Title: Advanced MEG Data Processing in Epilepsy Patients with RNS

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Introduction: The RNS® System is an FDA-approved implantable responsive neurostimulator for treating drug-resistant focal epilepsy (DRE). Its effectiveness is well documented; however, some patients may undergo additional tests to inform a further surgical intervention. Magnetoencephalography (MEG) is a valuable FDA-approved tool for evaluation of DRE. The cranially implanted RNS neurostimulator generates electric/magnetic fields that may interfere with MEG recordings. This study aims to test advanced signal processing methods to improve clinical utility of MEG recordings in patients with an RNS neurostimulator and leads.

Methods: Clinical resting-state MEG scans were performed using a 306-channel MEGIN Triux-Neo for two epilepsy patients (Subject 1: F, 42y/o; Subject 2: M, 32y/o) treated with the RNS Systems. We recorded data in two modes: (1) with stimulation disabled but detection and storage enabled (MRI mode) and (2) with stimulation, detection, and storage disabled (off mode). Conventional pre-processing, temporal signal space separation (tSSS), was performed on raw data. MEG sensor level data was then further pre-processed using MNE-Python. This advanced processing method included a band-pass filter of 1-70Hz, an independent component analysis (ICA), and automated removal of electrooculogram (EOG) and electrocardiogram (ECG) artifact components. The power spectral density (PSD) was computed for all channels using Welch's method for both conventional and advanced processing methods. The PSD from all channels was used to calculate the average signal-to-noise (SNR) ratio of the advanced processing to conventional processing. SNR was also calculated for both processing methods comparing channels directly above the RNS and channels on the contralateral hemisphere with less RNS interference.

Results: The SNR values from the RNS System in MRI mode have not been reported due to extremely limited MEG recording quality, possibly due to the increased electrical activity associated with the detection and storage functions. The SNR values in off mode are shown in Table 1. Negative SNR values imply that the noise is much greater than the signal, particularly in sensors above the neurostimulator. A board-certified epileptologist qualitatively confirmed improved readability of the signals after advanced processing.

Table 1. The results from SNR calculations (mean ± Standard deviation SD in decibels dB).

	Subject 1 SNR	Subject 2 SNR
RNS mode OFF (Conventional vs. Advanced (Average of All Channels))	0.14±0.75	-0.61±0.78
RNS mode OFF (RNS Channel vs. No RNS using Conventional method)	-18.49± 1.20	-18.22±1.90
RNS mode OFF (RNS Channel vs. No RNS using Advanced method)	-16.89±0.35	-15.66±1.07

Conclusions: MEG data with the RNS System yielded clinically viable data when the RNS was in off mode. Utilizing advanced signal processing, we were able to significantly improve the SNR as well as readability of the MEG data. However, the SNR in channels directly over the neurostimulator is still poor and may require modified MEG acquisition methods or strategic neurostimulator placement. Future work will compare MEG dipoles from both methods to SEEG and surgical outcomes.