Accelerated Serial MR Imaging in Multiple Sclerosis Using Baseline Scan Information

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Introduction: MRI is an important diagnostic tool providing noninvasive evidence of multiple sclerosis (MS) lesions in the central nervous system. Assessing longitudinal changes in lesion volume load using accepted imaging methods (T2, T2 FLAIR, and T1 weighted imaging after Gd contrast administration) serves as a valuable tool for evaluating treatment effects, monitoring disease progression and assessing disease activity [1]. Simultaneously, many quantitative MRI techniques such as diffusion tensor imaging, magnetization transfer imaging, and multi-component relaxometry can provide unique information about myelin and axon status, not available with conventional MRI. However, their introduction into routine clinical practice to supplement the standard MS imaging protocol will inevitably lead to a significant increase in scan times. In this work, we present a method to accelerate MS imaging using advanced reconstruction such as compressed sensing [2]. Our approach is based on the fact that many changes of interest occurring during disease progression, such as new T2w or Gd+ lesions, are of localized nature, making serial images of a MS patient highly correlated. Therefore, a large part of the anatomical information already present in baseline images potentially can be used to reconstruct subsequently acquired images from undersampled data.

Theory: The constrained reconstruction methods including compressed sensing have shown promise to accelerate serial imaging. While this concept was previously applied in fMRI imaging [3], the challenges of longitudinal scanning include co-registration of (potentially undersampled) images from different scan sessions, and session-dependant variability of image intensity due to B1 differences (both on transmit and receiver sides). We designed an approach capable of simultaneous minimization of these errors. Because many changes of interest are of a localized nature (T2w lesions, Gd+ lesions), while the majority of information remains relatively invariant, the difference between the baseline and follow-up images should be sparse. In compressed sensing terms it means that minimization of the gradient of the image difference should provide an efficient reconstruction tool. Mathematically, the follow-up image is reconstructed as the solution of the following minimization problem [4]:

$$\mathbf{f} = \arg\min_{\mathbf{f}} \left(\left\| \mathbf{E}\mathbf{f} - \mathbf{s} \right\|_2 + \lambda_1 \left\| \mathbf{L}\left(\mathbf{f} - \mathbf{f}_B \right) \right\|_{l1/l2} \right), \qquad [1]$$

where **E** is the encoding matrix including Fourier terms and coil sensitivities, **s** is the measured *k*-space data, $\mathbf{f_B}$ is the baseline image co registered to the follow-up scan, and **L** is the discrete image gradient operator. The minimization was done with hybrid *l1*/*l2* norm as described in [4].

Materials and Methods: The reconstruction method was tested on two sequential MRI scans obtained approximately five months apart on a 3T GE SIGNA scanner (Waukesha, Wisconsin, USA) in each of two relapsing-remitting MS patients who gave their informed consent under an IRB-approved protocol. Images included routine clinical T1-weighted 3D SPGR and 3D T2 FLAIR extended echo train acquisitions (CUBE) following administration of intravenous gadolinium contrast (0.1 mmol/kg). The undersampled acquisition was simulated from full follow-up acquisition (5 months after baseline scan). The co-registration between baseline and follow-up scans was done using simulated acquisition of 3-plane slices. Accelerated pseudo-radial acquisition was simulated from fully sampled follow-up images for each 2D slice of the image volume with acceleration factor 5 and 8 (80 and 50 uniformly distributed projections, respectively). The undersampled 2D reconstruction was performed for each slice using Voronoi diagram-based density compensation to improve spatial resolution as the more conventional zero-filling approach yields low resolution images.

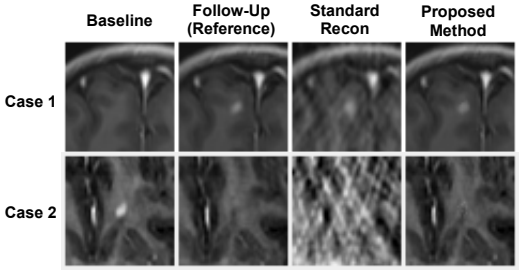

Figure 1. Reconstruction of undersampled T2 FLAIR (CUBE) images from accelerated (undersampled) data using proposed baseline scan regularized reconstruction (single coil channel, undersampling factors R=5 (top) and 8 (bottom)).

A senior neuroradiologist identified all focal T2-weighted lesions in the cerebral white matter on each image series, blinded to the reconstruction method used as well as the scan sequence. A total of 67 lesions were identified across both patients and time points. Sensitivity and specificity of lesion detection were calculated from true and false positive and negative rates, which were defined as follows: True positive and false negative rates = fraction of those lesions present on full follow-up acquisition that were or were not (respectively) detected by accelerated series; false positive and true negative rates = fraction of those lesions present at baseline, not present on full follow-up acquisition, that were or were not (respectively) detected by the accelerated series.

Results: Figure 1 shows example reconstruction of accelerated follow-up dataset from two patients. In the first case, no active lesion appeared in the baseline scan. The lesion and its evolution may be resolved both on fully sampled (reference) dataset and undersampled dataset reconstructed by proposed method. In the second scan, baseline contained active Gd+ lesion, which was subsequently resolved on the follow-up scan, which may be clearly seen on both reference and reconstructed images. However, the pattern of undersampling artifacts in the case of straightforward gridding reconstruction does not provide sufficient image quality to allow radiological interpretation. Figure 2 shows example reconstruction of 3D FLAIR data using the proposed method. The location of lesions are greatly correlated in both reference image and image reconstructed with the proposed technique. At the same time, gridding reconstruction of undersampled data introduces significant aliasing obscuring patient anatomy and lesions. The detection sensitivity was 98.5% (for acceleration factor *R*=5). The specificity assessment was not possible due to the small number of lesions present on baseline but not follow-up scans (total 7). The evaluation of specificity on a larger number of scans is the subject of the future research.

Discussion: In this abstract, we investigated feasibility of applying constrained reconstruction to accelerate serial scanning of MS patients with 3D pulse sequences (T2 FLAIR and Gd+). Our results indicate that the proposed technique has the potential to produce high-quality images from reduced follow-up acquisition and correctly depict T2 lesion load. In practice, acquisition of high resolution baseline scans may be done several times during the course of longitudinal examination (analogous to key frames in MPG compression), while intermediate scans may be done at much faster scan time. Interestingly, the proposed technique directly evaluates changes occurring between baseline and follow-up scans, a subject which was of interest in recent studies [5-7].

References: [1] Filippi M, et al. J Neuroimaging 2007. [2] E. J. Candès. Compressive sampling. Proceedings of the International Congress of Mathematicians, Madrid, Spain, 2006.. [3] Lin FH, et al. MRM, 2005; 54(2):343. [4] Samsonov et al. ISMRM 2008, p. 342. [5] Moraal B, et al. Radiology 2009; 250:506. [6] Duan Y et al. AJNR 2008; 29:340. [7] Dwyer M, et al. JNS, 2009; 282:86.

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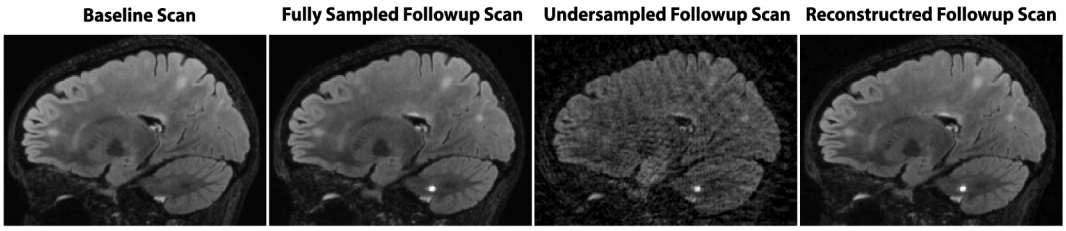

Figure 2. Reconstruction of undersampled T2 FLAIR (CUBE) images from accelerated (undersampled) data using proposed baseline scan regularized reconstruction (single coil channel, undersampling factor R=8).