Modulation of Inter-Slice Frequency Offsets for Magnetization Transfer Ratio Imaging

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Introduction

Magnetization Transfer (MT) imaging is a useful tool to understand macromolecular characteristic. A few MT imaging methods have been proposed, however, conventional methods for MT ratio (MTR) imaging takes a long time. Also, MT is represented as MT ratio, which is not quantitative and thus can vary depending on scan conditions and MRI scanners. Quantitative MT can overcome this limitation but requires data acquisition at multiple frequency offsets and multiple saturation powers, which increases scan time even further. Recently, inter-slice MT imaging using balanced steady state free precession (bSSFP) has been proposed as a fast MT imaging method [1,2]. Inter-slice MT effects are generated by the off-resonance saturation in the slice of interest by the RF pulses used for the acquisition of the prior slices. In order for the inter-slice MT imaging to advance to quantitative MT, methods for modulating the saturation offset frequency should be developed (the saturation power can be modulated by simply changing flip angle of the inter-slice bSSFP sequence). In this study, we tested two strategies to modulate inter-slice frequency offsets for the inter-slice bSSFP MT method: one is to modulate the inter-slice gap and the other is modulation of RF pulse duration (i.e., modulation of excitation bandwidth).

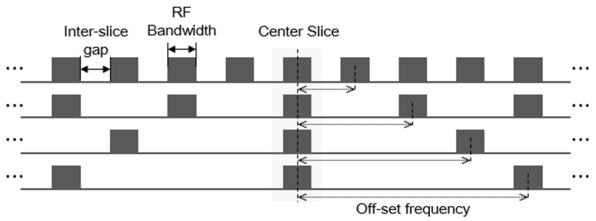

FIG.1. Simple scheme of modulating frequency offsets for inter-slice magnetization transfer imaging by changing the inter-slice gap.

Material and Methods

Three different experiments were performed on a Siemens 3T Trio system (Siemens Medical Solutions, Erlangen, Germany). Imaging parameters were TR/TE = 4.55/2.275 ms, matrix = 128×128, slice thickness = 5 mm. The parameters of a study with a phantom containing 3%, 6%, 9% agarose gels were FOV = 150×150 mm^2, gap = 7 mm, the number of slices = 15, excitation width = 1333 Hz, and flip angle = 50 ° resulting in 38 s of scan time. For MT free imaging 9 slices were scanned in 1 min 36 s. Both MT-weighted (I_{MT}) and MT-free (I_{REF}) images were acquired for MTR image ($(I_{MT} - I_{REF})/I_{REF}$). Inter-slice delay time was 0 sec and for MT-weighted image and 5 sec for MT free image.

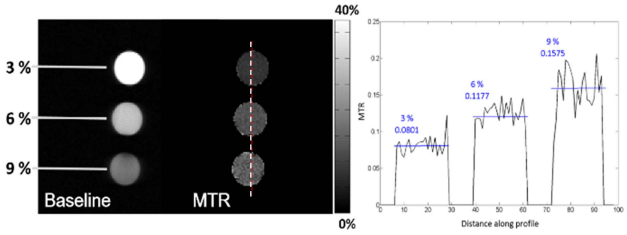

FIG.2. Inter-slice MT images of agarose phantom with different agarose concentrations (**left**). MTR values along white dash line in the MTR image (**right**).

Off-resonance frequency received by neighboring slices was calculated as following equation. $\delta_n = -BW \cdot (1 + GAP/THK) \cdot n \cdot sign(GRAD) \cdot ORD$, where BW is bandwidth of the RF pulse, GAP is interslice gap, THK is slice thickness, n is slice index, sign(GRAD) is sign of the gradient, and ORD is +1 for ascending and -1 for descending. Positive slice select gradient and descending slice order were used. Inter-slice MT imaging was performed with different gap size (Fig.1.) and RF pulse duration. The imaging parameters for gap-dependent study were : FOV = 220×220 mm^2, the number of slices = 15, and flip angle = 60 °, excitation width = 1000 Hz, inter-slice delay = 0 and 6 different gaps from 100 % to 1100 % with increment of 200 % (offset frequency = 2 kHz to 12 kHz with 2 kHz step). Total scan time was 3 min 54 s. The imaging parameters for the RF pulse duration-dependent study were: FOV = 220×220 mm^2, gap = 7 mm, the number of slices = 19, and flip angle = 35 °, excitation width = 1333 Hz, phase partial fourier = 6/8, inter-slice delay = 0, and 9 different RF pulse durations (0.43 ms, 0.47 ms, 0.5 ms, 0.6 ms, 0.9 ms, 1.2 ms, 2 ms, 3 ms, 4 ms) (corresponding increase in TR from 3.38 ms to 6.95 ms). Both studies were conducted on a 4 % agarose phantom and a normal human brain.

Results and Discussion

Different MTR images are acquired for each agarose phantom with different concentrations using the inter-slice MT imaging (Fig. 2). MTR signal intensity increased proportionally with increase in agarose concentration, similar to the results obtained using conventional MT methods [3]. This shows that the inter-slice MT imaging can represent the different exchange rates between the free water pool and bound water pool. Inter-slice MT imaging with variation in RF pulse duration showed no apparent changes and the variations were < 9% for the phantom and < 5% for in vivo brain (figure not shown). Inter-slice MT imaging with variation in gap size showed significant increase in offset frequencies with increase in gap size as shown in Fig. 3.

Since the average saturation power decreased with increasing RF duration and TR, little or no change in the measured signals for the RF duration-dependent study indicates that the MT effects indeed increased by decrease in saturation offset frequency (i.e., increase in RF duration or decrease RF bandwidth), implying the approach is feasible. We can also acquire MT images from different offset frequencies by simply varying the gap value. This allows us to acquire MT images from a range of offset frequencies within a reasonable clinical scan time for quantitative MT (e.g. less than 10 min). Thus, the proposed method is applicable to quantitative MT mapping and may also be useful for MT imaging in diagnostic situations where a shorter scan time is required.

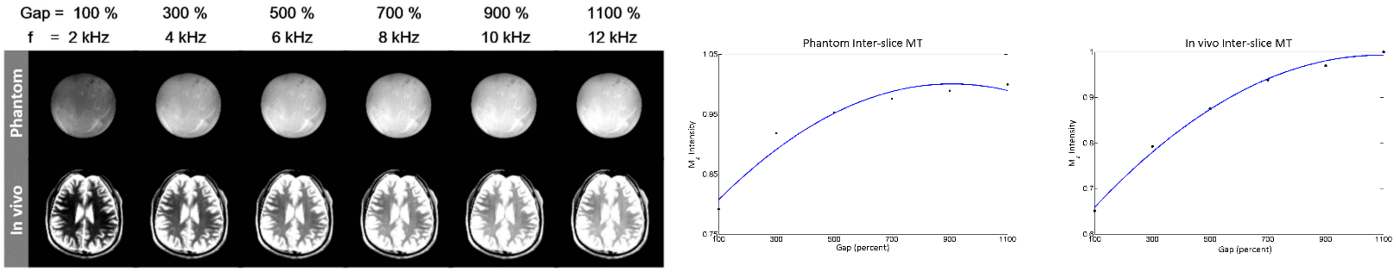

FIG.3. Inter-slice MT imaging with gap variation. Baseline images acquired with different offset frequencies (**left**), ROI mean signal intensity plots of agarose phantom (**middle**) and in vivo brain (**right**) are shown. The blue line indicates quadratic fitting of data. The total scan time was 3min 54s.

References: 1. Barker et al, ISMRM 2013 p2358. 2. Barker et al, ISMRM 2013 p2537. 3. Sled, Magn Reson Med 2001;46:923-931.