be removed simultaneously. Therefore this approach may play a vital role in both quantitative and qualitative analysis with MRI beyond its application for parallel imaging.

MATERIALS AND METHODS

The inversion reconstruction algorithm [6] was implemented in Matlab (Mathworks, Natick, MA). Based on the prior knowledge that the coil sensitivity is smooth, the nonlinear inversion reconstruction algorithm uses an iteratively regularized Gauss-Newton method to reconstruct the images and estimate the coil sensitivity, with the coil sensitivity regularized by the Sobolev norm.

Human experiments were performed under an IRB approved protocol on a 3.0 Tesla clinical scanner (GE Healthcare, Waukasha, WI) using an 8-channel phased-array coil. Two data sets with 90° and 45° excitation angle, respectively, were collected with both a RF spoiled gradient echo (GRE) sequence and a fast spin echo (FSE) sequence. With the FSE sequence, the refocus pulse remains unchanged in both acquisitions. Other acquisition parameters include echo train length/TR/TE = 16/10s/12.8ms and an imaging matrix of 256×256. Acquisition parameters for the GRE sequence include TR/TE = 10s /3.8 ms, and 128×128 imaging matrix. Images were reconstructed offline with both the nonlinear inversion approach and the conventional FT approach, and the final images were the root mean square of that of each coil element. The long TRs used minimize spin saturation and thus the transmission field was estimated using the double flip angle approach from the conventionally reconstructed images.

RESULTS AND DISCUSSION

The reconstructed FSE images are shown in Fig. 1. The images reconstructed with the conventional approach (Fig 1a, c) shown noticeable signal intensity variation, while those reconstructed with the inversion reconstruction (fig 1b, d) show nearly homogeneous signal intensity across the field of view. Fig. 1e shows the estimated overall coil sensitivity from reconstructing Fig 1b. Fig 1g shows the image compensated for transmission inhomogeneity when Fig.1e is considered as solely receptivity. The center of the image appears dark, which indicates that the transmission inhomogeneity has been compensated for to certain extent. If the coil sensitivity (Fig. 1e) estimated from the nonlinear reconstruction is assumed to include both the transmit and receive field effects, the receive field can be calculated by dividing Fig.1e by *sin(kB1+)*, where k is a constant converting the B1+ field to flip angle. The result is shown in Fig. 1h and denoted as the B1- field. With the sensitivity maps measured from one data set, one can correct for the signal intensity in the other data with the existing approach, and the results are shown in Fig 1i, j. Both images show similar improvement as those obtained from the direct nonlinear reconstruction.

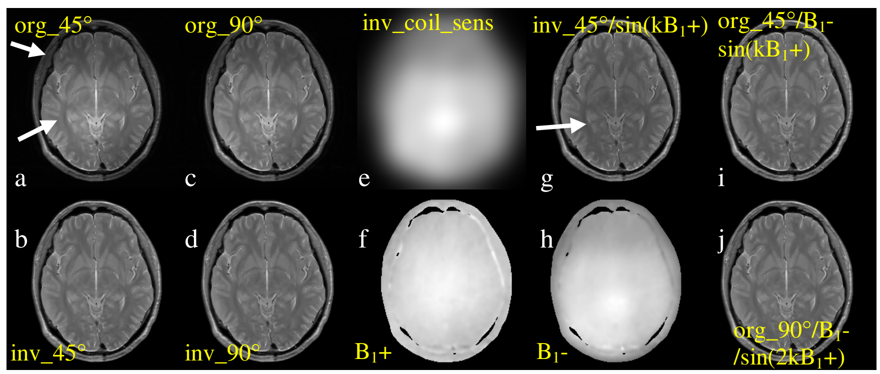

Fig. 1 FSE images demonstrate that the nonlinear inversion reconstruction removes signal intensity variation due to both receive and transmit field inhomogeneity.

When the same procedure was performed on the GRE data, similar effects have been observed. Fig. 2a, b show the images reconstructed using the conventional approach with significant signal intensity variation in both images. The corresponding images reconstructed with the inverse reconstruction (Fig. 1c, d) show nearly homogeneous signal intensity across the field of view.

As we have shown, the receptivity determined from one dataset can be applied to correct other data in the same exam if subject motion is minimal. However, the estimated coil sensitivity and image contrast of reconstructed images somewhat depend on the regularization term used; further studies is needed to examine its impact on the image contrast and optimize the regularization.

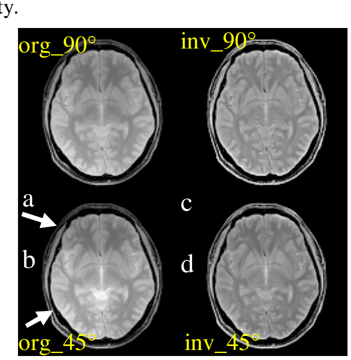

Fig.2 GRE images reconstructed with the conventional reconstruction and the nonlinear reconstruction.

CONCLUSIONS

The capability to compensate for signal intensity variation due to inhomogeneous transmit and receive field is important in both quantitative and qualitative MRI. We have shown that the nonlinear inversion reconstruction may inherently compensate for both effects without additional data acquisition or simulation, and thus can potentially provide a significant tool for many MRI applications.

REFERENCE 1. Stollberger et al. Magn Recon Med 1996; 35:246-251. 2. Boada et al. Int J Imaging Syst Technol 1997; 8:544-550. 3. Hoult DI, Concepts Magn Reson 2000; 12:173-187. 4. Collins et al. Magn Recon Med 2005; 54:1327-1332. 5. Ying et al. Magn Recon Med 2007; 57:1196-1202. 6. Uecker et al., Magn Recon Med 2008; 60:674-682.