Early detection of Parkinson’s disease can be achieved by detecting Substantia Nigra iron overloaded using MRI relaxometry parameter T2\*, unfortunately, accurate high-resolution T2\* mapping result is difficult to achieve at the brain stem due to tissue motion. A novel technique ka-SPGR is proposed to be motion robust and able to perform T2\* mapping, while neither analysis of the techniques’ T2\* mapping performance nor optimised scan parameters were suggested. In this study, optimal parameters (period and repetition time) of ka-SPGR specifically for PD biomarker detection are provided using computer simulation to minimise T2\* measurement bias, followed by a phantom experiment using optimised ka-SPGR and is compared with the Gold-standard (Multi-echo GRE) T2\* mapping result. 7-periodic or 12-periodic ka-SPGR with repetition time = 6ms are suggested for optimising the performance. The 12-periodic ka-SPGR is more robust to noise, while the 7-periodic provides better efficiency. The accuracy and precision of both sequences are proven by analysing simulation and phantom experiment results for a percentage bias < +-10%. However, the study is limited by the phantom’s lack of alignment with substantia nigra tissue property and can be improved using a phantom specifically adjust for SN. Additionally, to further prove the reliability of ka-SPGR for PD biomarker detection, massive in-vivo experiments are desirable to evaluate its performance in realistic and complex environments.