The optimal 6ms TR 7- and 12-periodic ka-SPGR sequences are both proved to achieve an accurate and precise T2\* value measurement with less than +-5% bias by computer simulation and less than +-10% bias by MRI phantom scan results (Figure 7, 9). Compared to previous work on T2\* mapping at SN using Multi-echo GRE which has a percentage error of around 8-15% [intro5], it supports that the optimised ka-SPGR sequence can be used to detect T2\* in the PD biomarker detection range. In Figure 9(b), an unexpected significant bias is found for the highest T2\* value fiducial spheres, it could be related to the increasing bias and variation of the gold-standard Multi-echo GRE technique. The T2\* variation using the Multi-echo GRE can also be observed in the T2\* mapping image constructed in previous studies [Disc1].

The T2\* mapping images (Figure 8) obtained and the effective T2\* SNR (Figure 10) both support the alignment of the ka-SPGR technique result with the gold-standard technique and suggest that it can be considered as an alternative T2\* measuring method to the traditional technique. Additionally, the T2\* mapping images also show the ability to distinguish PD and healthy SN T2\*, which can be identified using the blue and red colours respectively. As the blue and red coloured fiducial sphere are homogenous and does not have voxels containing extremely out-of-range colour, this shows the measurement variation will not affect the identification of the PD biomarker and ka-SPGR T2\* mapping image can be potentially used for PD biomarker detection.

Comparing the 2 optimised ka-SPGR sequences, both simulation and phantom scanning results suggest the 12-periodic is a more precise T2\* measurement technique and has more tolerance to noise as its standard deviation is almost halved compared to the 7-periodic (Figure 7, 9). It could be explained by the 5 additional F-states 12-periodic can reconstruct compared with 7-periodic, as the region data points cover is more favourable [intro7], the measurement variation decrease. Besides, Figure 10 suggests the T2\* measurement efficiency of 7-periodic ka-SPGR is higher than 12-periodic across the PD biomarker detection range and even about 40% higher than the gold-standard T2\* measuring technique for small T2\* detection when scanning under matched environment. It indicates the 7-periodic ka-SPGR will be a promising technique for detecting T2\* PD biomarkers, given its high efficiency in detecting low T2\* values. These choices of parameters are also observed in several previous studies, where 12 echoes [intro5], 7 echoes [Intro10] and similar 8 echoes [intro7, Disc2] are used to acquire T2\* mapping

However, the study has the following limitations and can be improved. Firstly, the phantom scanning experiment can’t completely represent the ka-SPGR’s T2\* measurement performance for SN, as the T1 of the phantom used in this experiment are not specifically aligned with the SN T1 value. This means the detected signal intensity will be different due to different T1 and will result in different T2\* measurement efficiency for both the ka-SPGR and gold-standard techniques. In order to perform a more realistic analysis for SN, the phantom sphere should be designed to align with the SN’s T1 and T2. Secondly, as the T2\* ground truth value for the phantom scanning experiment is measured using the Multi-echo GRE sequence, the obtained ground truth T2\* value itself has variation and bias that will affect the analysis. The solution would be using a phantom specifically designed for T2\* mapping with known ground truth T2\* values for each fiducial sphere. Last but not least, as the in vivo environment is much more complex than an ideal MRI phantom, the phantom scanning experiment is not enough to fully support the ka-SPGR’s ability for detecting the PD biomarker in vivo. Therefore, in vivo MRI scan experiments should be carried out to analyse ka-SPGR performance in more complex environments and a large number of in vivo tests would be required to statistically support T2\* measurement using ka-SPGR can be used for PD biomarker detection. Furthermore, the optimal parameters suggested in this study can be extended to perform in vivo experiments for exploring the motion robustness of the ka-SPGR, which is potentially a huge advantage compared with other existing techniques.

This study has found that using a 7- or 12-periodic ka-SPGR sequence with TR = 6ms is able to achieve acceptable accurate and precise measurement of T2 in the PD biomarker detection range. In order to perform a more efficient scan, 7-periodic ka-SPGR is more favourable and will be able to detect the PD-related T2\* drop effectively. With no time limitation, 12-period will be a better choice as it is more robust to noise. However, an MRI phantom designed using SN tissue property with known T2\* is highly desirable to perform a more accurate analysis of ka-SPGR T2\* mapping performance and further in vivo experiments are essential to support the optimised ka-SPGR’s ability to detect PD biomarker.

Simulation

1. Percentage bias

The optimal parameter period = 12, TR = 3.5ms is suggested by the simulation result, while 7-periodic/ 12-periodic ka-SPGR with TR = 6 ms is chosen for scanning due to the limitation of the scanner.

The mean T2\* percentage bias first decreases with TR and starts to raise when TR continuously increase. This trend is observed in all different periodic ka-SPGR and is expected behaviour due to the exponential fit efficiency. And the optimal parameter for ka-SPGR can be determined by finding the minimum point in the figure.

The optimal point is around TR = 3.5 ms on the 12-periodic ka-SPGR line plot, however, due to the limitation of the MRI scanner used for this project, the minimum TR able to achieve is 6ms. Therefore, 7-periodic and 12-periodic ka-SPGR with TR = 6ms is chosen based on the simulation.

MRI phantom scan

* 12 periodic has smaller standard deviation
* It again proves the accuracy and stability of the T2\* measurement using 7 or 12-periodic ka-SPGR within the PD biomarker T2\* detection range.
* No out-of-range colour, able to distinguish healthy and unhealthy SN

The blue and red colours in the colourmap can approximately indicate PD and healthy SN T2\* value respectively. As the blue and red coloured fiducial sphere are homogenous and does not have voxels containing extremely out-of-range colour, it proves the measurement variation will not affect the identification of the PD biomarker and ka-SPGR T2\* mapping image can be potentially used for PD biomarker detection.

* Align and 7-periodic more efficient at detection PD biomarker.

The results indicate the ka-SPGR efficiency aligns with the gold-standard method, suggesting that it can be considered as an alternative T2\* measuring method to the traditional method. Additionally, the 7-periodic ka-SPGR will be a promising technique for detecting T2\* PD biomarkers, given its high efficiency in detecting low T2\* values.