RIDER MR Phantom Data Acquisition Details and Measurement Summary

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## A. Phantom Design

The phantom used for all data acquisitions was a version of the EuroSpin II Test Object 5 as distributed by Diagnostic Sonar, Ltd (Livingston, West Lothian, Scotland). The phantom was comprised of 18 25-mm doped gel filled tubes and 1 20-mm tube containing 0.25 mM GdDTPA (Figure 1).

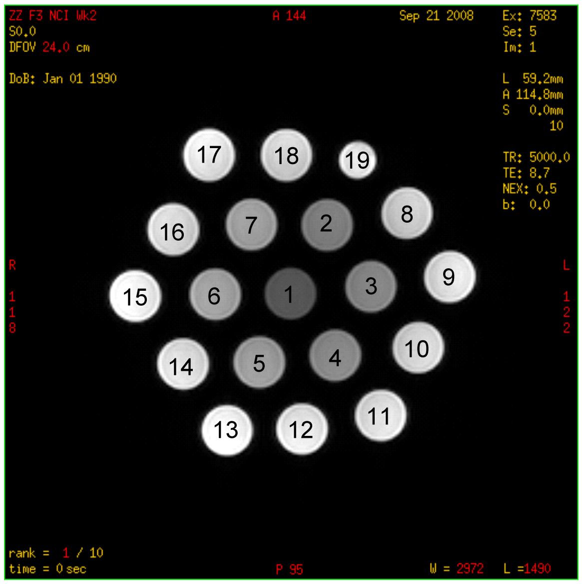



Figure 1: A $T_1$-weighted image of the phantom. The numbers in the image correspond to the tube numbers of the TO5 phantom set. Tube 19 is the 0.25 mM GdDTPA solution compartment.

## B. Scanners Evaluated

Scanner A – 1.5T GE 8-channel HD with BRM gradient subsystem (33 mT/m amplitude; 120 T/m-s)
Scanner B – 1.5T GE 8-channel HD with CRM gradient subsystem (50 mT/m amplitude; 150 T/m-s)
Scanner C – 1.5T Siemens Espree (VB13) with 33 mT/m amplitude, 100 T/m-s gradient subsystem
Scanner D – 3.0T GE 8-channel HD with TwinSpeed gradients (40 mT/m; 150 T/m-s in zoom mode)

For all measurements, an 8-channel phased array head coil was used.

## C. Data Acquired

1) $T_1$ Measurements Using 2D Inversion Recovery Sequence

The $T_1$ values for the 19 different components of the phantom were determined at 1.5T and 3.0T using a fast spin-echo inversion recovery sequence with inversion times of 50, 100, 250**, 500, 750, 1000, 1500, 2000, 2500, and 3000 ms. Other acquisition parameters were as follows:

TE / TR = 8.7 / 5000 ms
Echo train length = 3
Receiver bandwidth = ±31.25 kHz
256 x 192 matrix
1 excitation
24 x 19 cm FOV
Single 10-mm section
4:25 min acquisition time per inversion time

** The 250 ms inversion time data were not acquired on the 1.5T system.

The inversion recovery data were acquired once at 1.5T and twice at 3.0T (with a 2-week interval).

2) $T_1$ Measurements Using Multiple Flip Angle 3D Fast Spoiled Gradient Recalled Echo Sequence
The $T_1$ values for each compartment of the phantom were determined each time point and on each scanner using a 3D fast spoiled gradient recalled echo (FSPGR) sequence with flip angles of 2, 5, 10, 15, 20, 25, and 30 degrees. Other acquisition parameters were as follows:

TE = 1.2–1.4 ms (dependent on scanner, but fixed for all time points on a given scanner)
TR = 4.7–5.6 ms (dependent on scanner, but fixed for all time points on a given scanner)
Receiver bandwidth = ±31.25 kHz
256 x 192 matrix
1 excitation
24 x 19 cm FOV
10 contiguous 5-mm sections (matched to the DCE-MRI acquisition, below)
0:39-0:58 min acquisition time per flip angle (dependent on scanner, but fixed for all time points on a given scanner)

3) DCE-MRI Acquisition Using a 3D Fast Spoiled Gradient Recalled Echo Sequence
At each time point on each scanner, rapidly sampled 3D FSPGR data were acquired, simulating a DCE-MRI acquisition, using the following parameters:

TE = 0.90–1.35 ms (dependent on scanner, but fixed for all time points on a given scanner)
TR = 4.09–5.47 ms (dependent on scanner, but fixed for all time points on a given scanner)
30 degree flip angle
Receiver bandwidth = ±31.25 kHz
256 x 160 matrix
1 excitation
24 x 19 cm FOV
10 contiguous 5-mm sections (matched to the DCE-MRI acquisition, below)
7.6–10.1 s temporal resolution (dependent on scanner, but fixed for all time points on a given scanner)
6.8 – 7.9 min total scan time (dependent on scanner, but fixed for all time points on a given scanner)

4) Data Acquisition Time Points ("Coffee Break" and 1-2 Week Time Points)
For the multiple flip angle FSPGR $T_1$ measurement acquisitions (2 above) and the DCE-MRI FSPGR acquisitions (3 above), data were obtained twice on day 0 ("coffee break" scenario) and once at 1 week (1.5T scanners) or at 2 weeks (3.0T scanner) later. On day 0, the RF coil and phantom were positioned and data obtained. The RF coil and phantom were then removed from the scan table and the phantom moved to a second nearby scanner for day 0 measurements on that scanner. The RF coil and phantom were then repositioned on the first scanner and the second data set acquired on the first scanner (and subsequently on the second scanner).

## D. Data Analysis

$T_1$ Measurements: The $T_1$ measurement data (inversion recovery and multiple flip angle FSPGR) were analyzed using the T1/T2* Mapping module of the CineTool analysis package (version. 7.1.2, GE Healthcare, provided under research agreement with GE Healthcare Technology) running in the IDL environment (ITT Visual Information Solutions, Boulder, CO). $T_1$ measurements were obtained from ~200 mm$^2$ regions of interest (ROIs) centered within each of the 19 phantom compartments. For the inversion recovery data, the measurements were obtained from the single section. $T_1$ measurements from the inversion recovery sequence were considered to form the "ground truth" $T_1$ data for all subsequent analyses. For the multiple flip angle data, the measurements were obtained from the central 5 sections of the 10-12 acquired sections. The reported data from these measurements are the averages of the values obtained from the 5 sections.

$T_1$ Measurement Reproducibility: The reproducibility of the multiple flip angle 3D FSPGR $T_1$ measurements was assessed using correlation analysis and, as Bland and Altman noted the limitations of such correlation analysis when assessing repeatability (1), using the Bland-Altman coefficient of repeatability. Such analyses were performed to compare the reproducibility of the measurements in the "coffee break" scenario (Run 1 vs. Run 2 results for Week 0) as well as in the extended delay scenario (Average of Run 1 and Run 2 Week 0 results vs. Week 1 results). These results were obtained for each scanner (Scanners A – D).

Limits of Agreement of Inversion Recovery $T_1$ Measurements with Multiple Flip Angle FSPGR $T_1$ Measurements: The Bland-Altman limits of agreement (1) of the multiple flip angle FSPGR T1 measurements relative to the inversion recovery measurements were computed for each scanner to assess the accuracy of the multiple flip angle measures as compared to the assumed ground truth inversion recovery measures for each scanner (Scanners A – D).

Signal, Noise, and Contrast-to-Noise Ratio Measurements and Contrast Agent Uptake Simulations from the DCE-MRI Acquisitions: The variation in signal intensity, mean noise amplitude, and contrast-to-noise ratio (CNR) was assessed for each run on each scanner (Scanners A – E). In addition, simulated DCE-MRI uptake curves were generated using the signal measured from selected compartments of the phantom, the ideal signal response for a perfectly spoiled gradient recalled echo sequence, and the Solomon-Bloembergen equation converting change in $T_1$ relaxation rate to gadolinium concentration (assuming a $T_1$ relaxivity of 4.75 $mM^{-1}$ $s^{-1}$).

## E. Results

Inversion Recovery $T_1$ Measurement Results

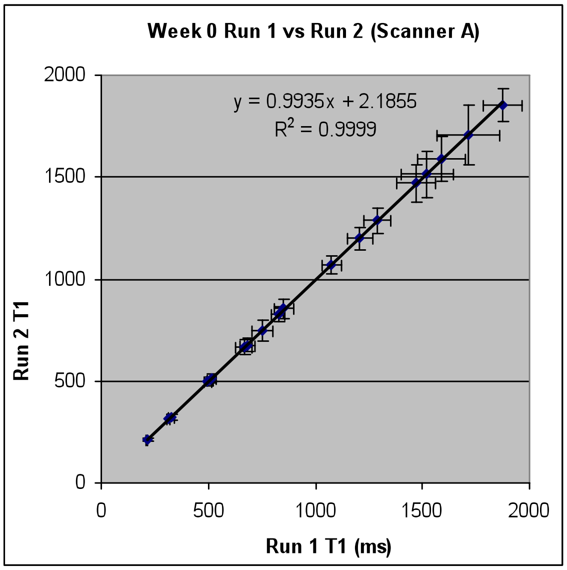
| Compartment # | 1.5T 07/23/2008 T1 (ms) | 3.0T 09/07/2008 T1 (ms) | 3.0T 09/21/2008 T1 (ms) |
|---|---|---|---|
| 1 | 215.25 | 209.52 | 207.45 |
| 2 | 320.18 | 315.26 | 312.12 |
| 3 | 303.80 | 295.63 | 294.14 |
| 4 | 493.36 | 489.73 | 485.67 |
| 5 | 484.81 | 475.12 | 470.31 |
| 6 | 471.17 | 469.14 | 465.80 |
| 7 | 656.59 | 647.36 | 644.06 |
| 8 | 634.46 | 632.02 | 634.03 |
| 9 | 809.73 | 814.26 | 814.05 |
| 10 | 768.12 | 764.98 | 757.88 |
| 11 | 1001.02 | 998.83 | 988.58 |
| 12 | 1728.28 | 1689.79 | 1669.26 |
| 13 | 1086.39 | 1076.17 | 1062.72 |
| 14 | 1173.85 | 1160.93 | 1149.45 |
| 15 | 1331.32 | 1325.55 | 1318.28 |
| 16 | 1479.87 | 1467.46 | 1458.69 |
| 17 | 1432.01 | 1433.79 | 1428.98 |
| 18 | 1624.85 | 1635.47 | 1625.03 |
| 19 | 669.70 | 681.82 | 684.08 |

Table 1: $T_1$ measurements for each compartment of the phantom obtained from the inversion recovery experiments. These measurements are considered to be "ground truth".

From the data in Table 1, the Bland-Altman coefficient of repeatability (1.96 times the standard deviation of the differences in $T_1$ at the two time points) for the 3.0T repeated measurement data is 11.1 ms, or approximately 1.3% of the mean.

Multiple Flip Angle $T_1$ Measurement Results

**Scanner A (1.5T)**



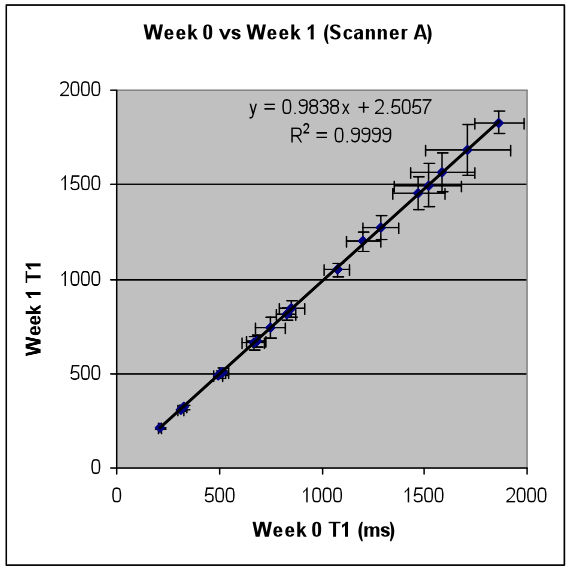




Figure 2: Scanner A multiple flip angle $T_1$ measurement correlations. Left: "Coffee break" Run 1 vs. Run 2. Right: Week 1 vs. average of the two "coffee break" week 0 runs. Error bars represent one standard deviation of the mean of the five $T_1$ ROI measurements made per compartment.

Coefficients of repeatability:

- Run 1 vs. Run 2: 9.7 ms (1.0% of mean)
- Week 1 vs. Week 2: 18.7 ms (2.0% of mean)

Limits of agreement (multiple flip angle FSPGR vs. inversion recovery):

- Run 1: 94.8 ms (10.4% of mean)
- Run 2: 88.9 ms ( 9.8% of mean)
- Week 0: 80.4 ms ( 8.9% of mean)

## Scanner B (1.5T)

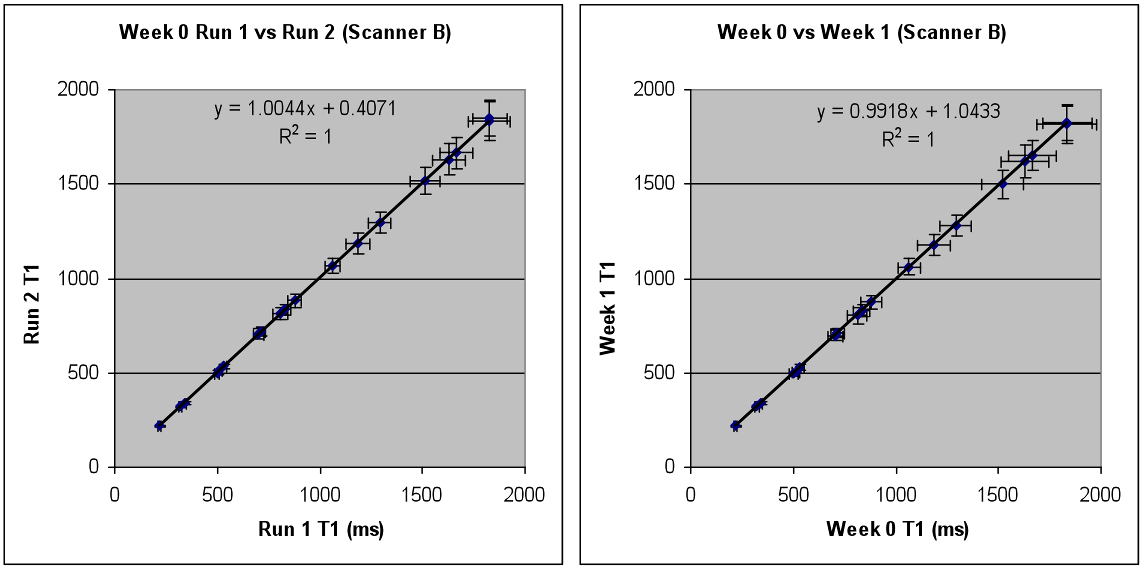



Figure 3: Scanner B multiple flip angle $T_1$ measurement correlations. Left: "Coffee break" Run 1 vs. Run 2. Right: Week 1 vs. average of the two "coffee break" week 0 runs. Error bars represent one standard deviation of the mean of the five $T_1$ ROI measurements made per compartment.

Coefficients of repeatability:

- Run 1 vs. Run 2: 8.6 ms (0.9% of mean)
- Week 1 vs. Week 2: 10.1 ms (1.1% of mean)

Limits of agreement (multiple flip angle FSPGR vs. inversion recovery):

- Run 1: 129.0 ms (14.0% of mean)
- Run 2: 131.8 ms (14.3% of mean)
- Week 0: 121.8 ms (13.3% of mean)

## Scanner C (1.5T)

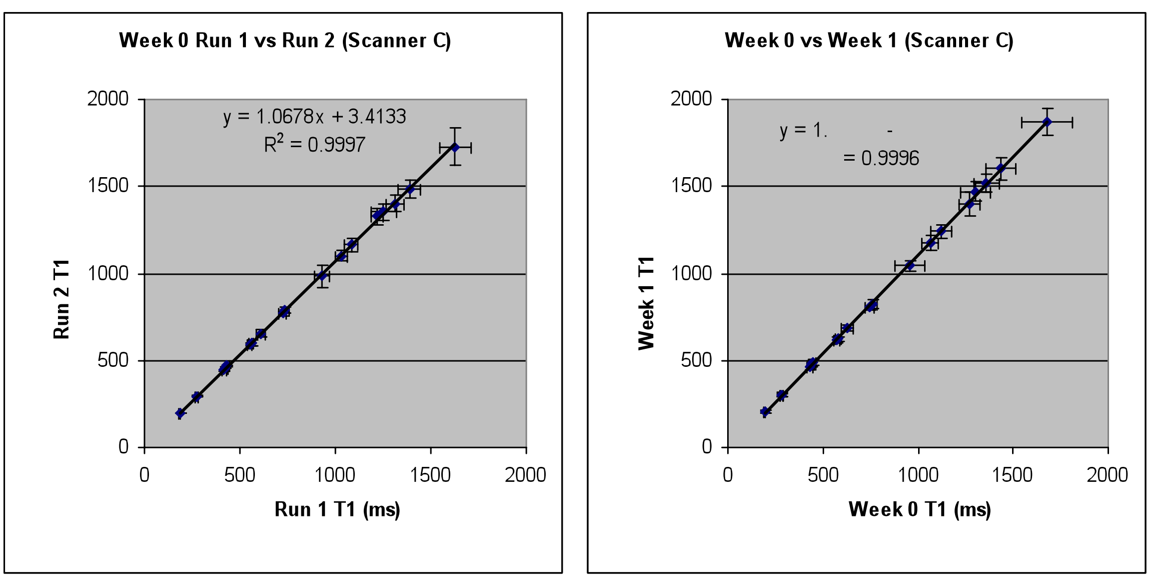


Figure 4: Scanner C multiple flip angle $T_1$ measurement correlations. Left: "Coffee break" Run 1 vs. Run 2. Right: Week 1 vs. average of the two "coffee break" week 0 runs. Error bars represent one standard deviation of the mean of the five $T_1$ ROI measurements made per compartment.

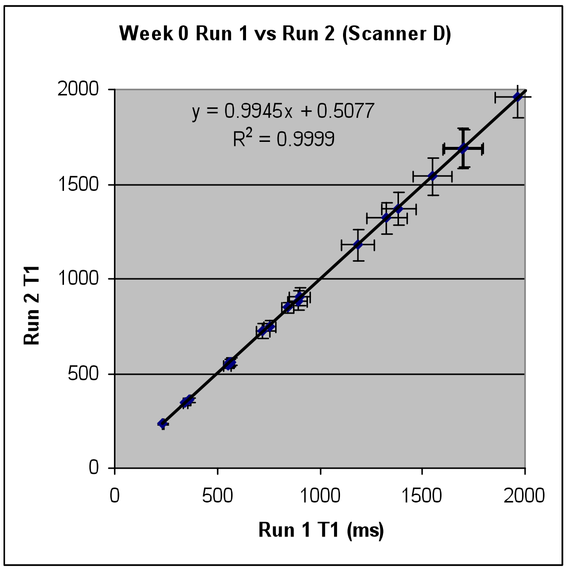
Coefficients of repeatability:

| | |
|---|---|
| Run 1 vs. Run 2: | 59.2 ms (7.2% of mean) |
| Week 1 vs. Week 2: | 114.1 ms (13.3% of mean) |

Limits of agreement (multiple flip angle FSPGR vs. inversion recovery):

| | |
|---|---|
| Run 1: | 113.2 ms (13.6% of mean) |
| Run 2: | 79.2 ms ( 9.2% of mean) |
| Week 0: | 107.2 ms (12.0% of mean) |

**Scanner D (3.0T)**



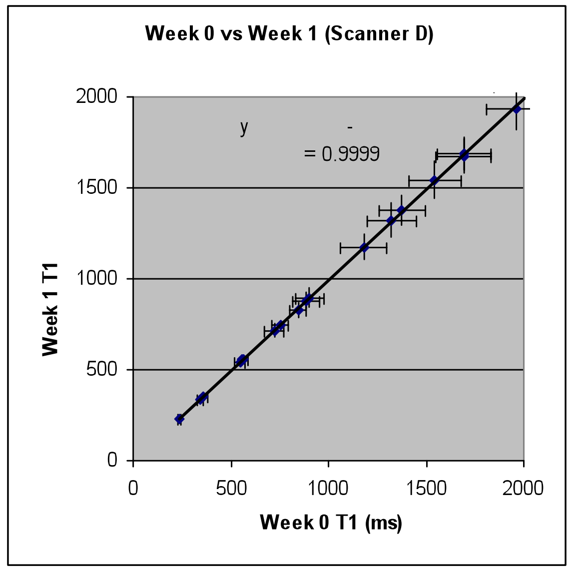




Figure 5: Scanner D multiple flip angle $T_1$ measurement correlations. Left: "Coffee break" Run 1 vs. Run 2. Right: Week 1 vs. average of the two "coffee break" week 0 runs. Error bars represent one standard deviation of the mean of the five $T_1$ ROI measurements made per compartment.

Coefficients of repeatability:

| | |
|---|---|
| Run 1 vs. Run 2: | 11.4 ms (1.1% of mean) |
| Week 1 vs. Week 2: | 14.2 ms (1.4% of mean) |

Limits of agreement (multiple flip angle FSPGR vs. inversion recovery):

| | |
|---|---|
| Run 1: | 201.1 ms (21.1% of mean) |
| Run 2: | 194.9 ms (20.5% of mean) |
| Week 0: | 190.6 ms (20.1% of mean) |

DCE-MRI Contrast-to-Noise Ratio and Signal Stability Measurements

**Scanner A (1.5T)**

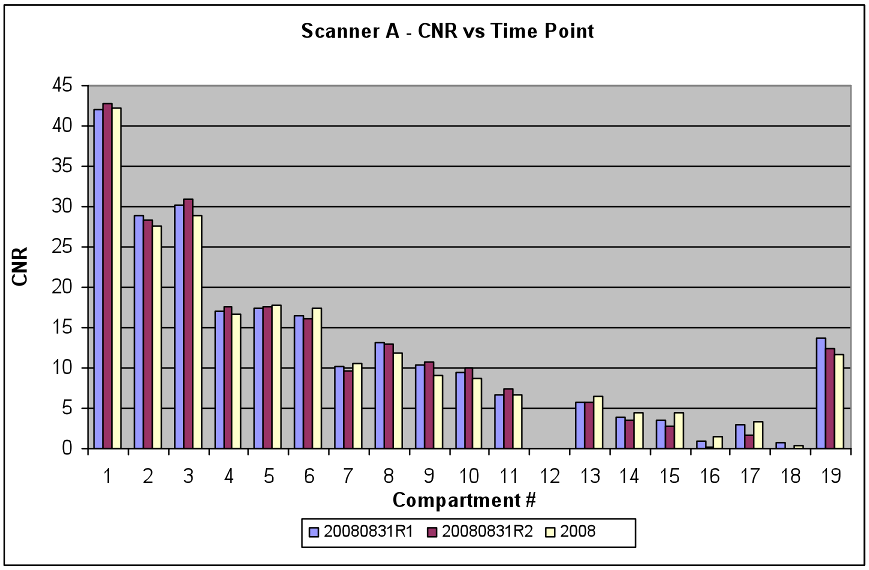



Figure 6: Scanner A contrast-to-noise ratio of individual phantom compartments relative to compartment 12 for the "coffee break" repetitions and the week 1 time point.

Average coefficient of variation of signal intensity over duration of DCE scan at each time point***:

| | |
|---|---|
| Run 1: | 0.4% |
| Run 2: | 0.5% |
| Week 1: | 0.5% |

Average coefficient of variation of CNR over the three time points***: 0.9%

**Scanner B (1.5T)**

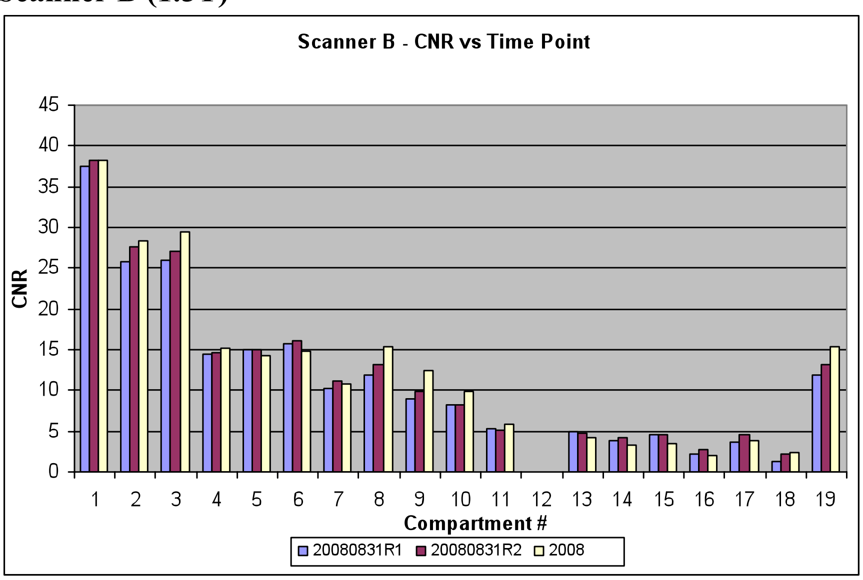



Figure 7: Scanner B contrast-to-noise ratio of individual phantom compartments relative to compartment 12 for the "coffee break" repetitions and the week 1 time point.

Average coefficient of variation of signal intensity over duration of DCE scan at each time point:

Run 1: 0.6%
Run 2: 0.6%
Week 1: 0.5%

Average coefficient of variation of CNR over the three time points: 3.9%

**Scanner C (1.5T)**

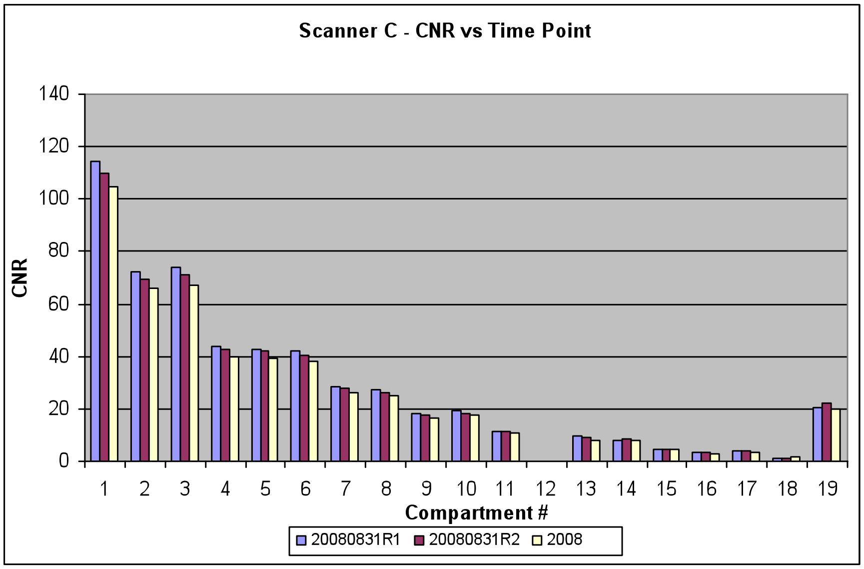



Figure 8: Scanner C contrast-to-noise ratio of individual phantom compartments relative to compartment 12 for the "coffee break" repetitions and the week 1 time point.

Average coefficient of variation of signal intensity over duration of DCE scan at each time point:
Run 1: 1.2%
Run 2: 0.9%
Week 1: 1.4%

Average coefficient of variation of CNR over the three time points: 4.3%

**Scanner D (3.0T)**

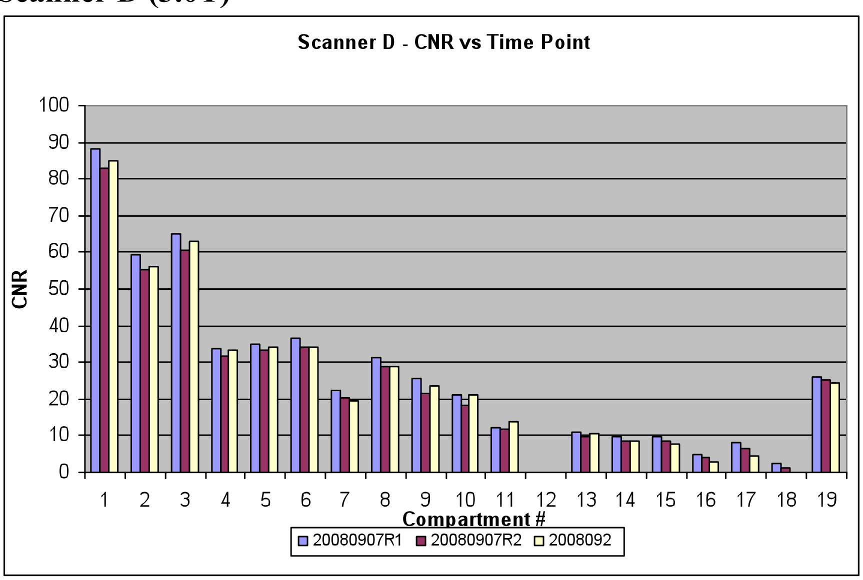


Figure 9: Scanner D contrast-to-noise ratio of individual phantom compartments relative to compartment 12 for the “coffee break” repetitions and the week 1 time point.

Average coefficient of variation of signal intensity over duration of DCE scan at each time point:

| | |
|---|---|
| Run 1: | 0.4% |
| Run 2: | 0.4% |
| Week 1: | 0.3% |

Average coefficient of variation of CNR over the three time points: 4.4%

***Average coefficient of variation refers to the value averaged over all 19 compartments of the phantom

Reference:

1) Bland JM and Altman DG, Lancet. 1986 Feb 8;1(8476):307-10.