**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

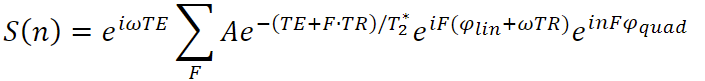
Using a gradient echo (GRE) based pulse sequence, the acquired MR signal decay with the time constant T2\*[Method1]. The gold-standard T2\* measuring method – multi-echo GRE is performed by simply measuring the MR signal at multiple TEs in one TR with GE sequence and fitting monoexponential decay to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

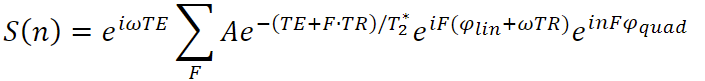
* ka-SPGR

The ka-SPGR sequence is based on fast GRE (short TR) [Method4], which yields a steady-state signal behaviour. Additionally, quadratic radiofrequency-spoiling (RF-spoiling) and appropriate 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 T2\* decayed signal at the time (TE+F\*TR) weighted by corresponding RF-spoiling generated phase modulation components, 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. Gradient spoiling is added to shift and split the k-space of F-states away from the centre by different amounts, as shown in Figure X.

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

1. Model Simulation and analysis

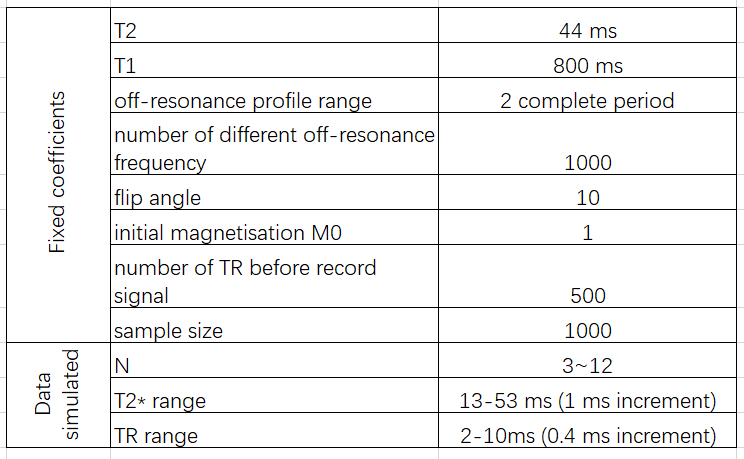
Based on the understanding of the ka-SPGR sequence, a Python-based simulation is built to analyse the T2\* mapping performance of ka-SPGR when different TR and N are used.

* 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 different tissue properties (T1, T2) under different applied pulse sequences (α, φ, TR, TE) can be modelled using matrix calculation. As the project focused on SN region T2\* mapping, SN’s T1 (800ms) and T2 (44ms) are used for the simulation model, coming from previous research on SN [Method7] [Intro5]. An optimal flip angle of 10° suggested by the Ernst equation is used [Method3], and RF-spoiling is applied by implementing phase shift calculated using equation (1). 500 times excitation is performed before the acquisition of signal to ensure the steady state is reached. An off-resonance profile is generated by adding an extra phase shift,

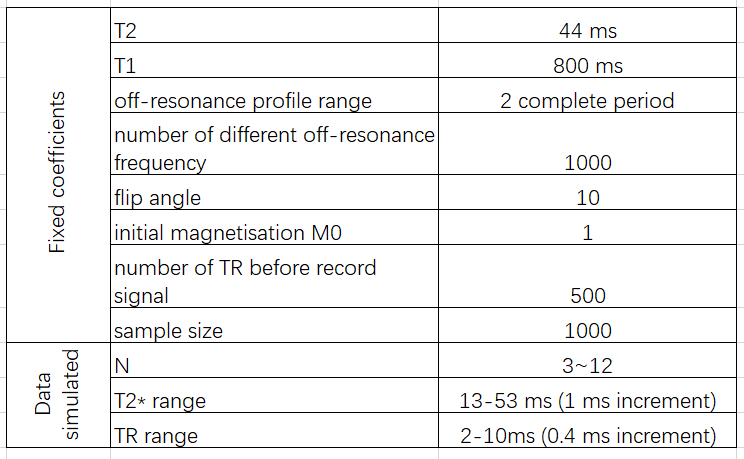
* + 1. Magnetic field inhomogeneity modelling

As the tissue and magnetic field inhomogeneity dependent T2\* and has a relationship

 (3)

with the pure tissue-dependent transverse decay time constant T2 [Method1], 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.

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



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

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

图片包含 表格

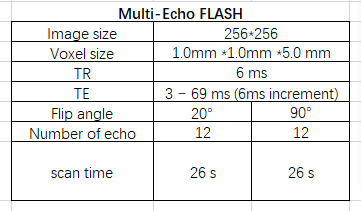
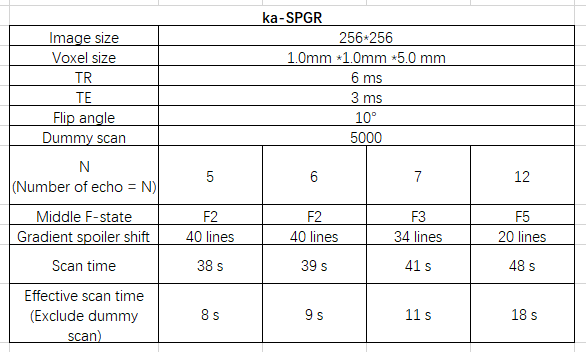
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(LHS: picture of NIST/ISMRM Premium System Phantom Model (SN:130-102), RHS: MnCl2-containing spheres layer being scanned)

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

**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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