System QC Tool for Analysis of PVP DWI Phantom at Ice-Water and Ambient Temperatures

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Disclosure: TLC is co-Inventor of technology IP assigned to and managed by the University of Michigan. The IP is unrelated to content of this presentation

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QC Tool = Physical Phantom “+” Analysis SW

https://umu24cirp.med.umich.edu/research/resources

“UM qDWI QC Tool” for quantitative DWI (ADC)

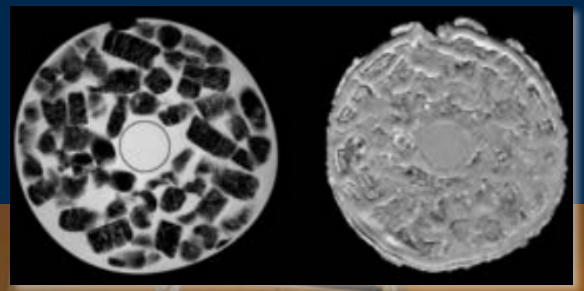
qDWI QC Tool Uses:

- Validate system performance relative to peers
- Site/system qualification for multisite trials
- Acquisition protocol design
- Periodic QA/QC, troubleshooting

DWI Phantoms Background

- Icewater-based platform proposed ~ISMRM 2008
  - Solved temperature control problem
  - Water at $0^{o}C$ = $1.1x10^{-3}$ mm^2/s is tissue-like & *absolute!*
  - Safe & economical
- Designed, built & delivered >100 phantoms for trials:
  - Breast: ACRIN 6698 & ACRIN 6702
  - Brain: NRG-BN001; PBTC; SVR III
  - Prostate ACRIN 6701




Key DWI System Performance Metrics Evaluated

- ADC bias measured at high precision (~1%)
- Random error
- b-value dependence
- Spatial dependence
- Estimate of DWI SNR (or stability) vs b-value
- Conformance to trial protocol

qDWI QC Workflow (Matlab)

Siemens DWI DICOM

GE DWI DICOM

Philips DWI DICOM

Study Protocol

"Build" Module

Exam catalogue for DWI identification

Uniform data structures for:

- Site / System Demographics
- Key acquisition parameters
- DWI each b-value
- ADC maps each b-pair and all b-values
- Multiple "Passes" for SNR grouped in "Sets"
- Protocol compliance report

Study/Phantom-Specific "Process/QC" Module

Semi-automated ROIs defined:

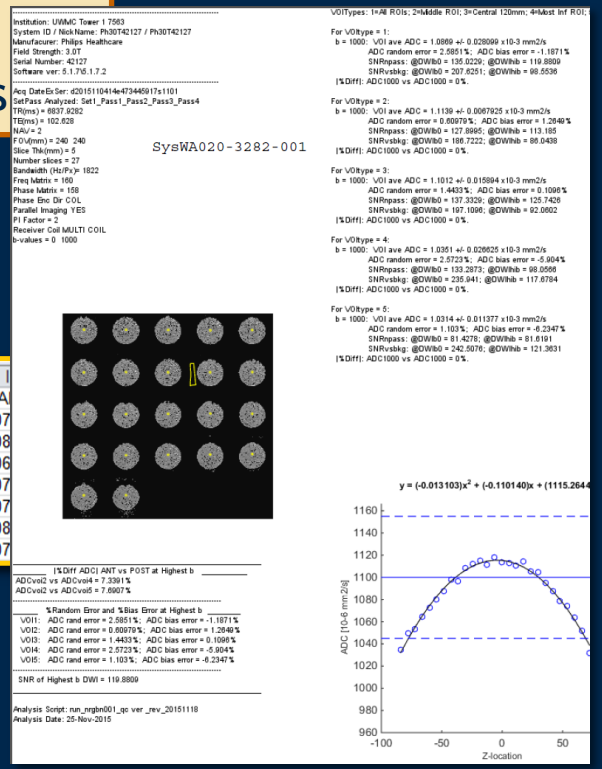
ROIs applied to all DWI & ADC maps

Uniform output structures of ROI statistics

PDF montage of ROIs on all slices

Output in PDF report(s) and CSV tables

	A	B	C	D	E	F	G	H	I
1	ROI#	X(lab)	Y(lab)	Z(lab)	npts(DWI)b0	snr(DWI)b0	nptsAllb	mean(ADC)allb	rerror(A
2	1	-1.5524	-14.882	-72	87	265.71	87	1.0456	0.007
3	2	-0.85079	-13.479	-66	89	216.43	89	1.0667	0.008
4	3	-0.85079	-12.777	-60	88	241.53	88	1.057	0.006
5	4	-0.14921	-10.673	-54	89	235.63	89	1.0815	0.007
6	5	-1.5524	-10.673	-48	87	260.7	87	1.0744	0.007
7	6	-0.85079	-9.9712	-42	88	236.94	88	1.0929	0.008
8	7	-0.85079	-7.8665	-36	89	263.88	89	1.0855	0.007

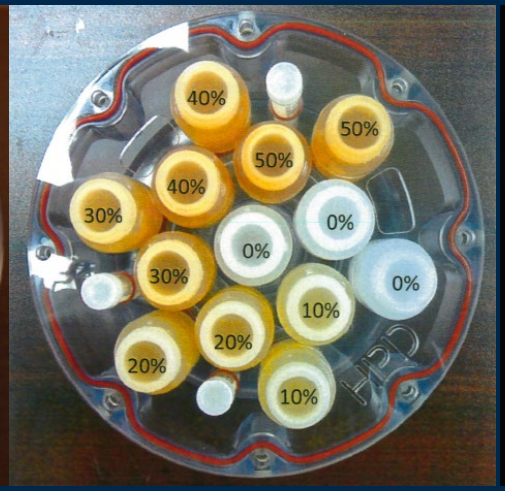


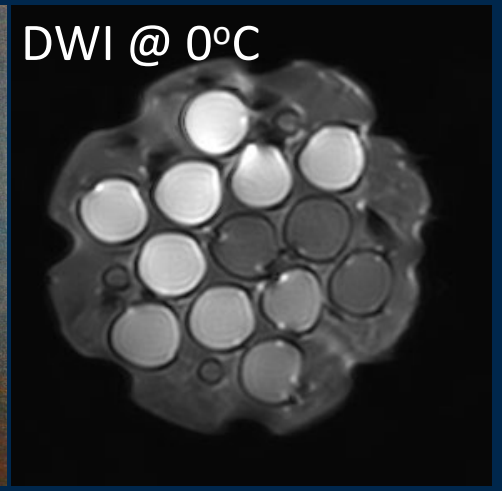
Polyvinylpyrrolidone§ (PVP) DWI Phantom

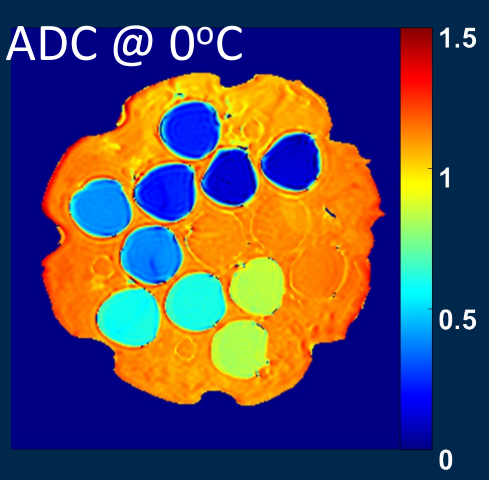
§ Pierpaoli C, et al Proc ISMRM 2009; 1414.

- Diffusion tunable by PVP concentration
- Mono-exponential decay with b-value
- PVP is non-toxic & stable
- QIBA/NIST development of PVP DWI phantom led by M Boss
- Commercially available from CaliberMRI (qmri.com)

Quantitative Imaging Biomarkers Alliance RSNA







CALIBER MRI

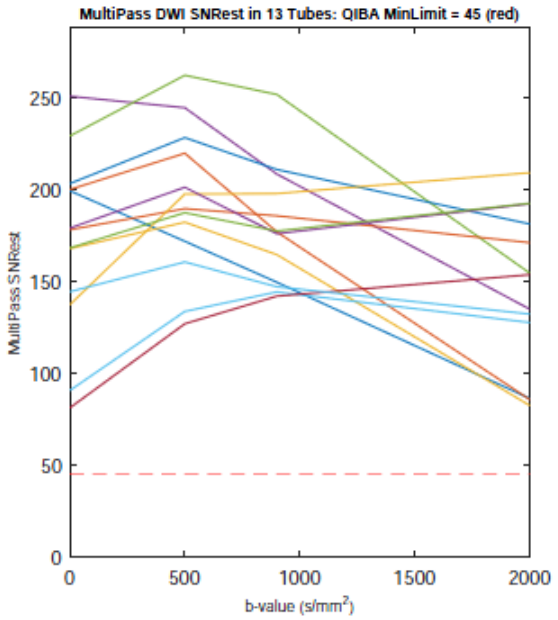
Systems Performance via UM qDWI QC Analysis of QIBA/NIST PVP Phantom

Vendor A - 3T

-SIGNALnNOISE

Slice Thk(mm) = 4; No. Slices = 25
Bandwidth (Hz/Px) = 1953.12
AcqFreq Mx = 128; AcqPhase Mx = 128
Phase Enc Dir: COL
Parallel Imaging: YES; PI Factor = 2
Receiver Coil: 8HRBRAIN
b-values = 0 500 900 2000
---------- *** Central Tube Allb-Fit ADC Results: *** ----------
Bias (%) = 0.95 %
TemporalRandomError (%) = 0.54 %
Spatial NonUniformity (%) = 0.79 %
b-value Dependence (%) = 0.46 %
wSigma (um2/ms) = 0.00069 um2/ms
wCV (%) = 0.06 %
RC (um2/ms) = 0.00191 um2/ms
Low-b DWI SNR via MultiPass = 200; via bkgnd = 22080
High-b DWI SNR via MultiPass = 86; via bkgnd = 2550

QC Script: run-PVP-qc-20210331; Date: 13-Sep-2021

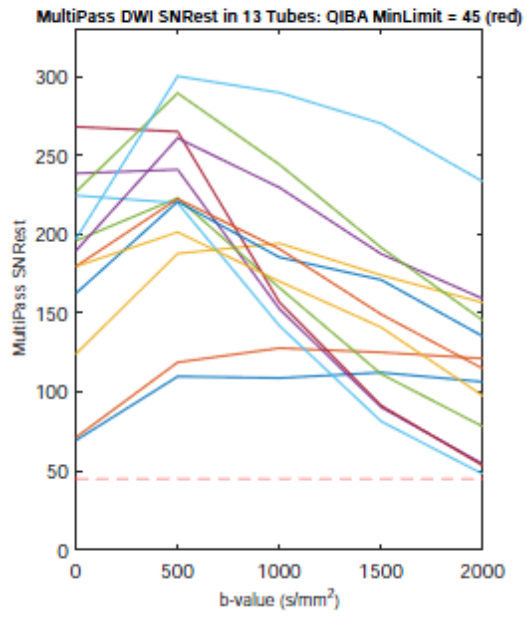


Vendor B - 3T

iGNALnNOISE

Slice Thk(mm) = 4; No. Slices = 25
Bandwidth (Hz/Px) = 1202
AcqFreq Mx = 130; AcqPhase Mx = 130
Phase Enc Dir: COL
Parallel Imaging: YES; PI Factor = 2
Receiver Coil: C:HEA;HEP
b-values = 0 500 1000 1500 2000
---------- *** Central Tube Allb-Fit ADC Results: *** ----------
Bias (%) = 0.51 %
TemporalRandomError (%) = 0.73 %
Spatial NonUniformity (%) = 0.51 %
b-value Dependence (%) = 0.29 %
wSigma(um2/ms) = 0.00036 um2/ms
wCV (%) = 0.03 %
RC (um2/ms) = 0.00101 um2/ms
Low-b DWI SNR via MultiPass = 268; via bkgnd = 1073
High-b DWI SNR via MultiPass = 53; via bkgnd = 247

QC Script: run-PVP-qc-20210331; Date: 31-Mar-2021

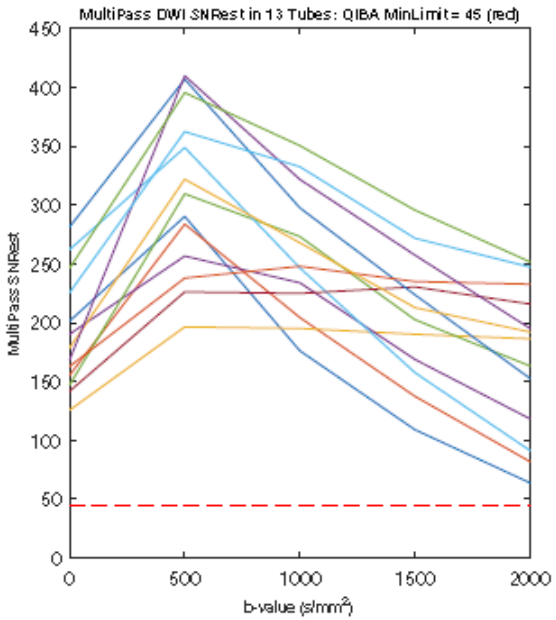


Vendor C - 3T

nNOISE

Slice Thk(mm) = 4; No. Slices = 25
Bandwidth (Hz/Px) = 1561
AcqFreq Mx = 128; AcqPhase Mx = 130
Phase Enc Dir: COL
Parallel Imaging: YES; PI Factor = 2
Receiver Coil: MULTICOIL
b-values = 0 500 1000 1500 2000
---------- *** Central Tube Allb-Fit ADC Results: *** ----------
Bias (%) = 0.97 %
Temporal Random Error (%) = 0.63 %
Spatial Non Uniformity (%) = 0.95 %
b-value Dependence (%) = 2.11 %
wSigma (um2/ms) = 0.00083 um2/ms
wCV (%) = 0.07 %
RC (um2/ms) = 0.00229 um2/ms
Low-b DWI SNR via MultiPass = 201; via bkgnd = 1212
High-b DWI SNR via MultiPass = 64; via bkgnd = 192

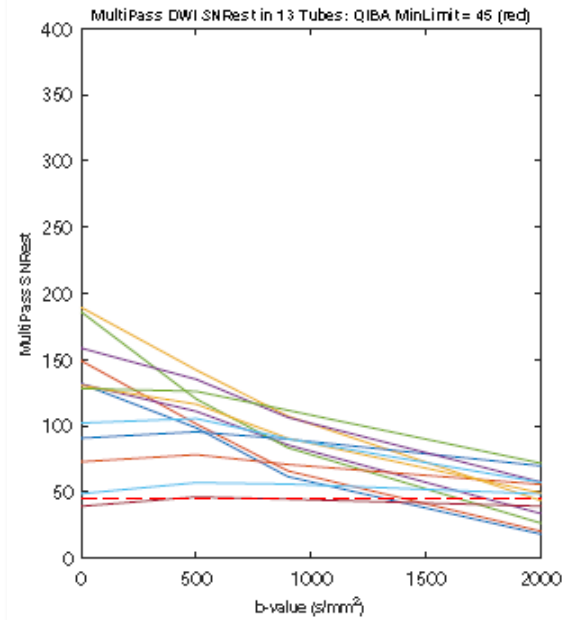
QC Script: run-PVP-qc-20210331; Date: 31-Mar-2021

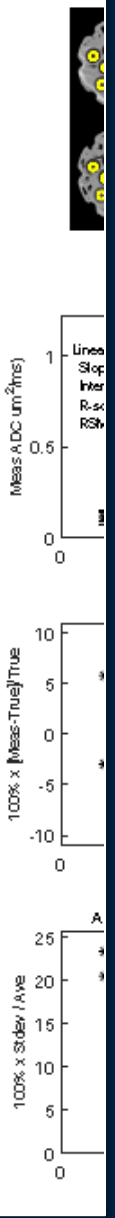


Vendor C - 1.5T

Slice Thk(mm) = 4; No. Slices = 25
Bandwidth (Hz/Px) = 1534
AcqFreq Mx = 128; AcqPhase Mx = 126
Phase Enc Dir: COL
Parallel Imaging: YES; PI Factor = 2
Receiver Coil: SENSE_HEAD_8
b-values = 0 500 900 2000
---------- *** Central Tube Allb-Fit ADC Results: *** ----------
Bias (%) = 0.73 %
Temporal Random Error (%) = 2.67 %
Spatial Non Uniformity (%) = 1.66 %
b-value Dependence (%) = 0.85 %
wSigma (um2/ms) = 0.00249 um2/ms
wCV (%) = 0.22 %
RC (um2/ms) = 0.0069 um2/ms
Low-b DWI SNR via MultiPass = 132; via bkgnd = 2067
High-b DWI SNR via MultiPass = 18; via bkgnd = 1361

QC Script: run-PVP-qc-20210331; Date: 27-Apr-2021



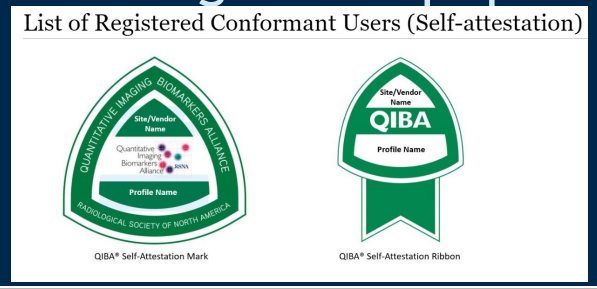


QIBA DWI Profile

https://qibawiki.rsna.org/index.php/Profiles

- QIBA DWI Profile Key Element: numerical claims regarding significance level of ADC change in brain, breast, liver & prostate
- MRI scanner assessment procedures & performance specs to meet QIBA claims were based on UM qDWI QC Tool analysis of icewater phantom or QIBA/NIST phantom (central vial) at 0°C (https://qibawiki.rsna.org/index.php/QIBA_Profile_Conformance)
- QIBA DWI Profile Conformance Attestation

  (https://qibawiki.rsna.org/index.php/List_of_Registered_Conformant_Users)


List of Registered Conformant Users (Self-attestation)

QIBA® Self-Attestation Mark

QIBA® Self-Attestation Ribbon

International Multi-Site Clinical Trials
CROs/Central-Managing-Labs

QIBA/NIST PVP phantom @ 0°C

Imaging Site/Vendor/CRO	QIBA Profile	Conformance Term
Invicro Imaging Center London	ADC Change Profile (ver2019)	April 8, 2020 - April 7, 2022
Liverpool Hospital, SWS Australia	ADC Change Profile (ver2019)	April 1, 2021 - April 1, 2023
Hospital Israelita Albert Einstein, Sao Paulo, Brazil	ADC Change Profile (ver2019)	April 1, 2020 – April 1, 2022
New York-Presbyterian/Weill Cornell Medical Center	ADC Change Profile (ver2019)	April 1, 2021 – April 1, 2023

For Wider Adoption of qDWI QC Process

- Feedback: … “feasible but too complicated for average site / user”
- Desire professional-grade QC solution to support clinical trials
  - Sustainable
  - Responsive
  - High-volume

- QIBA / CaliberMRI Collaboration

Goal: Validate qCal sw on shared datasets of QIBA/NIST phantom at 0°C

Quantitative Imaging Biomarkers Alliance RSNA

UM qDWI QC Tool

≅

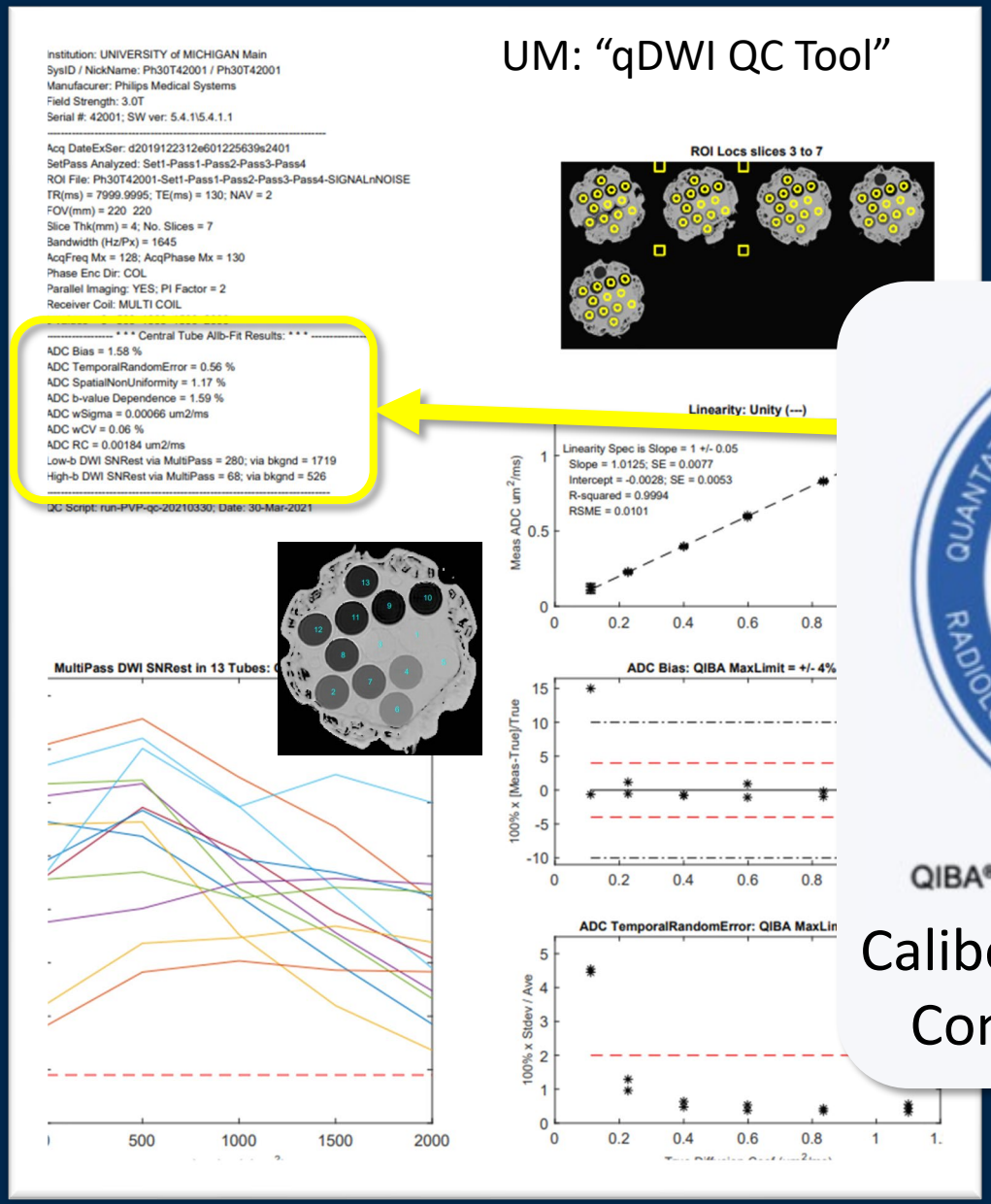
CALIBER MRI

qCal

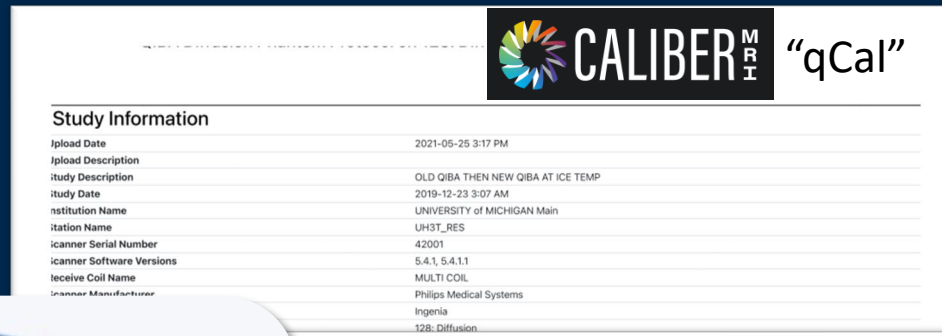
Technical Validation of CaliberMRI qCal SW @ 0°C

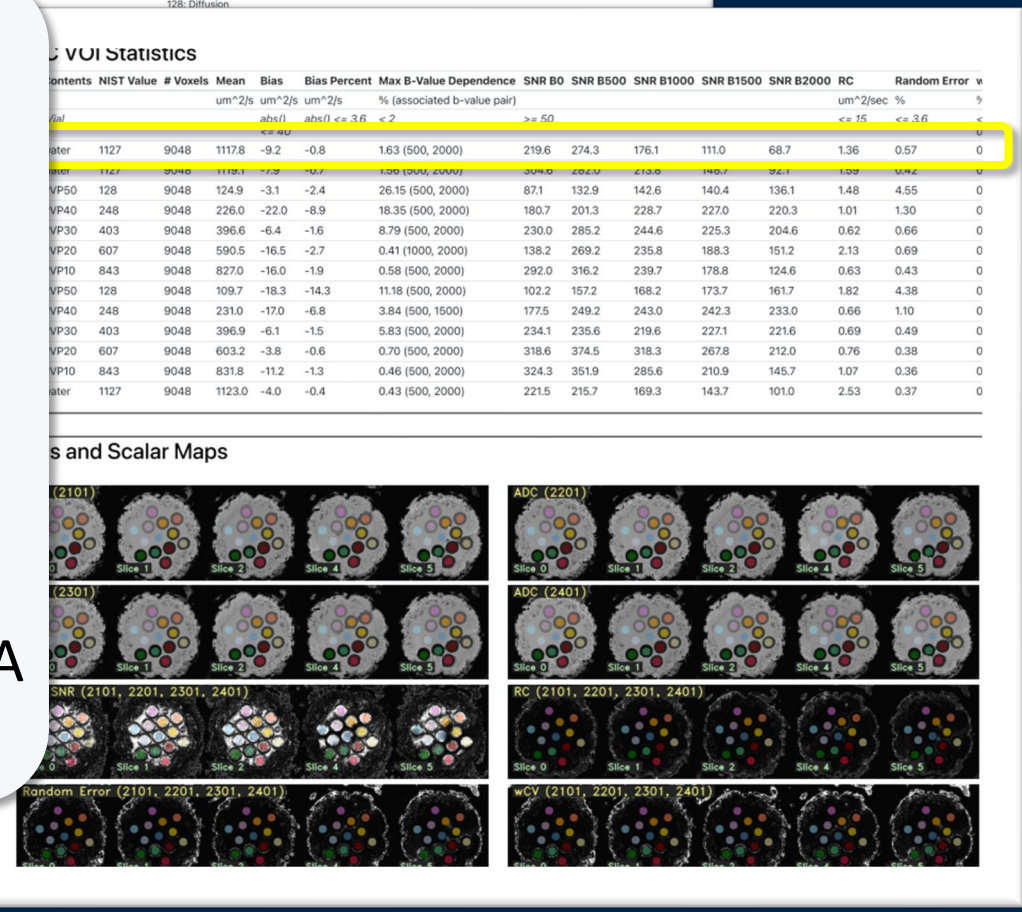
Quantitative Agreement UM qDWI Tool & CaliberMRI qCal Demonstrated

UM: “qDWI QC Tool”



“qCal”





QIBA® Conformance Certification Mark

CaliberMRI qCal for QIBA Conformance Testing

UM qDWI Tool Extended to Ambient Temperatures

https://umu24cirp.med.umich.edu/research/resources

Amouzandeh, G., et al., *Technical note: Temperature and concentration dependence of water diffusion in polyvinylpyrrolidone solutions.* Med Phys, 2022. **49**(5): p. 3325-3332.

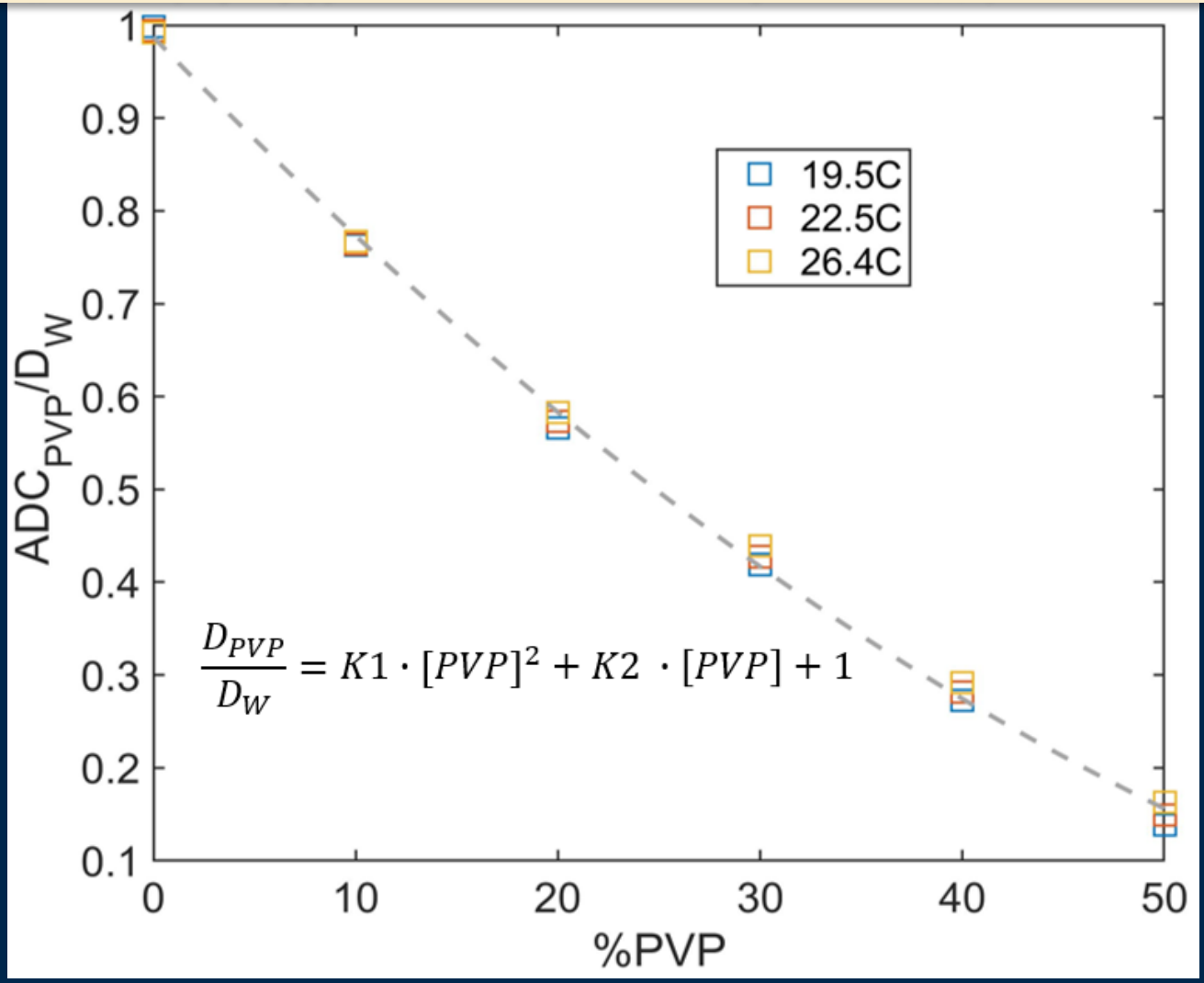
Process:

- Calibration values of ADC_{PVP} at discrete temperatures
- Normalized by D_{water} via Speedy-Angell model (J Chem Phys. 1976;65(3):851-858)

⇒Quadratic function wrt [PVP]

- Fit constants used to predict ADC_{PVP} at arbitrary [PVP] and room temperatures

❖ *Must measure internal phantom temperature at scantime !!!*



UM qDWI Tool Applied to QIBA/NIST Phantom at Ambient Temperatures

In Matlab:

>> *run_PVP_qc;*

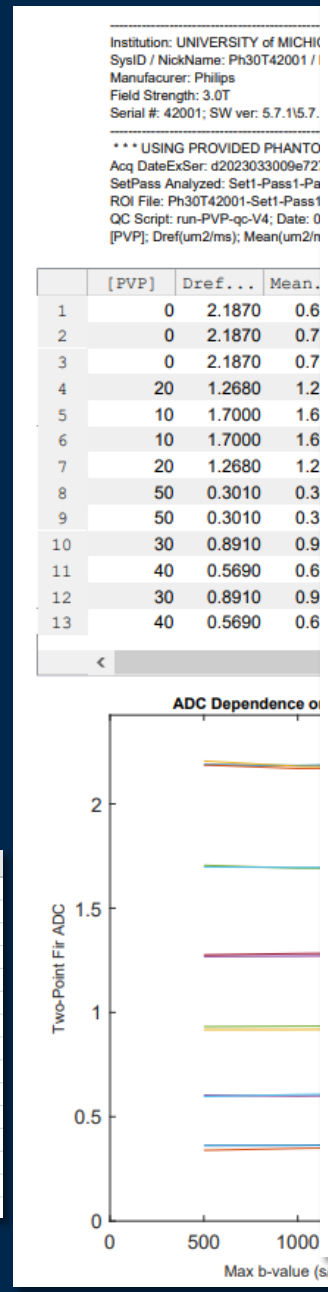
Select output from "build module"

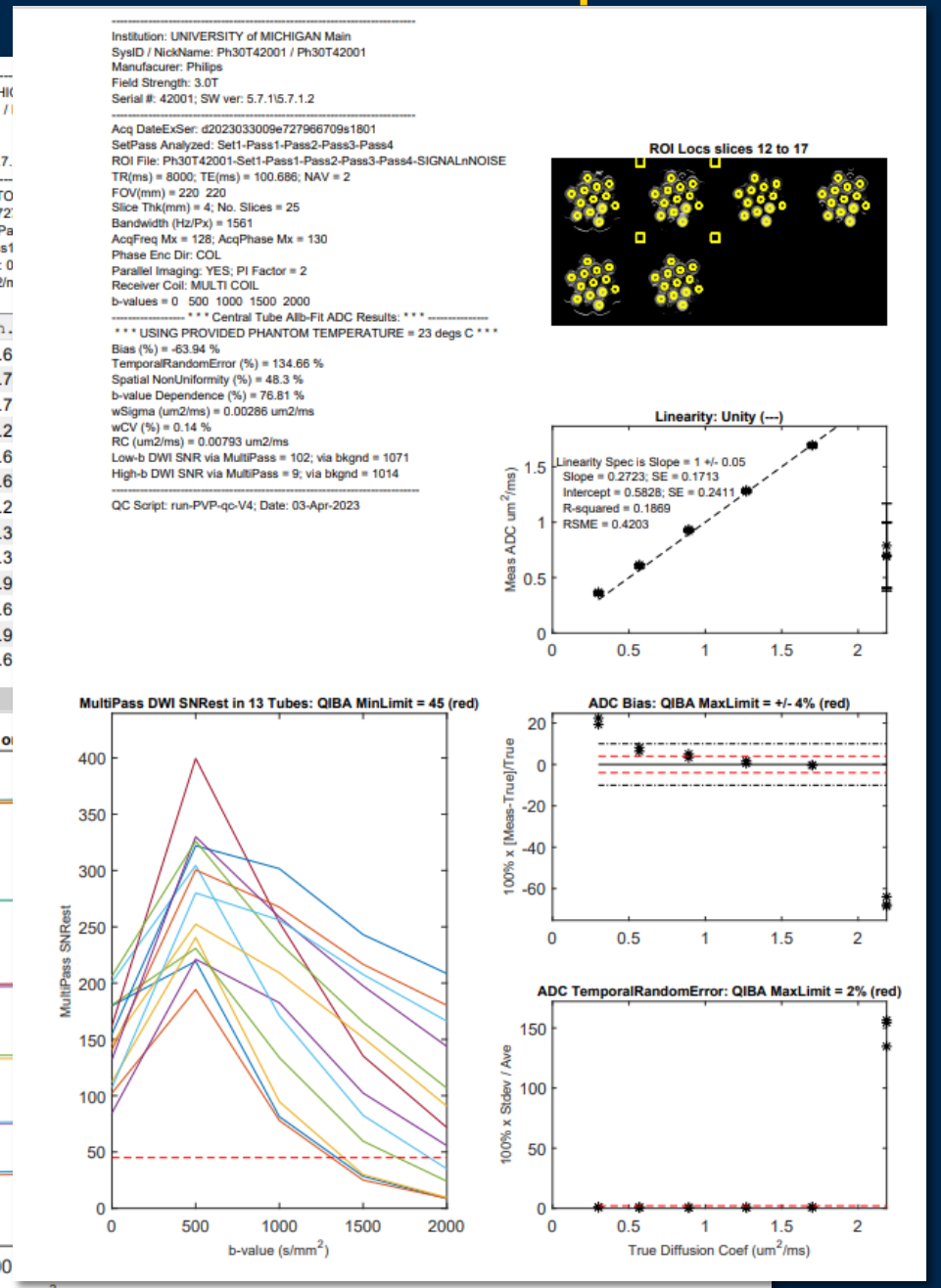
Enter Phantom Temperature (ºC)

Enter Desired Slice Range

- ROIs → VOIs automatically defined
- PDF Reports and CSV table created

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	[PVP]	Dref(um2/r	Mean(um2	TmpRandE	SpNonUnif	Bias(%)	wSigma(ur	wCV(%)	RC(um2/m	SNRb0	SNRb500	SNRb1000	SNRb1500	SNRb2000
2	0	2.187	0.689	156.48	44.73	-68.48	0.0029	0.14	0.00804	180	219	81	28	9
3	0	2.187	0.789	134.66	48.3	-63.94	0.00286	0.14	0.00793	102	194	78	25	9
4	0	2.187	0.703	154.48	41.96	-67.84	0.00449	0.21	0.01244	112	240	95	30	10
5	20	1.268	1.275	0.76	0.77	0.55	0.00235	0.18	0.00652	85	221	182	102	56
6	10	1.7	1.692	1.03	1.09	-0.48	0.00169	0.1	0.00469	181	231	134	60	24
7	10	1.7	1.696	0.7	0.54	-0.24	0.00147	0.09	0.00406	201	304	171	83	35
8	20	1.268	1.289	0.51	0.55	1.66	0.00112	0.09	0.00309	162	400	254	135	72
9	50	0.301	0.368	0.88	2.8	22.42	0.00129	0.35	0.00358	155	322	302	243	208
10	50	0.301	0.359	1.03	4.49	19.34	0.00113	0.31	0.00312	141	301	267	217	180
11	30	0.891	0.921	0.62	0.83	3.37	0.00156	0.17	0.00433	146	252	209	152	91
12	40	0.569	0.605	0.73	2.88	6.4	0.00106	0.18	0.00293	132	330	259	198	144
13	30	0.891	0.936	0.49	0.6	5.06	0.00139	0.15	0.00386	206	326	236	165	107
14	40	0.569	0.615	0.72	1.43	8.23	0.00084	0.14	0.00233	107	280	256	208	166
15														





Summary: qDWI QC Tools (phantom + analysis)

- Successfully applied in support of multiple clinical trials
- Aided design of QIBA DWI profile conformance procedures
- Applied to QIBA/NIST PVP phantom & to validate commercial CaliberMRI qCal for phantom at 0°C
- Extended for QIBA/NIST PVP phantom at *(measured)* room temperature
- QIBA conformance specs at room temperature are pending
- FYI: New CaliberMRI PVP phantoms have built-in MR-visible thermometer

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