**METHOD**

1. Theory

In MRI, the excitation is achieved by tipping the magnetised spins initially aligned with the main magnetic field (longitudinal direction) towards the transverse plane with a flip angle (α) from the longitudinal direction and a phase shift (φ) in the transverse plane using a radiofrequency pulse. After the excitation, the spin’s magnetisation relaxes towards the longitudinal direction with the recovery of the longitudinal component (with the time constant T1) and decay of the transverse component, and the transverse magnetisation is measured for MR image formation. The time between excitation and acquisition of the signal is known as echo time (TE), and the time between adjacent excitations is repetition time (TR). The MRI signal acquisition is performed in Fourier space (known as k-space), and the resulting image will be obtained by performing an inverse Fourier transform of the k-space. [Method2]

图示

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* Multi-echo GRE

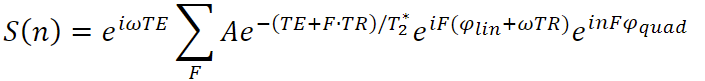
Using a gradient echo (GRE) based pulse sequence, the acquired MR signal decay with the time constant T2\* [Method1]. The gold-standard T2\* measuring method – multi-echo GRE is performed by simply measuring the MR signal at multiple TEs in one TR with GE sequence and fitting monoexponential decay to get the T2\* voxel by voxel as shown in Figure X.

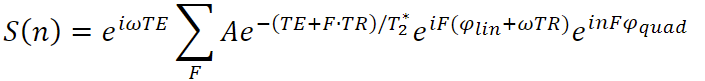
* ka-SPGR

The ka-SPGR sequence is based on fast GRE (short TR) [Method4] with TE = TR/2, which yields a steady-state signal behaviour. Additionally, quadratic radiofrequency-spoiling (RF-spoiling) and gradient-spoiling are required to perform the ka-SPGR sequence. RF-spoiling is applied by constantly exciting the spins with a quadratic phase cycling given by the function [Method4] [Intro10],

  (for n = 0,1,2….) (1)

By adding RF-spoiling, N different and periodically repeating steady-state signals S(n) are yielded, each signal is the summation of quadratic phase modulation weighted T2\* decayed signal at the time (TE+F\*TR), the analytical solution of S(n) is below [Intro10],

 (2)

The T2\* related component, , in the equation is known as the configuration state or F-state and is denoted as F0 if F in the equation equals 0. Furthermore, gradient spoiling is added to shift and split the F-states away from the centre of the k-space by different amounts, as shown in Figure X.

The k-space of each F-state can be reconstructed by summing up N-acquired signals with reverse phase modulation followed by shifting the k-space back to the centre. An inverse Fourier transform is then performed to generate the F-states images, which is used to fit T2\*. An illustration of the procedure is shown in Figure X.

1. Model Simulation and analysis

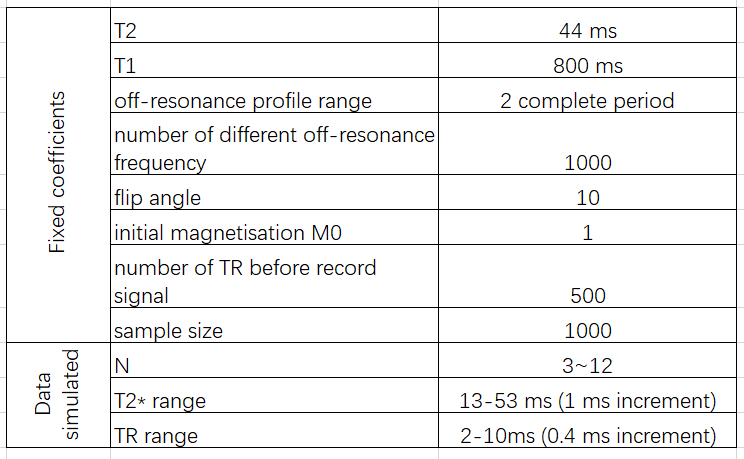
Based on the understanding of the ka-SPGR sequence, a Python-based simulation is built to analyse the T2\* mapping performance of ka-SPGR when different TR and N are used.

* 1. Simulation setup

图示

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* + 1. Bloch simulation



Based on the well know Bloch equation [Method2], the performance of the spin with certain tissue properties (T1, T2) under different applied pulse sequences (α, φ, TR, TE) can be modelled. As the project focused on SN region T2\* mapping, SN’s T1 (800ms) and T2 (44ms) are used in the computer simulation model, suggested by previous research on SN [Method7] [Intro5]. A 10°optimal flip angle calculated from the Ernst equation is used [Method3], and RF-spoiling is applied by implementing phase shift based on equation (1). Additionally, to ensure the steady state is fully reached, 500 times excitation is performed before the acquisition of the signal.

An off-resonance profile is then generated, which models the performance of spins under external disturbances by simulating spins with different extra phase shifts, and the Fourier transform of the off-resonance profile is equal to the configuration F-states [Method8].

* + 1. Magnetic field inhomogeneity modelling

A Lorensian distribution is convolved with the off-resonance profile to model the field inhomogeneity effect caused by iron overload in the tissue [Method10]. With known T2\* and T2 (tissue-only dependent), the amount of field inhomogeneous that the Lorensian distribution is based on can be calculated using the relationship below [Method1],

 (3).

Because of the special property of Fourier transforms, an equivalent operation can be performed in the configuration state by multiplying Fourier transform of Lorensian - an exponential curve with the time constant 1/T2’ = 1/γΔBinhomo.

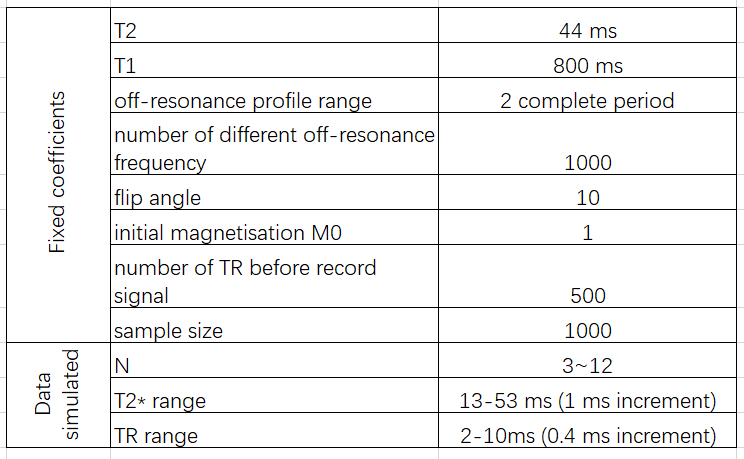
* + 1. Noise Modelling

In reality, complex zero mean Gaussian noise is generated during the MRI signal acquisition [Method9]. To model the effect of acquisition noise on the reconstructed F-states, a complex Gaussian noise with standard deviation equals F0/sqr(N)\*5% is applied to the F-state calculated in 2.1.2. The F0 magnitude at mean T2\* of the range is applied, regenerate for different N. randomly generate Guassian noise 1000 times to perform Monte Carlo simulation for T2\* range of interest for different pulse sequence coefficients used (TR, N)

* 1. Data Simulation
     + Range of TR chose
     + Range of T2\*

with known substantia nigra (SN) T2, PD patient SN T2\* and healthy patient SN T2\*, the field inhomogeneity caused by healthy and PD SN can be calculated.

* + - Period



* 1. Simulation result analysis
     1. Bias
     2. Standard deviation

1. MRI data acquisition and analysis
   1. MRI scan setup
      1. Phantom

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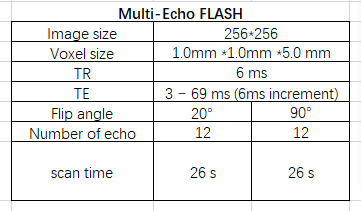
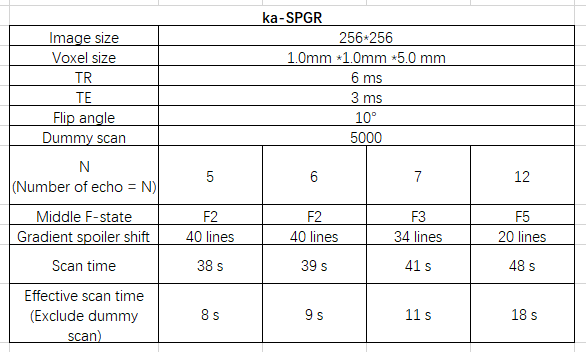
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(LHS: picture of NIST/ISMRM Premium System Phantom Model (SN:130-102), RHS: MnCl2-containing spheres layer being scanned)

NIST/ISMRM Premium System Phantom Model (SN:130-102) is used as the scanning object, and a slice acquisition is performed at the MnCl2-containing spheres layer (Figure X). The scanned layer is built for T2 mapping, so the exact T2\* value for each sphere is not given. However, the multi-echo FLASH (Siemens, 3T), one commonly used multi-echo GRE sequence, can be used as the gold standard T2\* mapping method to obtain the ground truth T2\* value for each phantom sphere.

It acquires images at multiple TEs in one TR and performs voxel-based fitting to get the T2\* value as shown in Figure X. Scanning parameters

* + - Resolution matching
    - TR & TE matching for T2\* fitting match
    - Flip angle – Ernst angle

* 1. Image processing
     1. Raw data to DICOM
     + Multi-echo FLASH

Use Matlab (Pete) to process the raw data, do the coil combination from the scanner and then export as a DICOM file, instead of directly using the DICOM file generated by the scanner, consistency.

* + - ka-SPGR

Summing images acquired with corresponding phase modulation weighting as described in the theory part to get each configuration state in k-space. Then shift each configuration state to the centre of the k-space, partial Fourier filling the k-space to get k-spaces containing only one configuration state. Inverse Fourier transforms k-spaces to get the configuration state’s images.

Use Matlab (Pete) for the reconstruction described above and export it as a DICOM file.

* + 1. T2\* mapping
    - Generate a mask to only acquire data in phantom spheres.
    - T2\* calculation method as described in the theory part to calculate T2\* for 14 phantom spheres. Exclude the phantom sphere exceeding the T2\* range of SN.
    - T2\* mapping images generated for both gold-standard and ka-SPGR to compare the result images. Colour coding the T2\* value for each sphere on top of a greyscale average image of multiple acquisition MRI data.

* 1. Result analysis
     1. Percentage error
     2. Effective T2\* Signal-to-Noise ratio

Method Reference:

1. Principles, techniques, and applications of T2\*-based MR imaging and its special
2. Principle of MR imaging (that book)
3. Principles of nuclear magnetic resonance in one and two dimensions (check for Ernst angle)
4. Steady state effects in fast gradient echo magnetic resonance imaging
5. Steady state of echo-shifted sequences with radiofrequency phase cycling
6. A motion-robust, short-TR alternative to multi-echo SPGR (Intro10)
7. MRI characteristics of the substantia nigra in Parkinson's disease: A combined quantitative T1 and DTI study
8. Extended phase graphs: Dephasing, RF pulses, and echoes - Pure and simple
9. The rician distribution of noisy mri data
10. Theory of NMR signal behavior in magnetically inhomogeneous tissues: The static dephasing

**RESULT**

1. Model Simulation
   1. Bias
      1. Bias contour plots

图表

低可信度描述已自动生成

* + 1. Optimal average bias

图示

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* 1. Standard deviation
     1. Standard deviation contour plots

图表, 折线图

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* + 1. Average standard deviation for different TR and Period

1. MRI data acquisition and analysis
   1. Quantitative T2\* mapping image

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* 1. Performance analysis
     1. Percentage error

蓝色的门

低可信度描述已自动生成

* + 1. Effective T2\* Signal-to-Noise ratio

图片包含 游戏机, 门

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