Implementing and Evaluating a Vendor-Independent balanced Steady State Free Precession Magnetic Resonance Imaging Sequence in an Open-Source Framework

Kelly Bonzon

Supervisor(s): Prof. Dr. Jessica Bastiaansen, Yasaman Safarkhanlo
Institution(s): University of Bern
University Hospital Bern (Inselspital),
Department of Diagnostic, Interventional, and Pediatric Radiology (DIPR),
and Department of Cardiology
Examiners: Prof. Dr. Jessica Bastiaansen, PD Dr. Ruud van Heeswijk

Introduction

Magnetic Resonance Imaging (MRI) for patients with implants presents unique challenges, especially when measuring quantitative MRI, which is essential for detecting abnormalities that conventional imaging might miss. These measurements are critical for doctors when making decisions about diagnosis and treatment. However, current MRI methods often struggle with reducing image artifacts and ensuring patient comfort. Additionally, the vendor-specific design of these sequences limits compatibility across different scanners, hindering multi-center research collaborations. This study aims to overcome these challenges by creating a novel three-dimensional (3D) imaging sequence that works across different vendors, called 3D phase-cycled (PC) balanced steady-state free precession (bSSFP). By using an open-source platform, this approach makes advanced MRI techniques more accessible and adaptable for both research and clinical use.

Materials and Methods

A 3D phase-cycled bSSFP sequence was developed using the Pulseq framework in MATLAB and its Python version, PyPulseq. This sequence was configured to closely match the parameters of a "gold-standard" Siemens sequence, enabling comparison of these sequences on a 3T MRI scanner. The studies were conducted on a phantom and a healthy volunteer. For qualitative analysis, magnitude images and bSSFP profiles were analyzed. For quantitative analysis, T1, T2, proton density (PD), and B0 maps were generated, and T1 and T2 values were estimated based on these measurements.

Results

The sequence was successfully implemented in the framework and executed on the scanner. In the phantom and volunteer studies, magnitude images showed better alignment with banding artifacts when using phase cycling at 180°. The combined images effectively removed these artifacts. The signal displayed an elliptical pattern in the bSSFP profiles. PD maps were consistent across different sequences, while T1 and T2 maps had increased noise, particularly in the Siemens sequence. B0 maps revealed significant field inhomogeneity in the Pulseq and PyPulseq sequences, whereas the Siemens sequence showed greater consistency with less variation.

Quantification of T1 and T2 values from the open-source sequences was comparable to the Siemens sequence, which itself matched well with values reported in the literature. However, there was a tendency for greater uncertainty at higher values. In the study involving the volunteer with an ICD, results were similar, with phase cycling corrections, but the bSSFP profiles showed a reduction in signal and irregularities in shape. B0 maps for this case indicated significant inhomogeneity.

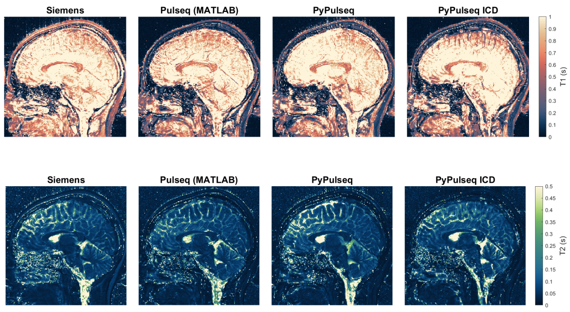

Fig. 1: T1 maps (Top) and T2 maps (Bottom) from volunteer scans using 3D PC-bSSFP sequence implemented in different frameworks (You must have authorization to publish this image)

Discussion

The Pulseq framework facilitated the implementation of the 3D phase-cycled bSSFP sequence without requiring extensive expertise in conventional pulse sequence programming. The image quality of the implemented sequences matched with the vendor-specific sequence. The 3D PC-bSSFP sequence effectively corrected banding artifacts and improved mapping, even in the presence of an ICD. This approach shows promise for quantitative MRI applications across different field strengths and vendors, and in the presence of implants.

References A Kelvin J. Layton, Stefan Kroboth, Feng Jia, Sebastian Littin, Huijun Yu, Jochen Leupold, Jon-Fredrik Nielsen, Tony Stocker, and Maxim Zaitsev, Pulseq: A Rapid and Hardware-Independent Pulse Sequence Prototyping Framework
77:1544–1552 (2017).

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