Balanced SSFP profile asymmetries reflect frequency distribution asymmetries: Evidence from Chemical Shift Imaging (CSI)

W. Chen[1], R. Tjissen[1], C. Rodgers[2], J. Near[1], and K. Miller[1]
[1]FMRIB, University of Oxford, Oxford, United Kingdom, [2]OCMR, University of Oxford, Oxford, United Kingdom

Introduction

Steady-state free precession (SSFP) is characterized by strong signal dependence on resonance frequency, often described by the SSFP frequency "profile". In a homogeneous voxel with a single frequency, the SSFP profile has a well-known symmetric shape. However, in an inhomogeneous voxel with an asymmetric frequency distribution, the profile becomes asymmetric. The SSFP profile can be modeled as the convolution of the homogeneous profile with the frequency distribution and any variation from a symmetric frequency distribution will result in an asymmetric SSFP profile[1] (Fig1). Asymmetry in the frequency profile has been suggested as a useful marker in tumors using spectroscopic imaging [3,4]. We hypothesized that CSI lineshapes obtained from healthy white matter tracts can be convolved with the homogeneous SSFP profile to predict the SSFP asymmetry profile. The predicted profiles were then compared with the measured SSFP profiles.

Methods

Eight subjects were scanned on a Siemens 3T Tim Trio system with a 12-channel head coil. BSSFP protocol: a balanced SSFP sequence using a 3D segmented EPI readout (8PE lines per T_R), T_R/T_E = 12/5.6ms, α=10°, FOV=192x192x120mm, matrix size=96x96x60, BW=1860. For consecutive volumes, RF phase was increased to shift to the next frequency and acquisition was repeated to obtain 85 images at 1 Hz resolution. CSI SE protocol: 5x5x5mm voxels, T_R/T_E =1050/20ms, FOV=120x120mm, matrix=32x32, slice thickness=5mm. The raw CSI lineshape is rephased by fitting it with a single complex Lorentzian (i.e. the Fourier transform of the mono-exponential decay). The predicted SSFP asymmetry profile is obtained by the convolution of the real part of the rephased CSI lineshape with the SSFP homogeneous profile (calculated with T1/T2=830/80ms). 2 main regions of interest were defined: the corpus callosum and the left/right cortical spinal tracts. T1 weighted MPRAGE images were used as references to locate these regions. MPRAGE parameters: T_R/T_E /T_I = 1300/4.61/900ms, α=16°, FOV=200x200x110mm, matrix size=192x192x44.

Results and Discussions

In the measured BSSFP profiles, voxels corresponding to the corpus callosum displayed a much larger asymmetry compared to voxels in the left and right cortical spinal tracts (Fig2). This is in agreement with data previously reported[2]. The asymmetry profiles predicted from the convolution of the homogeneous profiles with the CSI lineshapes show similar trends with the measured SSFP profile, in which the positive frequencies show a lower signal peak compared with the negative frequencies. The difference in the asymmetry between the 2 ROIs is less obvious in the predicted SSFP profile and this discrepancy between measured and predicted profiles may be due to several factors. The convolution of the CSI lineshape with the homogeneous profile is expected to be approximate since the CSI lineshape includes T_2 broadening as well as the true frequency distribution. The selection of ROIs also plays an important role. This is especially so in the narrow cortical spinal tract regions where the accuracy of ROI selection may be compromised. Finally, the precision and accuracy of rephasing the CSI spectrum has a large effect on the apparent asymmetry of the calculated profile; tiny phase shifts may result in very different asymmetry profiles. The ambiguity of rephasing the CSI spectrum highlights the benefits of using SSFP profiles to detect asymmetries in the frequency spectrum. Because the SSFP signal is based on self-cancellation of signal from different parts of the frequency spectrum, SSFP is effectively a self-referencing method with no equivalent "rephasing" problem. In addition, the 180° phase discontinuity in SSFP creates signal cancellation, which effectively amplifies small frequency shifts.

Conclusion

SSFP asymmery profiles have been predicted from the convolution of CSI lineshape with the theoretical homogenous BSSFP profile. Similar trends of greater asymmetry in the corpus callosum region compared to the cortical spinal tracts were observed which was in line with observations made on the measured BSSFP asymmetry profiles. The reduced difference in asymmetry in the 2 regions observed in the predicted profile may be partially due to the non-ideal behavior of the CSI lineshape, the choice of ROIs and difficulties in accurately rephasing the CSI lineshape. The ability of SSFP profile to amplify small frequency shifts makes it a promising contrast mechanism for probing tissue microstructures.

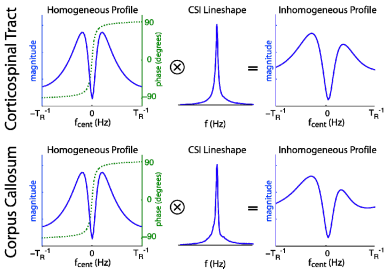

Fig 1. Prediction of BSSFP asymmetry profile from CSI lineshape.

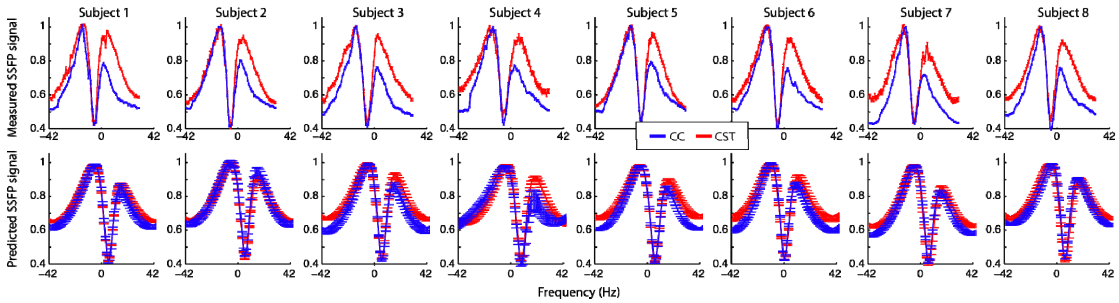

Fig 2. Comparison between measured SSFP asymmetry profile with predicted SSFP profile from CSI lineshape.

References: [1] Scheffler, NMRBiomed, 2001. [2] Miller, MRM, 2009. [3] Medved, MRM, 2004 [4] Foxley, MRM 2008.