Precision and Bias in ADC Measurements on Pre-Clinical MRIs Using a Standardized DWI Phantom and Procedure

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CIRP (virtual) Annual Meeting 2022

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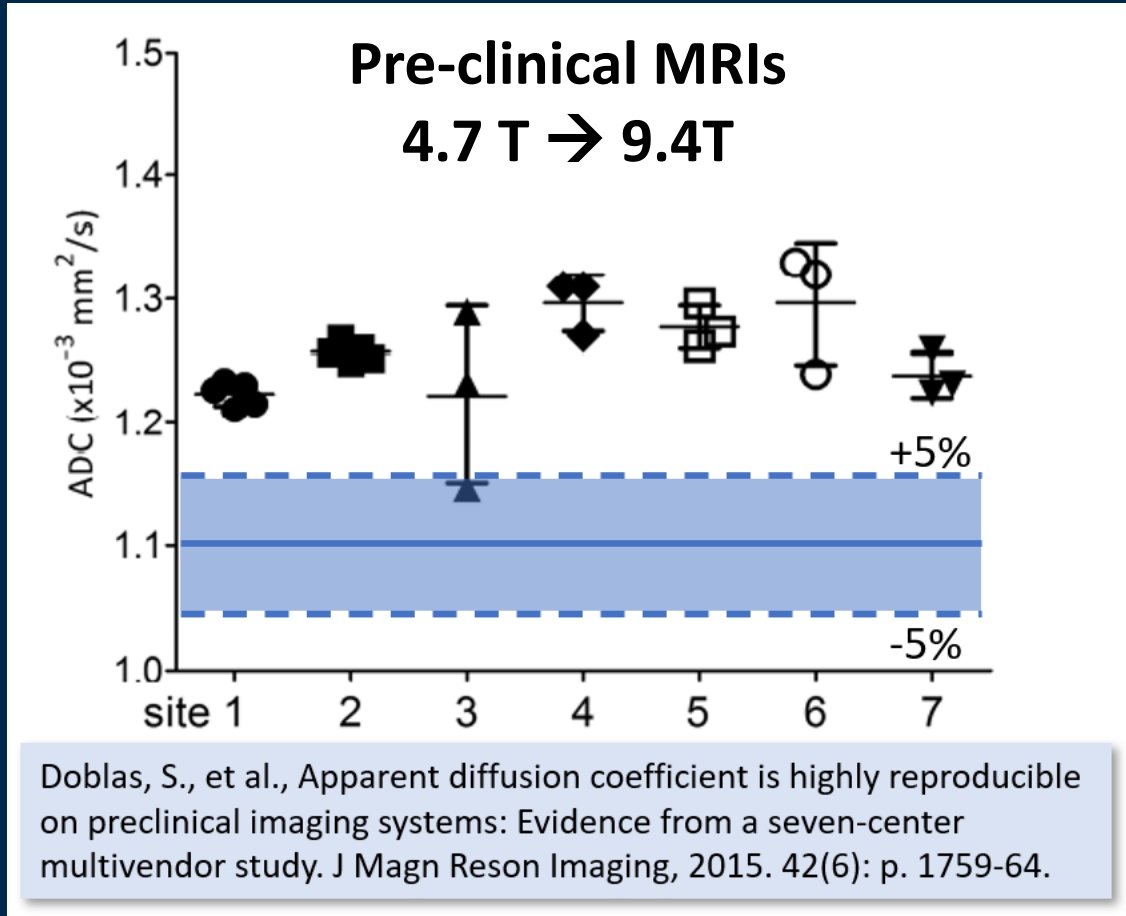
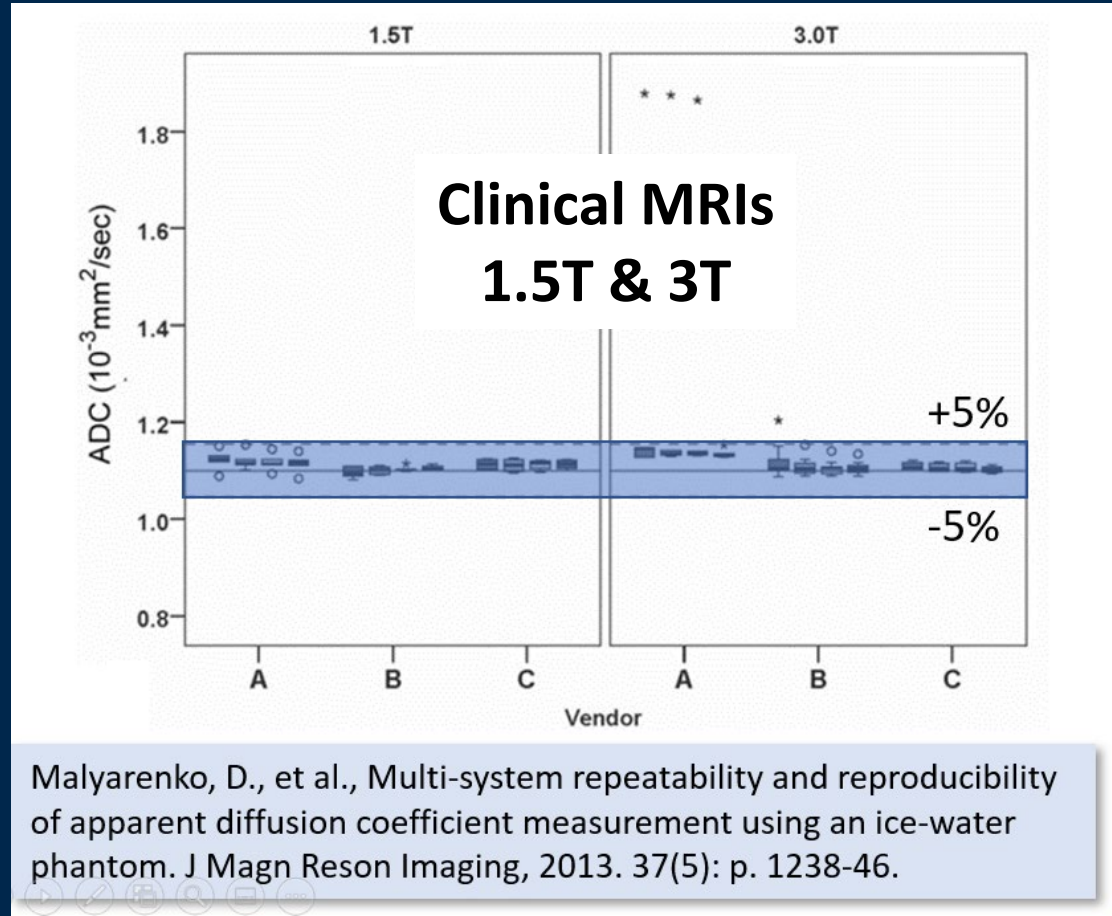
Background & Motivation

- Prior work indicates reasonable repeatability (≈3%) and reproducibility (≈6%) of ADC measurements on pre-clinical MRIs, though inferior relative to clinical MRIs
- Pre-clinical MRIs exhibited significant absolute bias (≈15%)



Doblas, S., et al., Apparent diffusion coefficient is highly reproducible on preclinical imaging systems: Evidence from a seven-center multivendor study. J Magn Reson Imaging, 2015. 42(6): p. 1759-64.



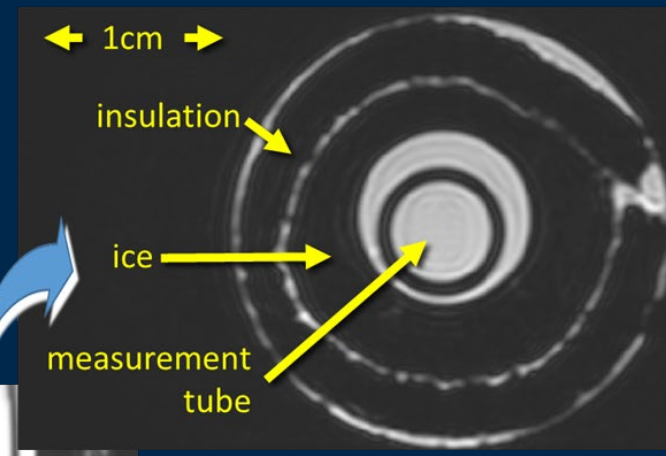
Malyarenko, D., et al., Multi-system repeatability and reproducibility of apparent diffusion coefficient measurement using an ice-water phantom. J Magn Reson Imaging, 2013. 37(5): p. 1238-46.

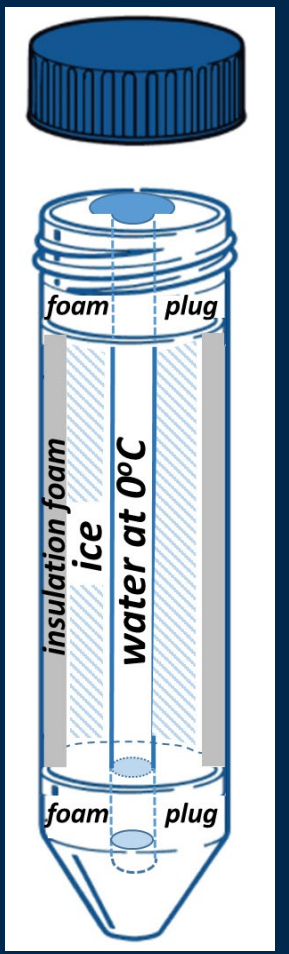
Objectives

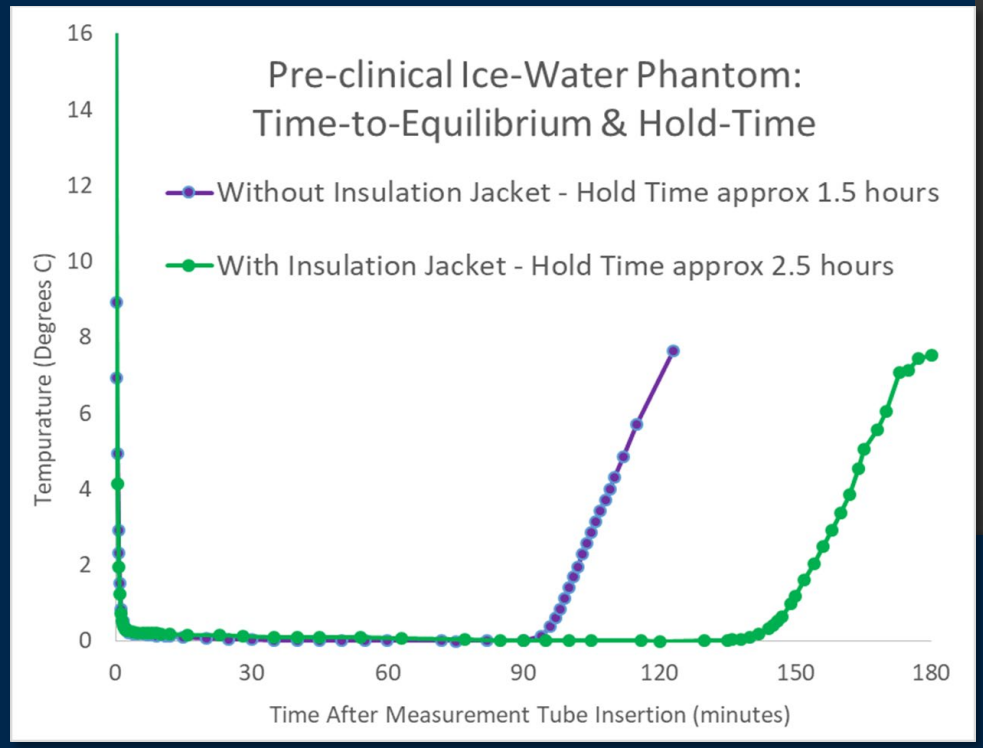
- Investigate apparent discrepancy of ADC measurement on clinical vs pre-clinical systems
- Assess ADC repeatability and reproducibility on pre-clinical MRIs
- Measure absolute bias, spatial uniformity, and SNR_{DWI}
- Generate multi-vendor DWI/ADC data in vendor-native format
- Assess sites' ITK-compatible format of same multi-vendor data
- Compare site- vs central-lab ADC measurements on common datasets

Experiment Design

- Round-robin of ice water-based DWI phantom
- Detailed phantom preparation instructions
- Standardized (simple) 3 bvalue DWI protocol
- Acquire test-retest data for short- & long-term repeatability







CIRP / IADP Participation Summary

- 10 systems
- 7 sites
- 3 vendors
- 6 field strengths (3 – 14T)

CIRP / IADP Workgroup DWI Phantom Round-Robin												
					Day1		Day2					
Sys	Site	Vendor	Magnetic Field (T)	SW version	Scan1	Scan2	Scan1	Scan2	Site ROIs	Central ROIs	Vendor Format	ITK Format
1	UMICH	Bruker	7	PV7.0.0	✓	✓	✓	✓		✓	✓	MHD
2	UPENN	Bruker	9.4	PV6.0.1	✓	✓	✓	✓	✓	✓	✓	MHD & DICOM
3	MDACC	Bruker	7	PV6.0.1	✓	✓	✓	✓	✓	✓	✓	DICOM
4	WUSTL	Bruker	9.4	PV360 v2.0	✓	✓	✓	✓		✓	✓	DICOM
5	WUSTL	Agilent	11.74	VnmrJ4. 2 revA	✓	✓	✓	✓		✓	✓	DICOM
6	UCSF	Bruker	3	PV6.0.1	✓	✓	✓	✓	✓	✓	✓	DICOM
7	BAYLOR	Bruker	9.4	PV360 v3.0	✓	✓	✓	✓	✓	✓	✓	NIFTI
8	UWASH	Bruker	4.7	PV6.0.1	✓		✓		✓	✓	✓	DICOM
9	UWASH	Bruker	14	PV5.1	✓		✓		✓	✓	✓	DICOM
10	UMICH	MR Solutions	3	v4.0.2.4	✓	✓	✓	✓		✓	✓	MHD & DICOM

Data Processing Workflow

DICOM Format DWI

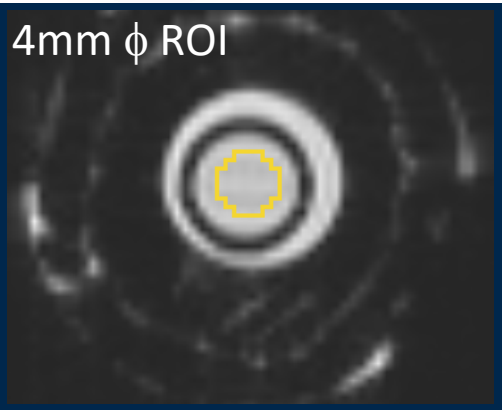
Native Vendor Format DWI (b=0, 1k, 2k) (2dseq; fdf; sur)

Matlab Scripts

Matlab Scripts 'lscov' least-sq linear fit of log(S) vs b-value

MHD format:
Low-b DWI
High-b DWI
ADC map

3DSlicer

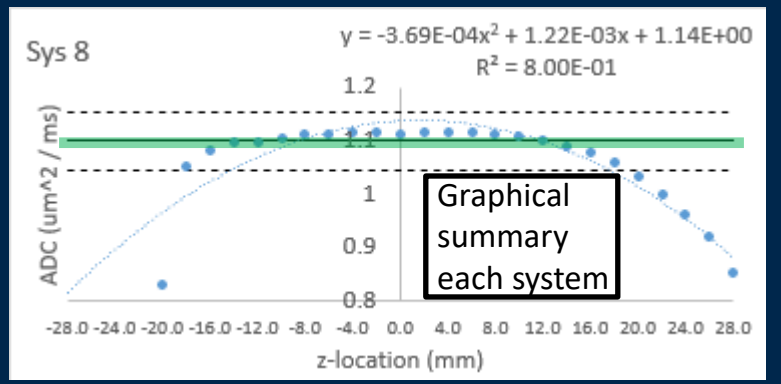


Type	Index	Count	Volume mm^3	Volume cc	Min	Max	Mean	StdDev
0	0	113580	56790.0	56.79	-0.626823544502	1.88733768463	nan	nan
1	1	3782	1891.0				nan	nan
2	2	50	25.0	0.025	-0.08130776882...	0.400735706091	0.0481575447321	0.0970932294324
3	3	51	25.5	0.0255	-0.09765338897...	0.3997631073	0.0501125334698	0.107839443327

Independent stats each slice

Z (mm)	Index	Count	Volume n	Volume c	Min	Max	ROI mean ADC	ROI Stdev	Include ROI	ADC (um^2/ms)	StdDev
-28.0	1	3782	1891	1.891	-0.396	0.4709	nan	nan	N	#N/A	#N/A
-26.0	2	50	25	0.025	-0.081	0.4007	0.048157545	0.097093229	N	#N/A	#N/A
-24.0	3	51	25.5	0.0255	-0.098	0.3998	0.050112533	0.107839443	N	#N/A	#N/A
-22.0	4	49	24.5	0.0245	-0.041	0.6088	nan	nan	N	#N/A	#N/A
-20.0	5	50	25	0.025	0	1.1279	0.829172775	0.290736272	Y	0.829172775	0.2907
-18.0	6	50	25	0.025	0.8555	1.308	1.052811496	0.092321762	Y	1.052811496	0.0923
-16.0	7	50	25	0.025				9755	Y	1.083415822	0.0436
-14.0	8	52	26	0.026				0796	Y	1.095817536	0.0252
-12.0	9	52	26	0.026				3172	Y	1.097620318	0.0131
-10.0	10	52	26	0.026	1.0747	1.1402	1.105769428	0.015011503	Y	1.105769428	0.015
-8.0	11	52	26	0.026	1.0884	1.1408	1.111513711	0.011947366	Y	1.111513711	0.0119
-6.0	12	52	26	0.026	1.0903	1.1358	1.113322095	0.009936806	Y	1.113322095	0.0099
-4.0	13	52	26	0.026	1.0972	1.1369	1.11549457	0.008090819	Y	1.11549457	0.0081
-2.0	14	51	25.5	0.0255	1.0923	1.1326	1.115408009	0.010001895	Y	1.115408009	0.01
0.0	15	52	26	0.026	1.0916	1.1312	1.11375949	0.009930045	Y	1.11375949	0.0099
2.0	16	51	25.5	0.0255	1.0894	1.145	1.117525105	0.010295895	Y	1.117525105	0.0103

Export to CSV / excel



Graphical summary each system

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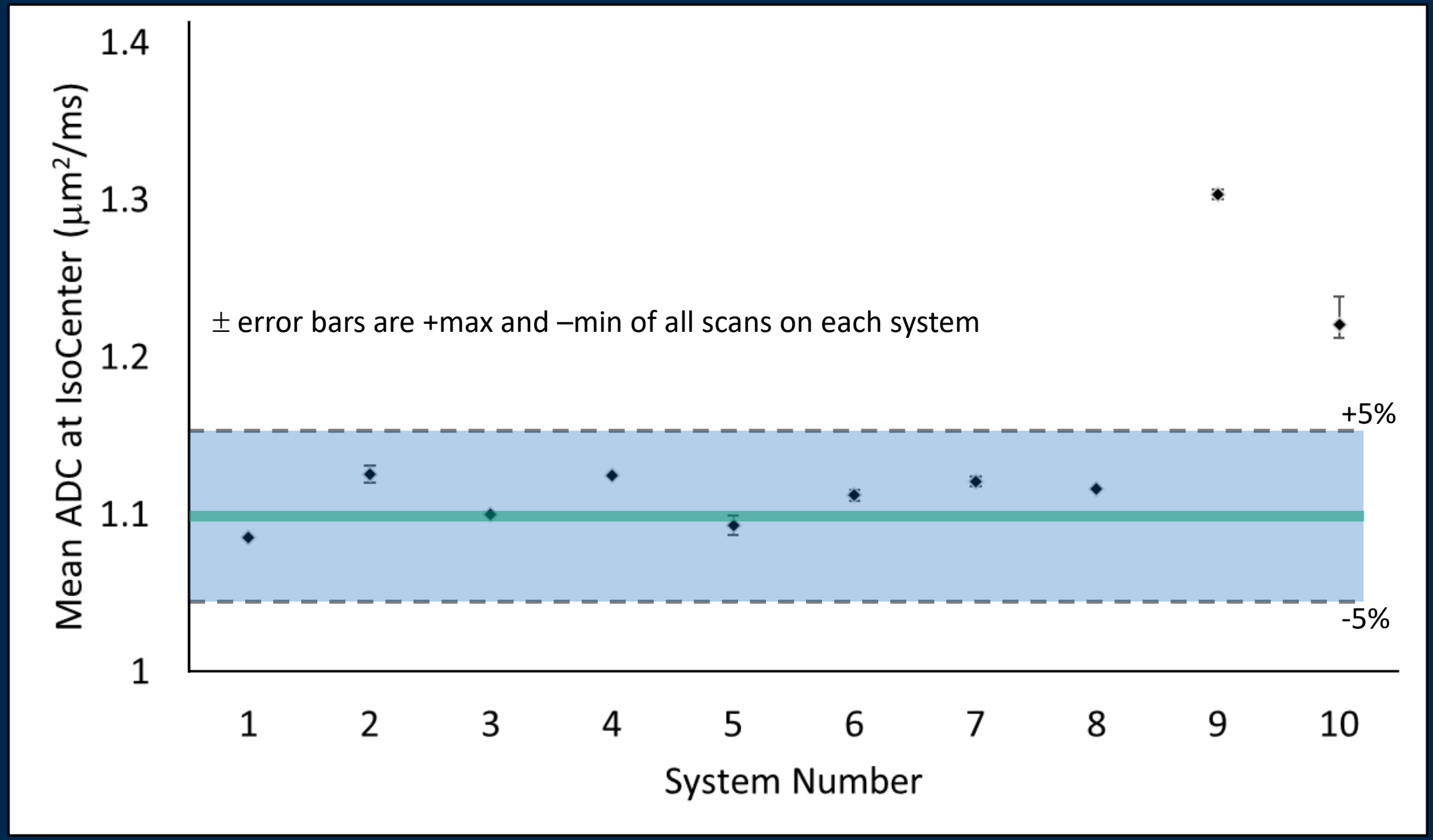
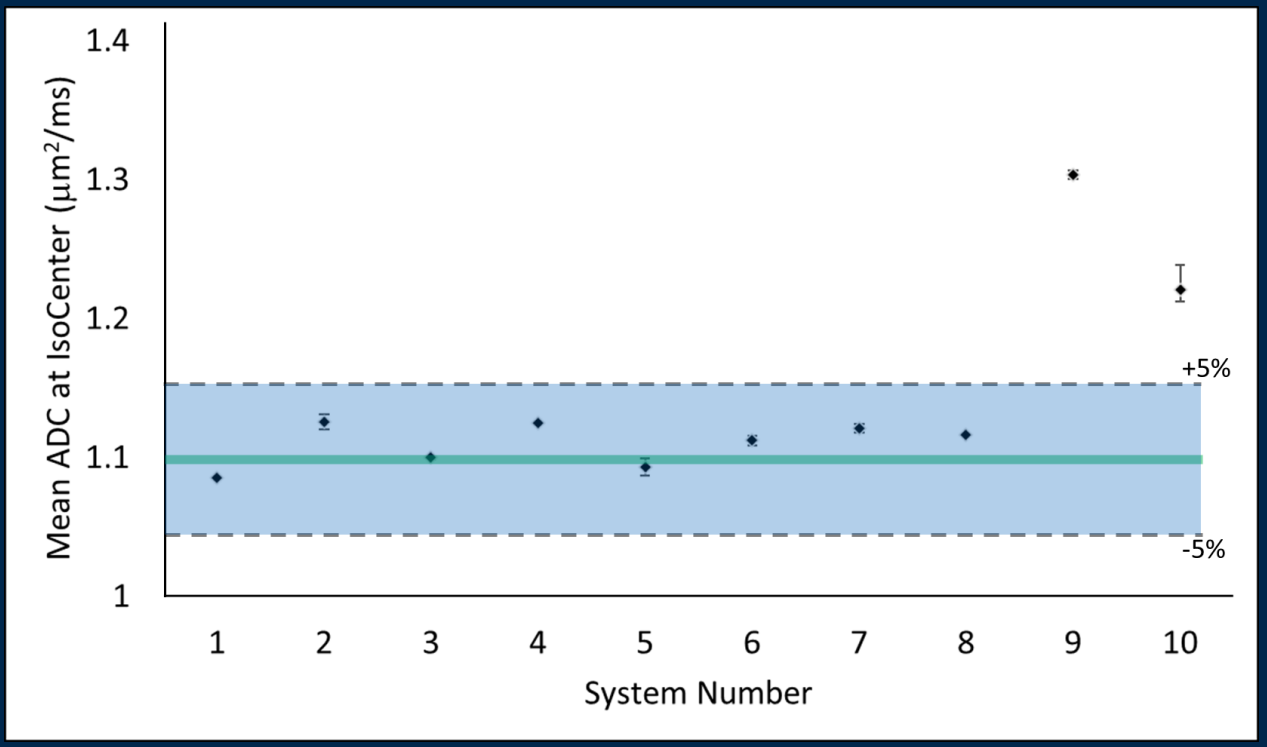
Results: Individual System Bias vs at Magnet Isocenter

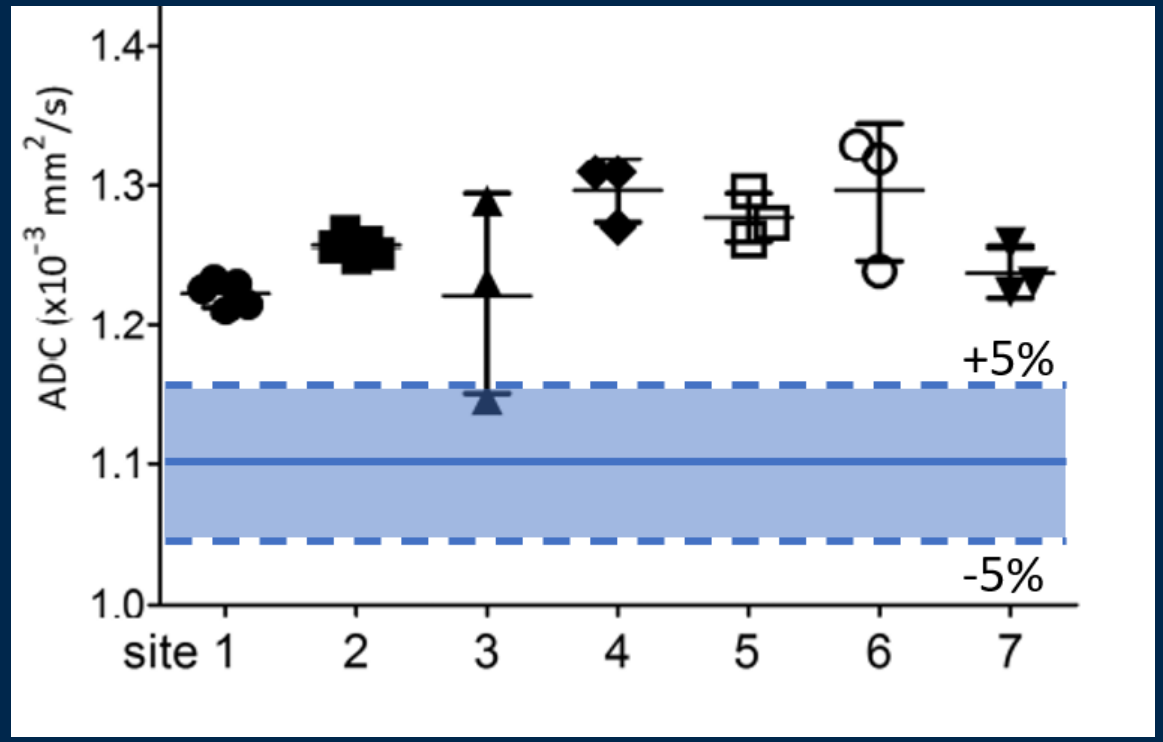


Individual System Bias vs at Magnet Isocenter

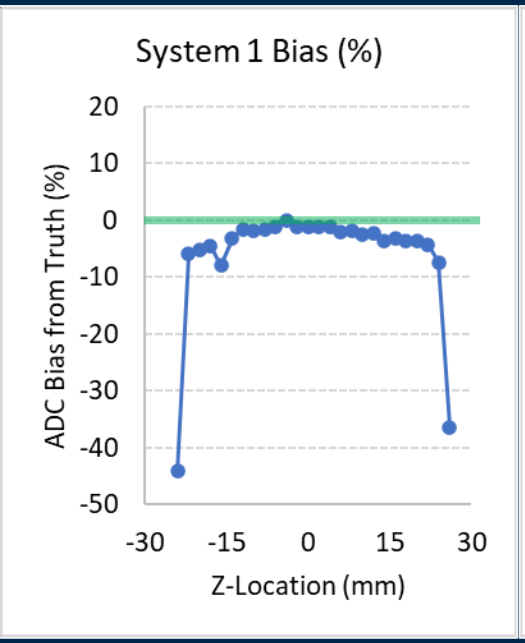
CIRP – IADP Study

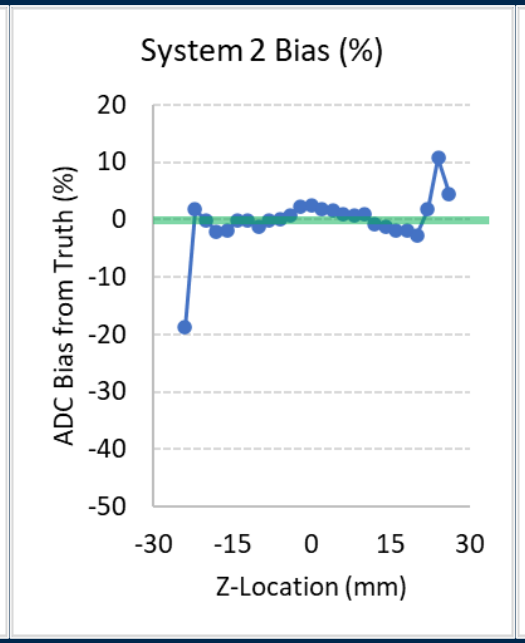


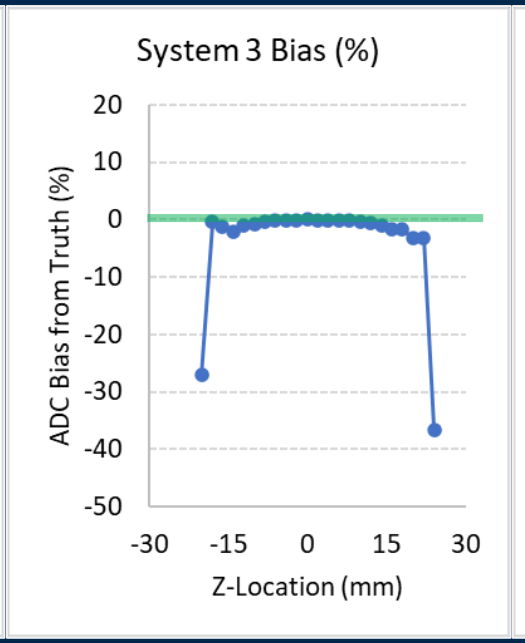
Prior Study

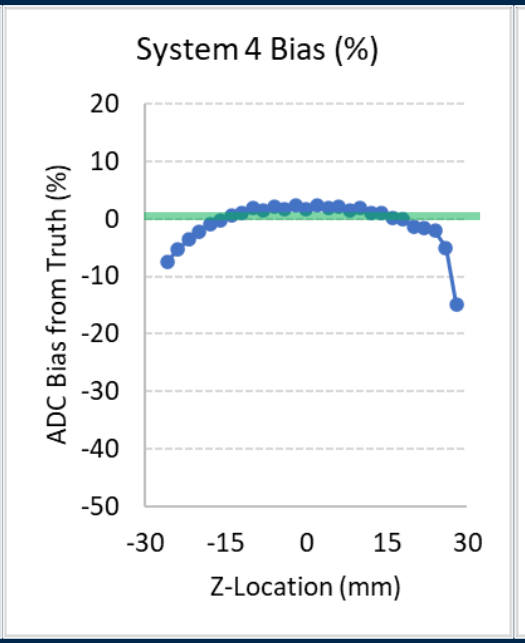


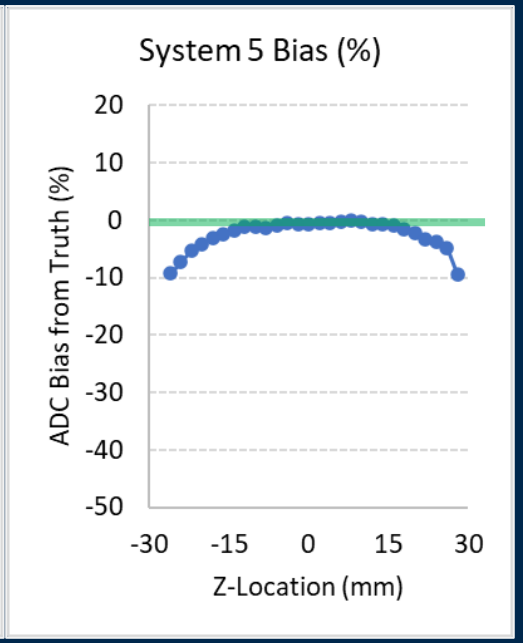
Individual System Bias vs Z-location

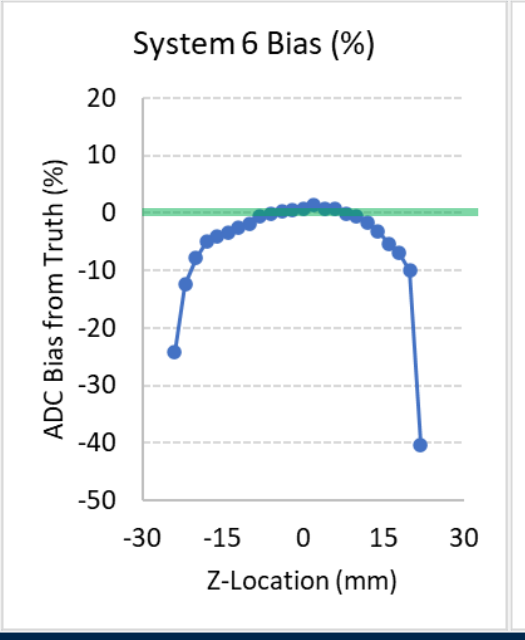


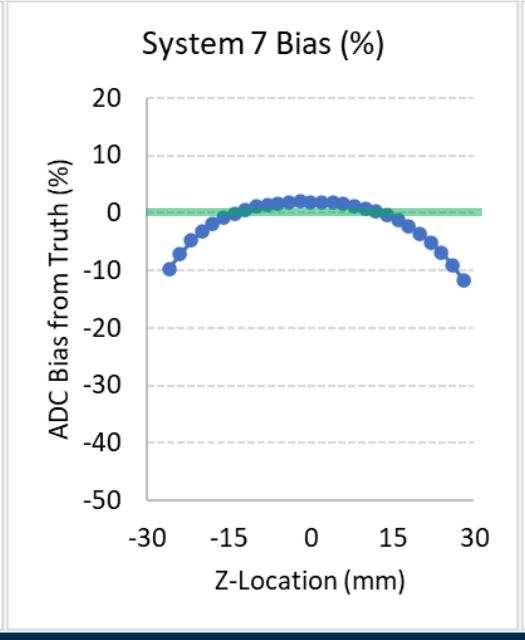


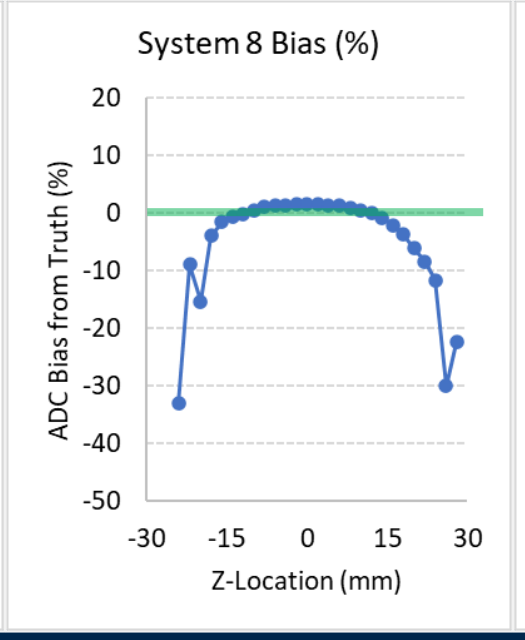


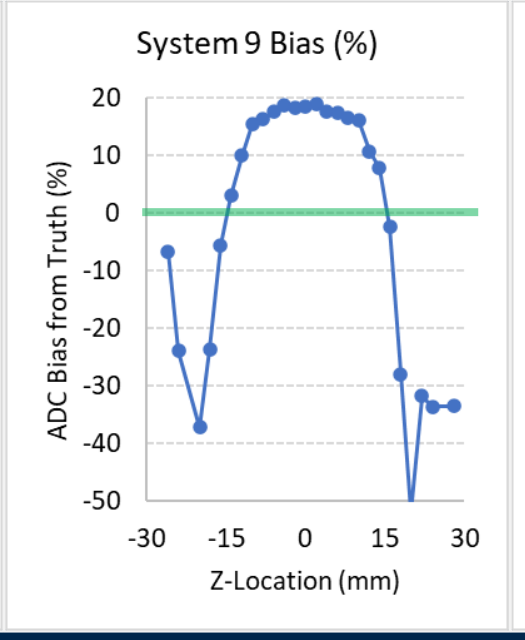


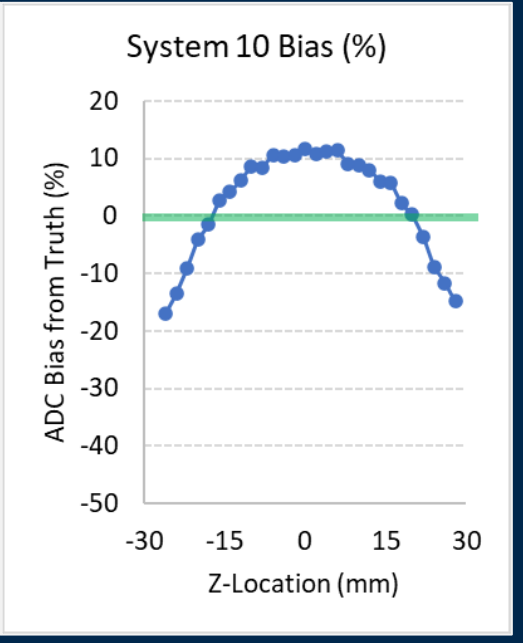




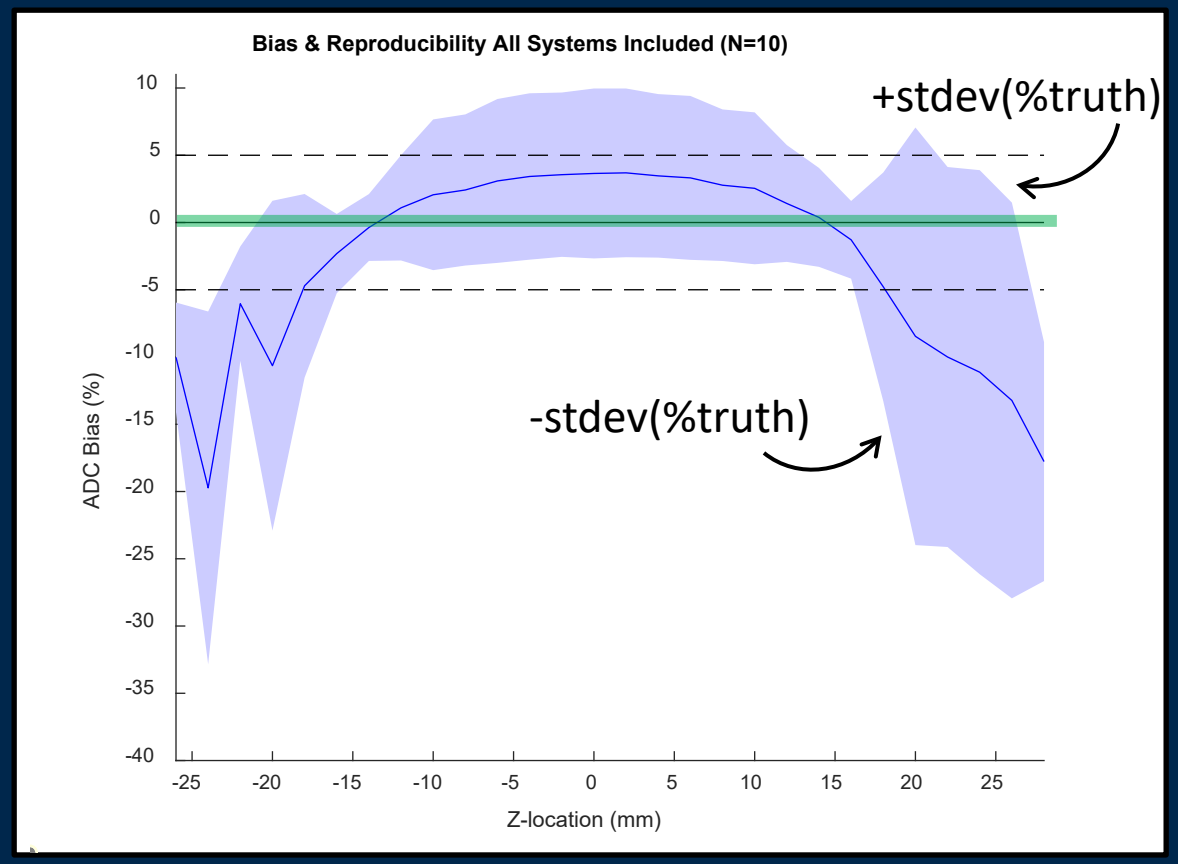


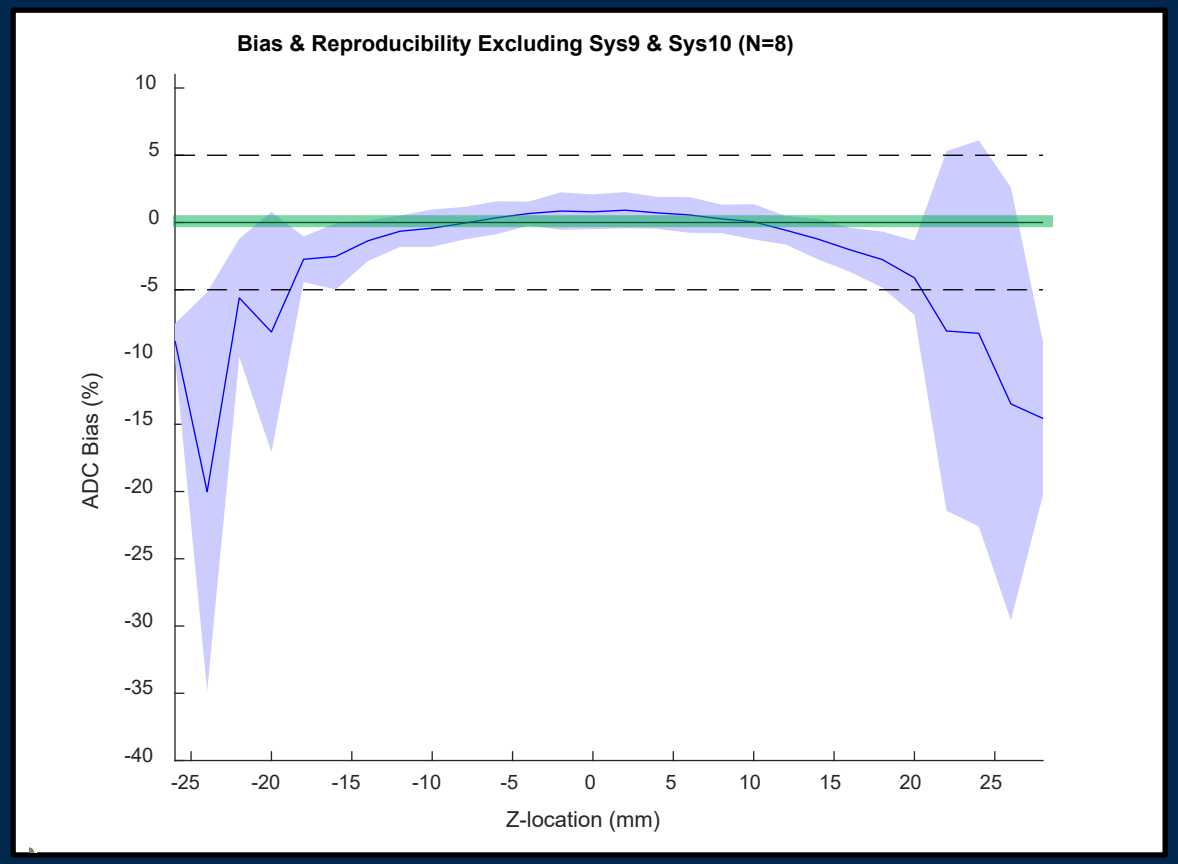




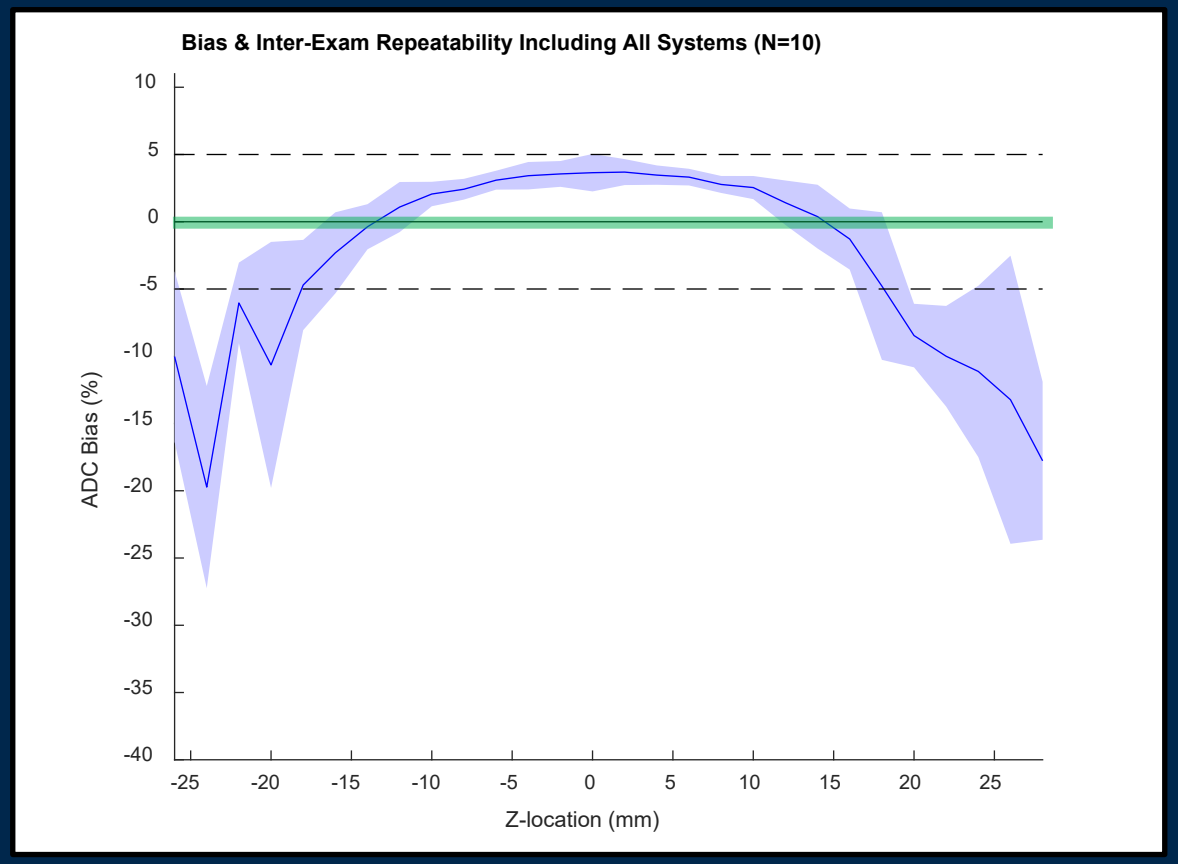


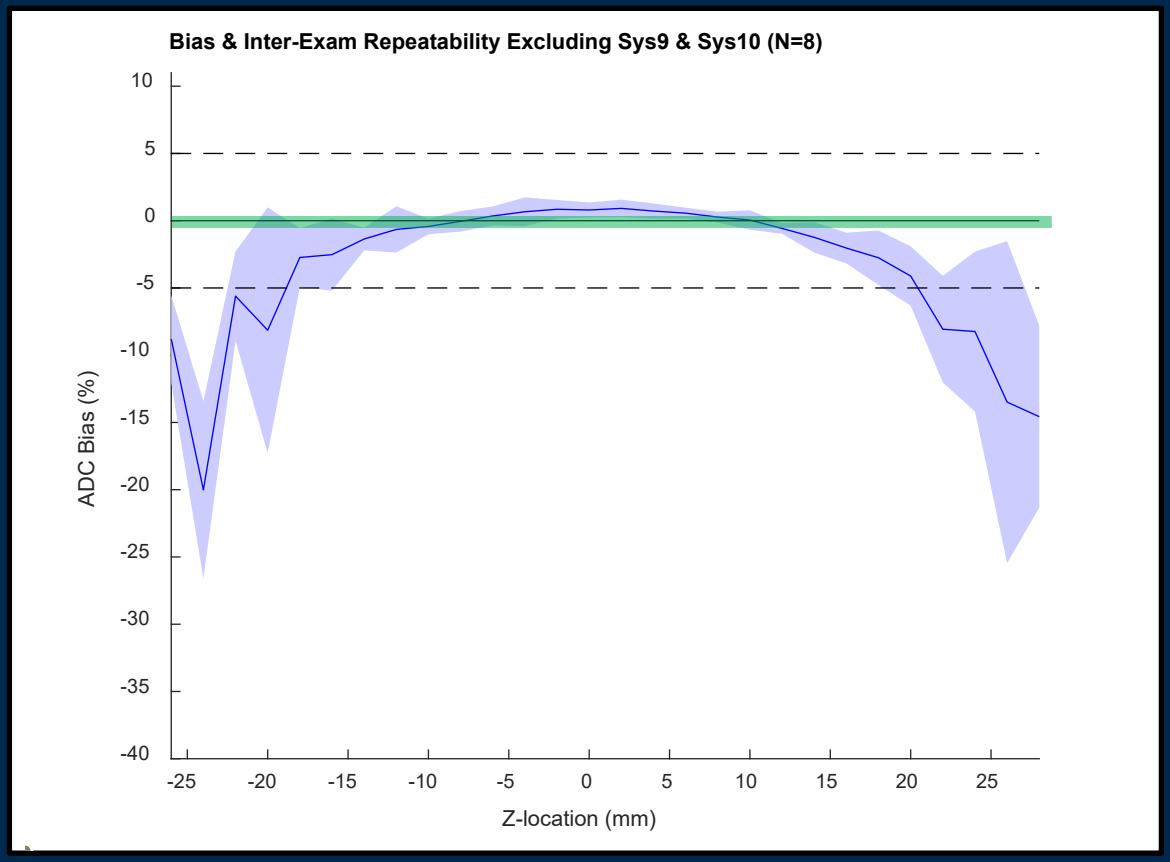
Bias & Cross-System Reproducibility vs Z-location



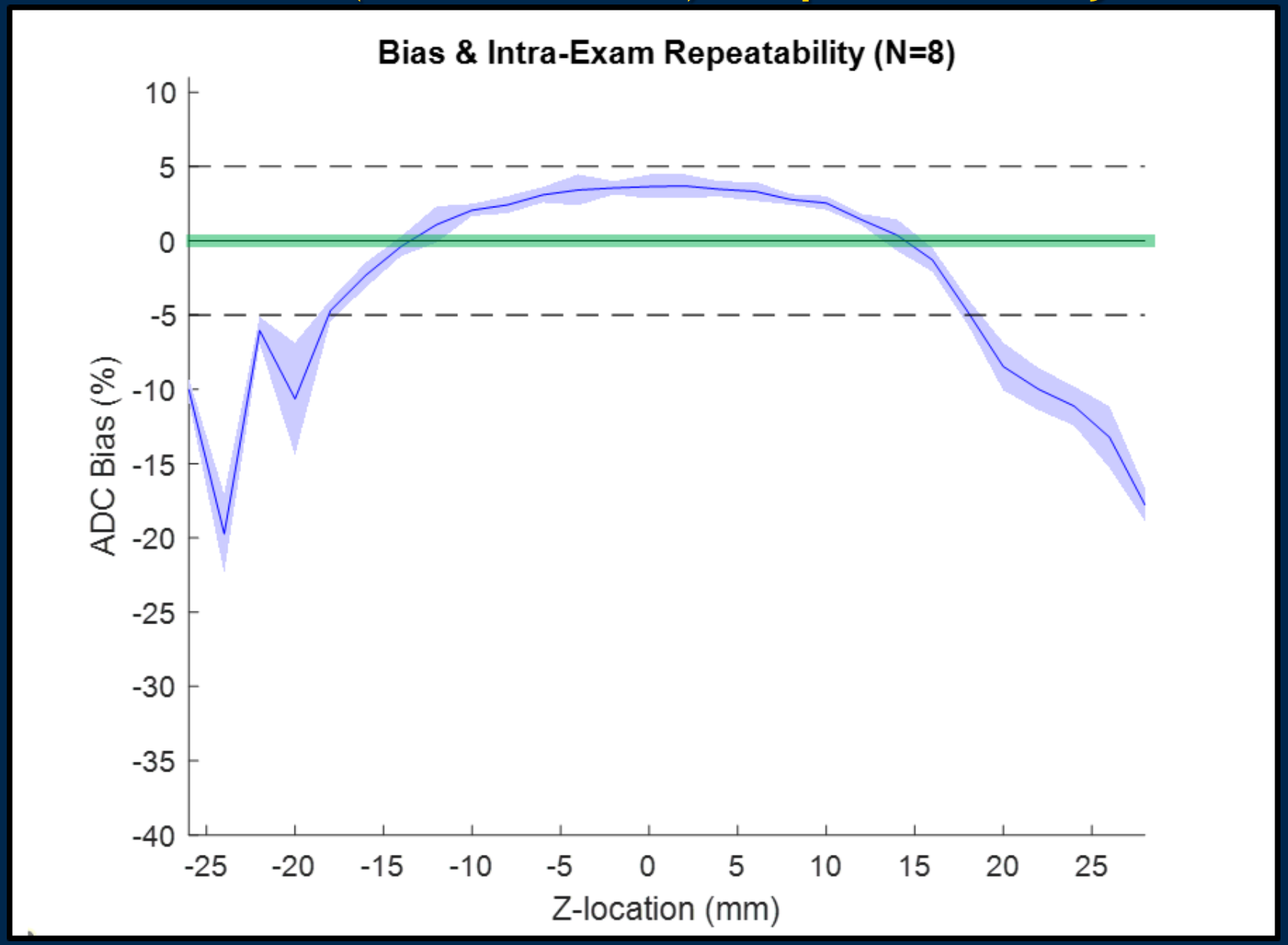


Bias & Inter-Exam (long-term) Repeatability vs Z-location





Bias & Intra-Exam (short-term) Repeatability vs Z-location



System SNR Estimation

- Two-scan method: pixelwise average and difference of identical scans

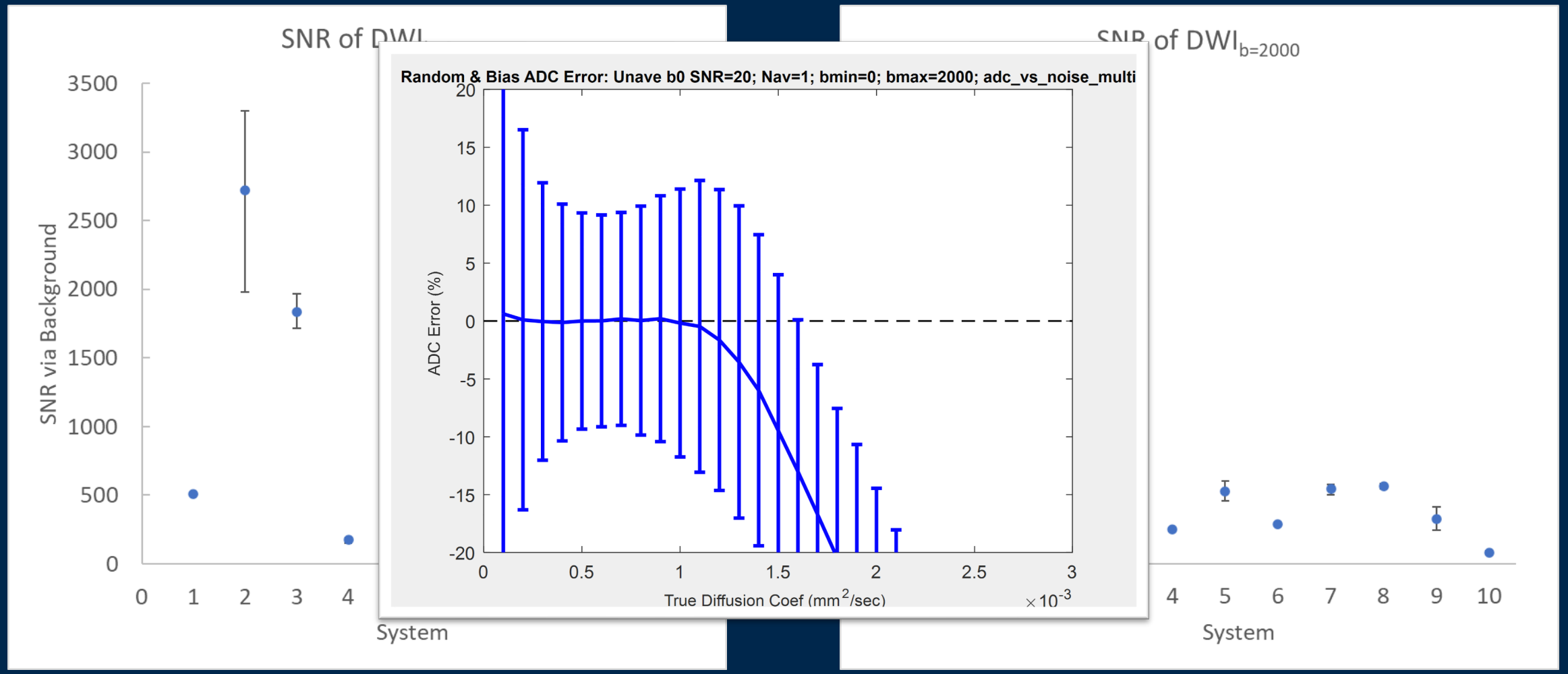
$$M = \frac{[scan_1 + scan_2]}{2};\ D = [scan_1 - scan_2]$$

$$SNR_{ROI} = \sqrt{2}\,\frac{ROI\ Mean\ (M)}{ROI\ Stdev\ (D)}$$

- Identical receiver gain confirmed on only 3 of 10 systems
- Background noise method: estimate noise from background (slice1)

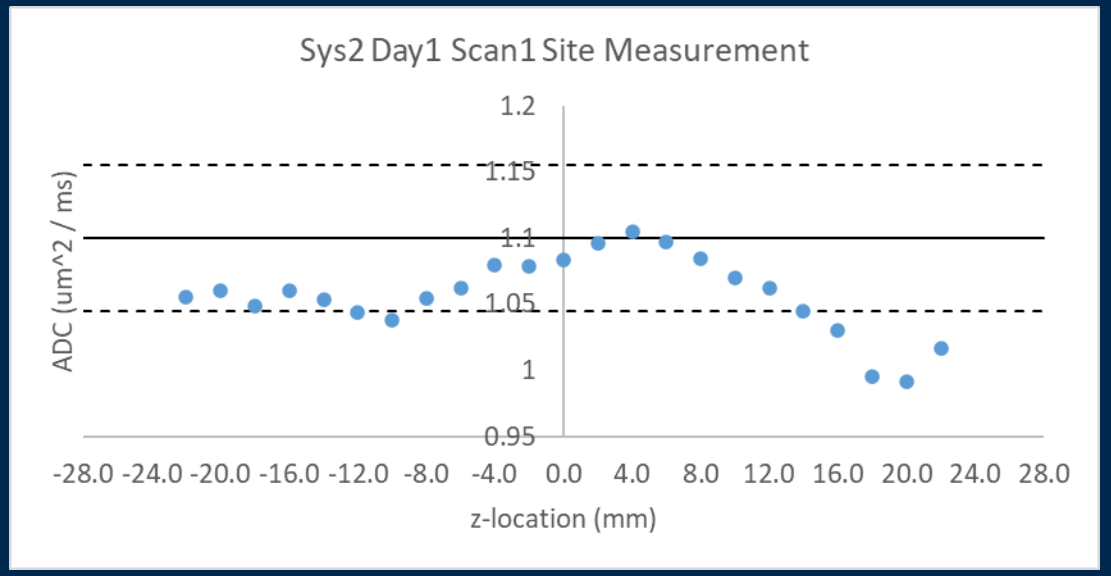
$$SNR_{ROI} = \sqrt{(2 - \frac{\pi}{2})}\,\frac{ROI\ Mean\ (scan_i)}{Stdev\ (background_i)}$$

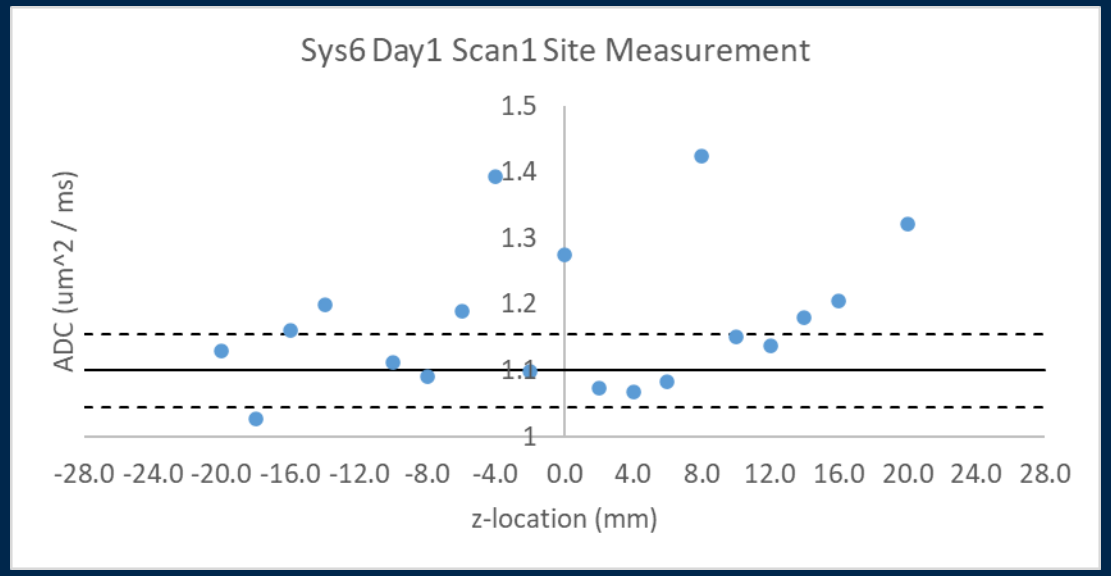
System SNR Estimation

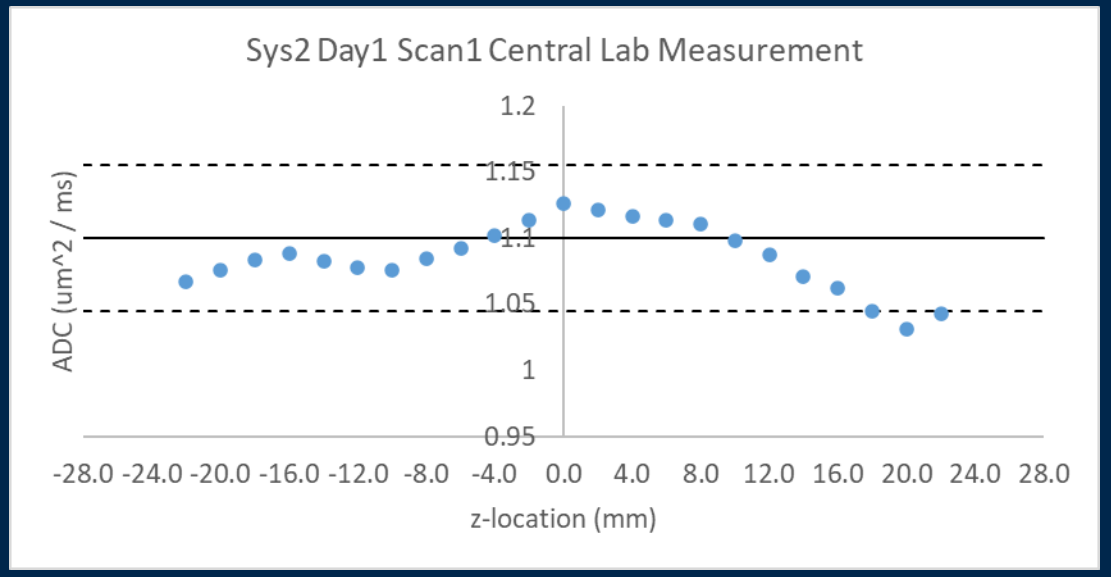


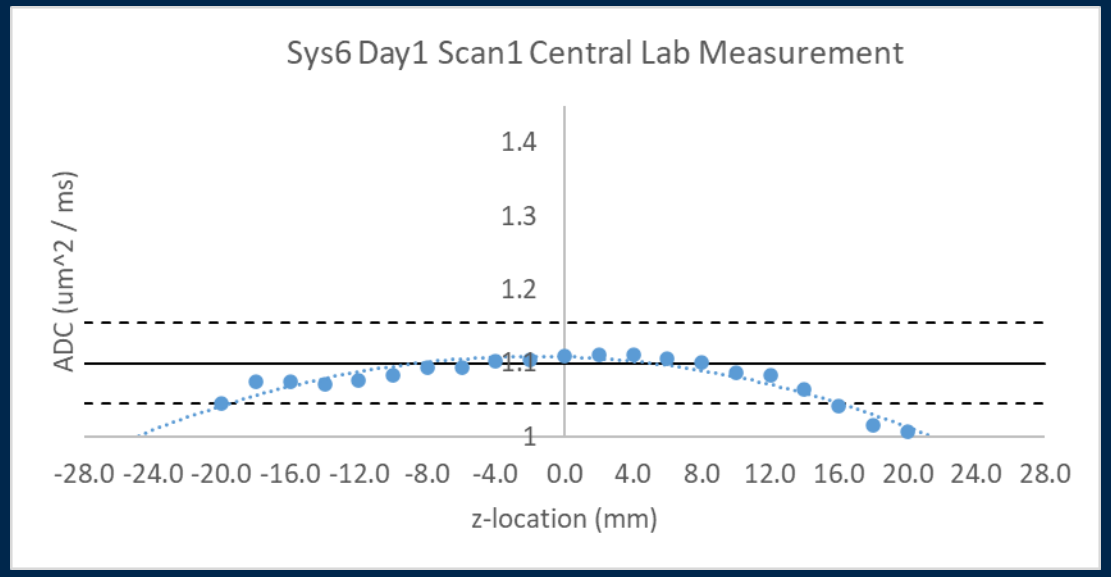
- Based on estimated SNR & simulations, noise should not contribute to bias on any of these systems (iso-center ± 15mm)

Site vs Central Lab ADC Measurement









Summary & Conclusions

- Main objectives met
- ADC reproducibility, repeatability *AND* bias of pre-clinical MRIs is comparable to clinical MRIs at isocenter – two outlier systems identified: ave bias < 5% at isocenter; excl outliers ave bias < 2%
- Increased bias and poorer reproducibility / repeatability with distance from isocenter
- SNR estimates indicate noise is not a contributor to bias
- Spatial pattern of bias is consistent with gradient non-linearity
- Sources of site- vs central-lab ADC measurement discrepancies:
  - ADC fit routine
  - improper interpretation of DICOM intensity scaling

Thank You!