Magnetization transfer effect on T2 measurement using steady-state free procession

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Introduction: Driven equilibrium, single pulse observation of T2 (DESPOT2) is a rapid T_2 mapping technique based on acquisition of a pair of (or several) balanced steady-state free precession (SSFP) images and prior knowledge of T_1 [1]. However, recent research has reported that in biological tissues the steady-state signals of SSFP deviate from theoretical predictions based on Bloch equations, which could be attributed to magnetization transfer (MT) [2]. Evident signal reduction is observed with imaging parameters that are always used in traditional SSFP images including DESPOT2, which cast doubt on the accuracy of DESPOT2. In this paper, the effect of MT on T_2 measurement was analysed. Optimized imaging parameters were proposed to avoid the MT effect on T_2 mapping.

Theory: Continuous excitation of RF pulses can saturate the magnetization of protons associated with macromolecules and membranes in biological tissues. As a result, exchange of these protons with free pool protons constituting the steady state leads to a reduction of SSFP signal [2]. The SSFP signal intensity S without MT effect and S_{sat} with MT effect are respectively:

$$S = \frac{M_0(1-E_1)\sin(a)}{1-E_1E_2-(E_1-E_2)\cos(a)} \quad (1) \qquad\qquad S_{sat} = kS \quad (2)$$

where M_0 is the equilibrium magnetization, a is the flip angle of the excitation pulse, $E_1 = e^{-TR/T_1}$, $E_2 = e^{-TR/T_2}$, k is the attenuation factor which is the ratio of the signal intensity with MT effect to signal intensity without MT effect.

DESPOT2 allows for T_2 measurement from a pair of SSFP images acquired at constant TR and two flip angles a_1 and a_2. Equation (1) can be represented in the linear form [1]:

$$\frac{S}{\sin(\alpha)} = m\times\frac{S}{\tan(\alpha)} + b = \frac{E_1-E_2}{1-E_1E_2}\times\frac{S}{\tan(\alpha)} + \frac{M_0(1-E_1)}{1-E_1E_2} \quad (3) \qquad T_2 = -TR/\ln\left(\frac{m-E_1}{mE_1-1}\right) \quad (4)$$

$$m = \frac{S_1/\sin(a_1) - S_2/\sin(a_2)}{S_1/\tan(a_1) - S_2/\tan(a_2)} = \frac{S_1/(k_1\sin(a_1)) - S_2/(k_2\sin(a_2))}{S_1/(k_1\tan(a_1)) - S_2/(k_2\tan(a_2))} \quad (5)$$

From which, we learn that the attenuation factor can lead to T_2 inaccuracy. Only when $k_1 = k_2$, this deviation can be avoided. Simulation in Fig.1 shows the T_2 inaccuracy caused by MT effect.

Methods: b-FFE sequences with variable TR and flip angles were implemented on a Philips 1.5 T MR imager. The effect of flip angle was investigated by varying it from 10° to 80° in steps of 10°. For a fixed flip angle, imaging were performed with TR = 4.0, 5.1, 6.2, 7.9, 8.8, 10.3 ms, respectively. 17° and 80° flip angle, previously proposed as optimized flip angle for white matter (WM), were used to calculate T2 [2]. Two FFE sequences with flip angles 3° and 12° were also performed to acquire T_1. Table 1 lists the measured T_2 value (an average value from a region of interest shown in Fig.2) of WM using DESPOT2.

Result and Discussion: Simulation and experiment demonstrates that T_2 measurement using DESPOT2 can be greatly affected by MT effect. Optimized flip angles were widely used in DESPOT2 to achieve precision, of which the signal intensities acquired at the two flip angles equal (Fig.3.a). However, from Fig3.b we learn that attenuation factor k_1 is not equal to k_2 at the two optimized flip angles, which results in great T_2 inaccuracy. In Fig.3.b, it is also easy to find that k_1 is close to k_2 around 25° and 80°. Therefore, to avoid MT effect, we propose the use of a new set of flip angles 25° and 80° as better choice in T_2 mapping using DESPOT2.

References: [1] *Deoni et al.* MRM 49:515-526 (2003); [2] *Scheffler et al.* MRM 56:1067-1074 (2006)

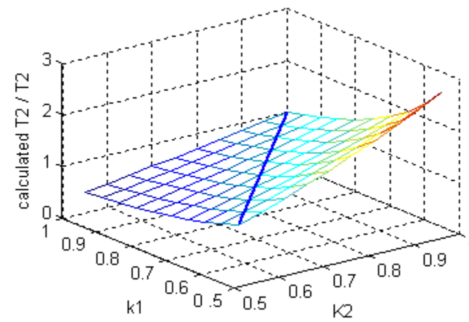

Fig.1. Simulation of calculated T_2 with MT effect *vs* T_2 without MT effect. T_1 and T_2 was assumed to be 1800 ms and 340 ms. Solid blue line indicates that T_2 is not affected by MT effect when $k_1 = k_2$.

Fig.2

TR (ms)	T_2 (ms)
4.0	55
5.1	56
6.2	59
7.9	60
8.8	62
10.3	62

Table 1

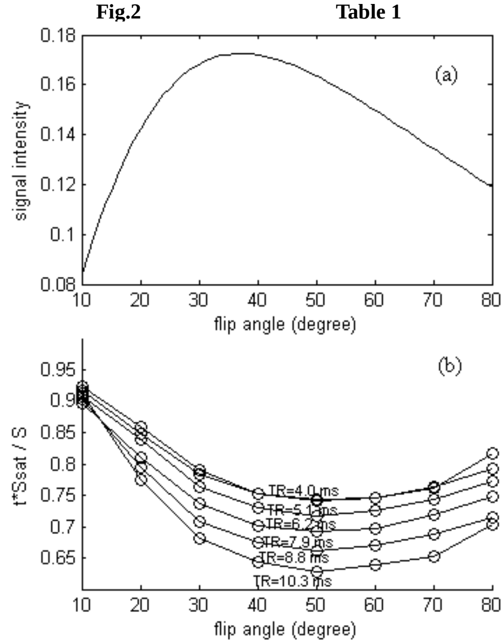

Fig.3. (a) Signal behavior of WM for TR = 4 ms, T1 = 615 ms, T2= 69 ms. (b) Relation between relative attenuation and flip angle. t is constant.