Novel FSE method to improve T2map accuracy by calculating B1map simultaneously

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Introduction

T2map is a useful application to observe soft tissues such as cartilage, ligament, and tendon. When used for the diagnosis of OA (osteoarthritis), for example, the estimation error of T2 value should be small enough compared to the difference between mild OA and severe OA, which is about 5-10ms, while the accuracy of estimated T2 value depends on B1 inhomogeneity especially in high magnetic fields such as 3T or 7T.

The purpose of this study is to improve the T2 estimation accuracy in T2map by calculating B1map simultaneously with a novel FSE method. Due to B1 inhomogeneity, refocus FA (Flip Angle) can unexpectedly be less than 180 degrees, which induces STE (STimulated Echo). In the legacy T2map, FSE (Fast Spin Echo) data is acquired by CPMG method to align the phase of STE to that of SE (spin echo), where the transmission phase of refocus pulses is perpendicular to that of excitation pulse. Thus, STE deteriorates the T2 decay curve from exponential decay. In this study, the transmission phase of the refocus pulses is modified, so as to extract 1st STE from 2nd echo. Actual pixel-by-pixel FA can be calculated by using this signal and 1st SE (B1map). Then T2 value can be estimated by using the value of refocus FA on each pixel (T2map).

Theory

The signals of 1st SE and 1st STE (from 2nd echo) can be analytically calculated by Bloch equation as

$$\text{1st SE:}\quad M_1 = E_2 \sin a \sin^2 \frac{b}{2} \qquad \text{1st STE:}\quad M_2 = \frac{1}{2} E_1 E_2 \sin a \sin^2 b,$$

where a is the flip angel of the excitation pulse, b is that of the refocus pulse, $E_1 = \exp(-\mathrm{ESP}/T_1)$, and $E_2 = \exp(-\mathrm{ESP}/T_2)$. 1st SE can be measured as the 1st echo. When the transmission phase offset of the refocus pulses is different from the excitation pulse by 45 degree, the phase of 2nd SE is perpendicular to that of STE in the 2nd echo. Thus 1st STE can be separated from 2nd SE. As E_1 is almost 1 because of ESP << T_1, the refocus FA can be calculated by 1st SE and 1st STE as

$$b \approx 2\cos^{-1}\sqrt{\frac{M_2}{2M_1}}.$$

Then, T2 value is optimized to reduce the residual error between the acquired signals and the numerical signals simulated by the Bloch equation using the refocus FA.

Numerical simulation and discussion

In the numerical simulation, the signals of 8 echoes were calculated by the Bloch equation for the legacy CPMG method and the proposed method (45-degree refocus pulses). Gaussian-white-noise was added to each echo with standard deviation 0.5% of equilibrium magnetization. 2-parameter exponential fitting was applied in the legacy CPMG method, while the residual error against the Bloch simulation was minimized in the proposed method. The T2 estimation error was calculated 25 times with changing noise value.

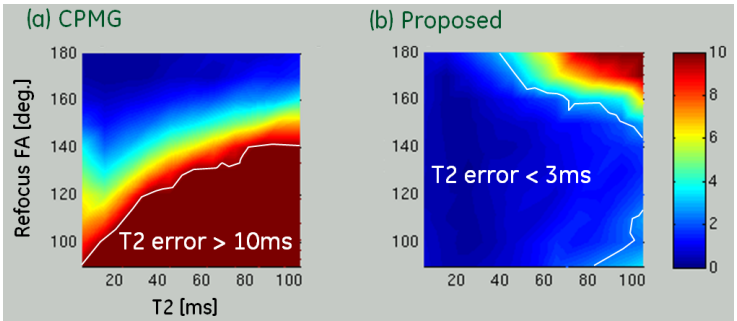
Fig 1 shows the average of T2 error [ms] for each T2 [ms] and refocus FA [degree] with using the legacy CPMG method (Fig 1(a)) and the proposed method (Fig 1(b)). In the legacy CPMG method, the T2 error is too large for clinical usage with refocus FA less than 140 degree because large STE deteriorates the T2 decay curve from exponential decay. In the proposed method, T2 error is reduced in a wider T2 and refocus FA range because the refocus FA is taken into account to estimate T2 value. For short T2 (<40ms), T2 estimation error is low enough with any refocus FA in this range. For longer T2 with high refocus FA around 180, the T2 error is larger in the proposed method because the magnitude of the 1st STE is almost 0, which causes estimation error of refocus FA due to noise.

As it's difficult to reduce the B1 inhomogeneity itself, the proposed method is useful to improve the T2map accuracy. The proposed method has other merits:

- B1map is acquired simultaneously as additional information.
- Refocus FA can be lowered, SAR decreases, and then the number of max slices per acquisition increases.

Conclusion

Novel FSE method is proposed to improve the T2map accuracy by calculating B1map simultaneously without scan time elongation. Compared with the legacy CPMG method, T2 estimation error is low enough in a wider range of T2 and refocus FA. In addition, lower refocus FA is applicable to the proposed method, which would decrease SAR and increase the number of max slices per acquisition.



[Fig 1] T2 estimation error versus T2 & refocus FA

(a) Legacy CPMG method
T2 estimation error is sufficiently low if refocus FA is beyond 160 everywhere.

(b) Proposed method
T2 estimation error is sufficiently low in the wider range of T2 and refocus FA than (a). Especially, it's robust to B1 inhomogeneity.