T1/T2 Mapping Across 3T Scanner Fleet Using ISMRM/NIST Model 130 Premium Phantom

Michael Cuddy, MS, Alex Ward, MS, Jeremiah W. Sanders, PhD, Anshuman Panda, PhD, Kalen J Riley, MD, Yuxiang Zhou, PhD,
Department of Radiology, Mayo Clinic at Arizona

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SCAN PARAMETERS

Sequence	GE T1	Siemens T1
Sequence Type	2D FSE IR (FSE-XL)	2D TSE IR (tir2d1_6)
Plane	Coronal	Coronal
Slice Thickness (mm)	6	6
TR (ms)	4500	4500
TE (ms)	7.9	8.5
TI (ms)	50, 75, 100, 125, 150, 250, 500, 1000, 2000, 3000, 4000	35, 75, 100, 125, 150, 250, 1000, 1500, 2000, 3000, 4000
Matrix	256 x 192	256 x 192
Bandwidth (Hz/px)	391	279
FOV FE (mm)	250	250
FOV PE (mm)	200	250
PE Direction	RL	RL
Single Series Time (min)	3.98	2.3
Full Protocol Time (all series) (min)	43.8	25.5
Notes / Options	Auto prescan first acquisition, manual prescan subsequent acqusitions to hold TG and CF constant	Sum-of-Squares reconstruction

Sequence	GE T2	Siemens T2
Sequence Type	2D Spin echo (memp)	2D Spin Echo (se2d32)
Plane	Coronal	Coronal
Slice Thickness (mm)	6	6
TR (ms)	5000	5000
TE (ms)	Series 1: 15, 30, 45, 60 Series 2: 25, 50, 75, 100 Series 3: 40, 80, 120, 160 Series 4: 200, 400, 600, 800	10,20,30, ..., 310, 320 (32 echoes)
TI (ms)	-	-
Matrix	256 x 192	256 x 192
Bandwidth (Hz/px)	150	227
FOV FE (mm)	250	250
FOV PE (mm)	200	250
PE Direction	RL	RL
Single Series Time (min)	13.8	15.9
Full Protocol Time (all series) (min)	55.3	15.9
Notes / Options	Auto prescan first acquisition, manual prescan subsequent acqusitions to hold TG and CF constant	-

CONTACT

Yuxiang Zhou, PhD
Mayo Clinic Arizona
Phoenix, AZ
zhou.yuxiang@mayo.edu

INTRODUCTION

The primary goal of this project was to characterize T1 and T2 mapping performance across 3T MRI scanners at our institution using the ISMRM/NIST Model 130 phantom, which provides NIST-traceable reference standards for these measurements. The long-term goal is to develop improved tools for validating quantitative clinical MRI measurements. To improve the efficiency of data analysis, a Python-based processing pipeline was developed to automate ROI placement and result processing. The resulting measurements were also compared with the analysis generated by the phantom vendor's online software, qCal-MR.

METHODS AND MATERIALS

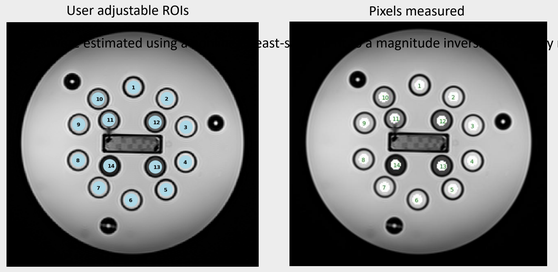
Scans of the ISMRM/NIST Model 130 Premium System Phantom (CaliberMRI, Boulder, CO) were acquired on multiple 3T MRI scanners from GE and Siemens. Variable inversion time (TI = 35–4000 ms) acquisitions were used for T1 mapping, and multi-echo spin-echo acquisitions (TE = 10–320 ms) were used for T2 mapping (see left panel). A head coil was used for each scanner (Siemens Head/Neck 20, GE 8Ch Brain for Signa PET-MR, and GE TDI Head/Neck for Premier). Semi-automated 10-pixel-diameter ROI placement, measurement, and analysis were performed using in-house Python software. T1 values were estimated using a nonlinear least-squares fit to a magnitude inversion-recovery model with an inversion efficiency term. T2 values were estimated using a mono-exponential decay model with or without a constant noise offset. For T2 analysis, spheres 1 and 5 were excluded according to the phantom vendor's recommendations, while spheres 13 and 14 were excluded from both T1 and T2 analyses. For Siemens systems, the first echo (10 ms) was excluded. Estimated relaxation times were compared with temperature-corrected phantom reference values.

SEMI-AUTOMATED ROI PLACEMENT

Using a python notebook, an initial guess is made for the locations of the spheres in the relevant insert of the ISMRM phantom. The user can adjust ROI size and final placement. ROIs are then propagated across all images in the set, measurements made, and results calculated using curve fitting from the SciPy package. Reference values for measured phantom temperature are then fetched from vendor-provided data sheets. For images acquired of objects and materials other than the ISMRM phantom, numbered ROIs can be placed across the images as desired by the user.

User adjustable ROIs

Pixels measured



estimated using a least-s a magnitude inve y model with an inversion

BIAS CALCULATION

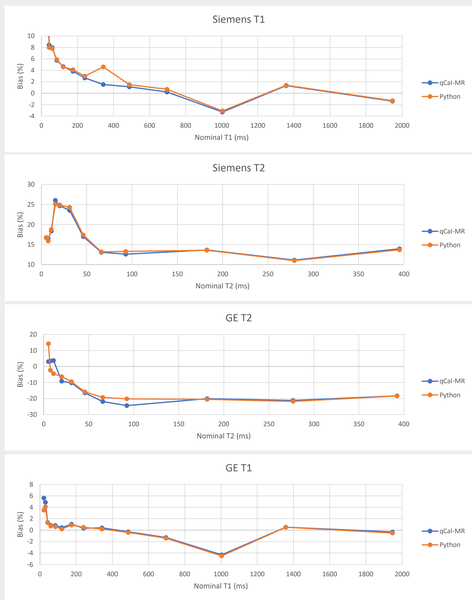
The primary result of this data analysis is percent bias, calculated as follows:

$$\text{bias (\%)} = \frac{(\text{measured relaxation time} - \text{reference relaxation time})}{\text{reference relaxation time}} x\ 100$$

NIST-traceable reference values were acquired from the manufacturer for the spheres in our phantom. Values are corrected for measured phantom temperature at the time of scanning.

CALCULATION VALIDATION

Caliber MRI offers qCal-MR online software, which provides analysis of uploaded phantom images. Our results were compared to the software output as a sanity check. As shown below, our results (orange) were generally in good agreement with qCal-MR results (blue).



MODEL FIT CHOICE

For both GE and Siemens, T1 analysis used a nonlinear least-squares fit to a magnitude inversion-recovery model with an inversion efficiency term f:

T1 Model

$$S(TI) = \left|S_0\left(1 - f\, e^{\left(-\frac{TI}{T1}\right)}\right)\right|$$

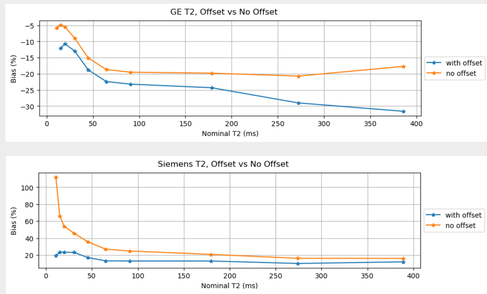
Initially, T2 analysis used a mono-exponential decay model with a constant noise offset for both vendors. However, experimental results yielded lower bias for GE scanners when using a model without offset (see plots below.)

T2 Model (GE)

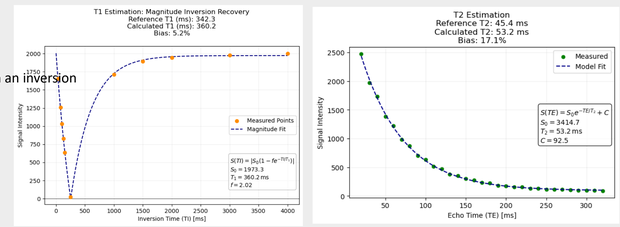
$$S(TE) = S_0 e^{\left(-\frac{TE}{T2}\right)}$$

T2 Model (Siemens)

$$S(TE) = S_0 e^{\left(-\frac{TE}{T2}\right)} + offset$$



The optimize.curve_fit() function from the SciPy package was used to fit measured values to the models, as shown below.

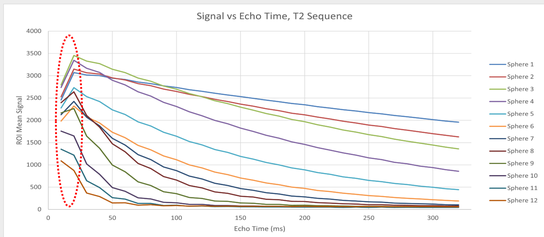


NUMBER OF TI/TE SAMPLES

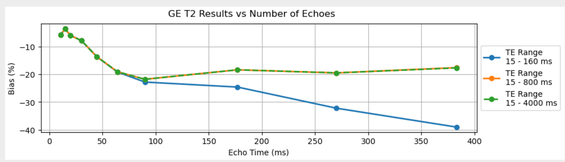
Scan parameters were set with the phantom manual (Rev L) parameter tables as a starting point. Some changes were made after trial and error to arrive at the best bias results while maintaining a reasonable overall scan time. Final scan parameters are shown in the left-side panel.

For both vendors, an additional T1 scan with TI=4000 ms was added.

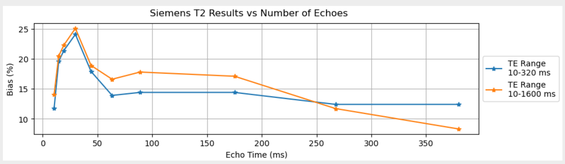
For Siemens T2 scans, the first echo was omitted from the analysis due to poor fit, as has been previously discussed[1]. The region of poor fitting is illustrated below (red dashed line region.)



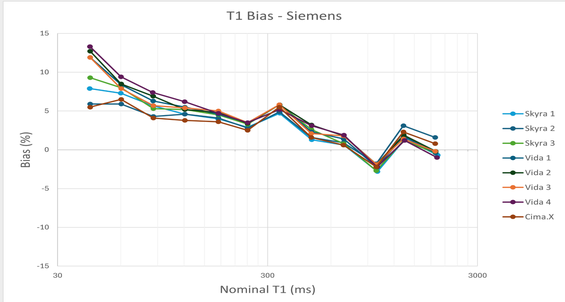
For GE T2, the manual recommended a set of three series with increasing TE values up to 160 ms. Two more series were added to determine if more samples would yield better results (series 4: 200,400,600,800 ms, series 5: 1000,2000,3000,4000 ms). Adding series 4 showed better results, while results were not improved from adding series 5, as shown in the following plot.



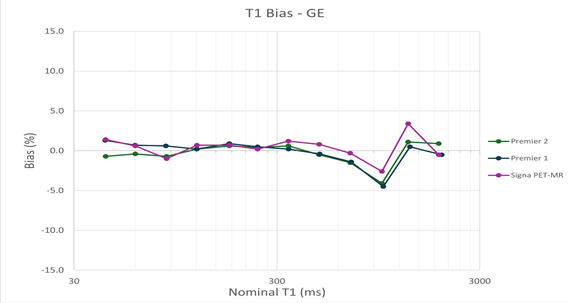
For Siemens T2, the manual recommended a single series with 32 echoes from 10-320 ms. Adding a second series with echoes 50-160ms was evaluated, but this did not result in significant benefit beyond the longest-T2 data point (see below) and was discontinued.

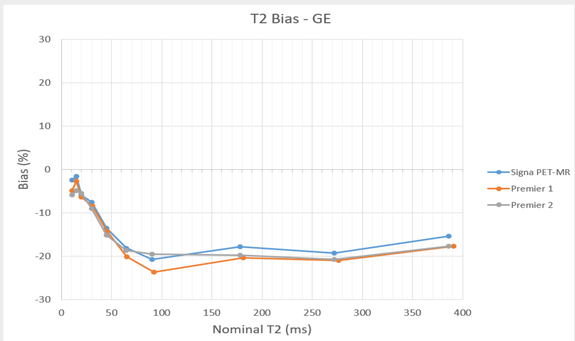


RESULTS - SIEMENS



RESULTS - GE





DISCUSSION

Results showed that T1 bias was generally less than +10% for Siemens systems and within ±5% for GE systems. T2 bias ranged from +10% to +28% for Siemens and from −2% to −24% for GE. The results were consistent across the 3T scanner fleet and showed good agreement with the qCal-MR software analysis of the same image datasets.

CONCLUSIONS

This work established a method for collecting baseline T1 and T2 mapping performance data across Siemens and GE 3T MRI scanners. These methods and baseline data can support ongoing quality control by monitoring scanner performance and consistency over time. A semi-automated and efficient pipeline for ROI placement and data analysis was developed and can be extended to non-phantom images when quantitative T1/T2 mapping is required. Future work will focus on using these data to validate quantitative clinical measurements. Additional studies will investigate whether scan parameters can be optimized to reduce acquisition time without compromising measurement accuracy, thereby minimizing interruptions to clinical scanner availability.

REFERENCES

1.) Ben-Eliezer, N., Sodickson, D.K. and Block, K.T. (2015), Rapid and accurate T2 mapping from multi–spin-echo data using Bloch-simulation-based reconstruction. Magn. Reson. Med., 73: 809-817. https://doi.org/10.1002/mrm.25156

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