Highly Parallel Volumetric Echo-Planar Spectroscopic Imaging with 2D Acceleration

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INTRODUCTION.

Ultra fast single average volumetric MR spectroscopic imaging (MRSI) can be accomplished by combining fast gradient-encoding techniques such as Proton Echo Planar Spectroscopic Imaging (PEPSI) [1] and parallel imaging reconstruction. We have recently introduced the combination of 3D-PEPSI and 2D-SENSE reconstruction with acceleration along the two phase-encoding dimensions [2-3]. However, when using an 8-channel array only moderate accelerations were obtained. High accelerations in MRSI are challenging due to low SNR availability and the well known noise amplification factor (g-factor). Array coils with a large number of small elements have been demonstrated to increase the acceleration capability by providing higher sensitivity and disparate coil sensitivity encoding along all spatial dimensions [4]. Moreover, they offer improved depth penetration for volumetric acquisitions [5]. In this study we demonstrate highly accelerated 3D metabolite mapping using a combination of 3D-PEPSI encoding and 2D-SENSE reconstruction with an array coil of 32 elements at 3 Tesla.

METHODS.

3D-PEPSI data were acquired on healthy volunteers using a Siemens Trio 3 Tesla scanner equipped with a commercial 8-channel array coil and a 32-channel receive-only array coil built with close-fitting helmet design and soccer ball geometry [6]. The 32-channel array coil provides coil sensitivity encoding along all spatial dimensions and increased sensitivity. Outer volume suppression (OVS) was applied along the perimeter of the brain using 14 slices: 8 slices were manually positioned in the axial plane and 6 slices were positioned along the boundaries of the 3D slab and the shim volume. Data acquisition included water suppressed (WS) and non water suppressed (NWS) scans. A second NWS scan with much shorter readout duration and TR (500 msec) was acquired to estimate coil sensitivity maps. A trapezoidal readout gradient encoded simultaneously one spatial axis (k_x) and the spectral time domain (t). 3D data were acquired in an axial orientation using a 32x32x8 spatial matrix to reconstruct 8 axial slices (FOV: 240x240x100 [mm]). Fully sampled data were acquired in 8.5 min using TR= 2 sec and TE= 15 msec. 2D acceleration was performed by subsampling uniformly the NWS and WS acquisitions along the y and z directions by factors Ry and Rz respectively. Two accelerations were employed: R= 4 (Ry=Rz=2) and R= 8 (Ry= 4, Rz= 2). For comparison purposes the fully-sampled data was also acquired. Raw data was filtered in k-space with a 3D Hamming window.

2D-SENSE reconstruction [7] was applied to each time point of the accelerated even and odd echo data separately. Diagonal weighting was applied to regularize the solution [8]. Using the matrix formulation of the encoding equation $\mathbf{y} = \mathbf{E}\mathbf{x}$, the solution is given by $\hat{\mathbf{x}} = (\mathbf{E}^H\mathbf{E} + \lambda\mathbf{I})^{-1}\mathbf{E}^H\mathbf{y}$, where the regularization parameter λ was set inversely proportional to the power of the reference signal used for coil sensitivity estimation. This approach improved the conditioning of the system particularly in positions located at appreciable distance from the coils where the sensitivity profiles are broad and overlapped. Coil sensitivity maps were estimated using spectral water images obtained from the second NWS scan. A 3rd order polynomial fitting was used to refine the sensitivity maps. After 2D-SENSE reconstruction, coil-by-coil PEPSI reconstruction was performed [2,9]. Metabolite images were obtained from spectral fitting using LCModel [10] with a simulated basis set that matches the PEPSI acquisition. Cramer-Rao bounds (CRB) were employed to compare the performance of the method for the different accelerations.

RESULTS.

The 32-channel array coil provided substantially lower g-factors than the 8-channel array coil (Fig.1). Regularization using diagonal weighting improved the reconstruction in central zones. The accuracy of spectral fitting decreased with higher accelerations, primarily due to SNR loss. Results obtained for 4-fold acceleration were similar to those obtained with fully sampled data with moderate increases in CRLBs (Fig. 2). For R=8, acceptable reconstruction was obtained in upper and central slices where sensitivity was higher than in lower slices. However, the uppermost slice also suffers from slightly increased peripheral lipid contamination that degraded reconstruction at higher acceleration factors.

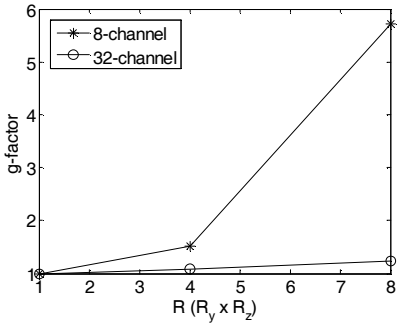

Fig. 1: Noise amplification factor comparison from additional phantom data.

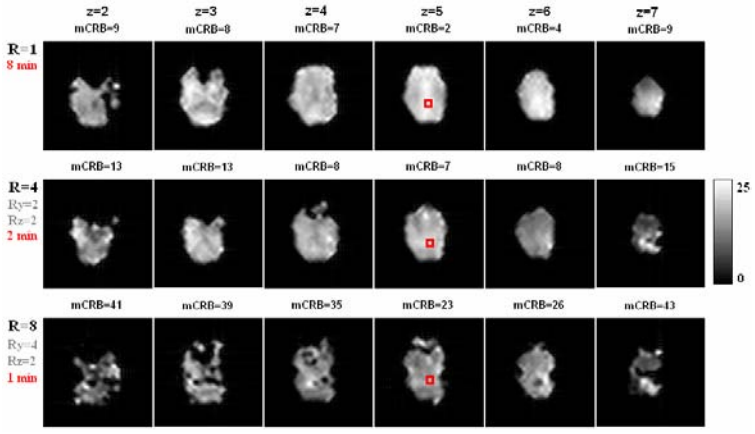

Fig. 2: Creatine concentration maps (CRB≤40%). mCRB: CRB averaged over the slice.

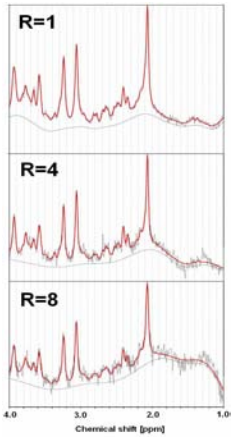

Fig. 3: Spectral fitting examples (from red box).

DISCUSSION.

This work demonstrated highly accelerated 3D-MRSI using a large array coil (32 elements), combining PEPSI encoding with 2D-SENSE reconstruction. The increased number of independent signal projections, higher SNR even in the center and lower noise amplification in the reconstruction allowed for high acceleration factors. However, in order to take advantage of the larger acceleration capability and to achieve adequate volume coverage for 3D volumetric studies it is necessary to maximize the uniformity of the spectral quality using improved volumetric shim algorithms and automatic image based placement of the OVS slices.

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