Double Quantum Filtered Magnetization transfer imaging by 'soft' pulses – a step towards clinical application

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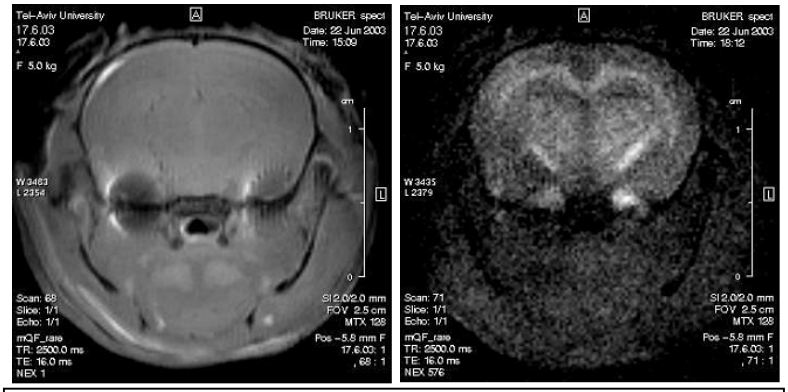
Introduction In a previous work we demonstrated that images that are weighted exclusively by the macromolecular contents of tissues can be obtained by using double quantum filtered magnetization transfer (DQF-MT)[1]. In that method, the double quantum filtration is obtained using hard pulses of 90°. The pulses must be short enough to prevent the effect of transverse relaxation (on the order of several tens of microsecond) of the macromolecular magnetization during their application and to cover the broad spectral width of the macromolecules. Thus it should be difficult to implement the method on clinical scanners, where the shortest 90° pulses are of few hundreds of microseconds. Here we present a method, labeled SP-DQF-MT that gives the same contrast, while employing, instead of the four short pulses in the DQF-MT, only two, but much longer pulses.

Theory It has been shown [2] for isolated pairs of protons that double quantum coherences can be created by selective pulses (i.e., pulses whose effective bandwidth is smaller than the dipolar interaction between pairs of protons. Such selective pulse can transform the M_z magnetization (the expectation value of the spherical tensor $T_{1,0}$) directly into double quantum coherences (denoted by $T_{2,\pm2}$). This is in contrast to the original DQF-MT method, where this transition was done in two stages: first $T_{1,0}$ was excited by a hard pulse to give $T_{1,\pm1}$, that subsequently evolved into $T_{2,\pm2}$. The nutation angle due to selective pulses is given by $\boldsymbol{\omega_1^2 t_p/\omega_d}$, where $\boldsymbol{\omega_1}$, $\boldsymbol{\omega_d}$ and $\mathbf{t_p}$ are RF angular frequency, the dipolar interaction and the pulse duration respectively. Thus, the pulse length required for obtaining maximum excitation using the selective pulses are much longer than their non-selective counterparts. Additionally, the decay of the DQ magnetization under such excitation is slower, thus permitting the use of longer pulses for excitation. The above principle of macromolecular selective excitation was implemented using the following sequence: $P_{selective}$-t_{DQ}- $P_{selective}$-t_{LM}- 90°- acquisition. The DQ magnetization created by the first selective pulse evolves during t_{DQ} and is reconverted to longitudinal magnetization ($T_{1,0}$) by the second selective pulse. Thus, in the beginning of the t_{LM} period, only longitudinal macromolecular magnetization exists. It is transferred to the water via chemical exchange. Finally, a pulse tilts the water magnetization to the xy plane for detection, by spectroscopy or imaging. The detected signal, originated in macromolecules, is long-lived due to the long T_2 of water.

Experimental The above method was tested on excised mouse brain. The results have confirmed the validity of the DQ filter, and the images obtained by this method (not shown) were almost identical to those obtained by the original DQF-MT (the method that utilizes four hard pulses). A major concern was filtering out DQ signal from the intermolecular dipolar interaction of the bulk water[3]. We found that this signal can be effectively blocked by magic angle gradients. Additionally, we found that the macromolecular DQ signal and the intermolecular DQ signal have a different dependency upon the RF power, thus it was possible to find pulses that maximized the macromolecular signal but gave no detectable intermolecular signal.

Results and discussion Rat head images, obtained by the same sequence implemented on mouse brain, with and without phase-cycling are presented. The image without the phase cycling corresponds to a standard FSE image, while completing the phase cycling results in a double quantum filter. The lengths of the first two selective pulses used in the SP-DQF-MT were 90μs, much longer than the non-selective pulses (18μs) used in the DQF-MT. As for the latter sequence, white matter is highlighted. Strikingly, the brain is the only tissue that gives considerable SNR. Although the total signal intensity is small compared to DQF-MT by hard pulses, we have demonstrated that the unique macromolecular contrast can be achieved by much longer pulses that can be generated on clinical scanners.



FSE images of a rat head. FOV=2.5cm, TR=2.5s, TE=8.12ms, the 90º pulse was of 2ms and the 180° pulse was of 1.61ms, slice thickness was 2mm, matrix size was 128x128, 4 echos were collected in a train. (a) a conventional FSE image of a rat head for reference and (b) soft-DQF-MT image of the same slice. Soft pulse length was 90μs,t_{DQ}=1μs, t_{LM}=150ms, 576 signals were averaged.

References

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