IMAGING RESEARCH LABORATORY
UNIVERSITY of WASHINGTON
Department of Radiology

Quantitative Imaging Biomarkers Alliance RSNA

PET/CT Digital Reference Object

Paul Kinahan, Larry Pierce, Brain Elston, *University of Washington*
David Clunie, *Corelab Partners*
Dennis Nelson, *MiMVista*

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Problem statement

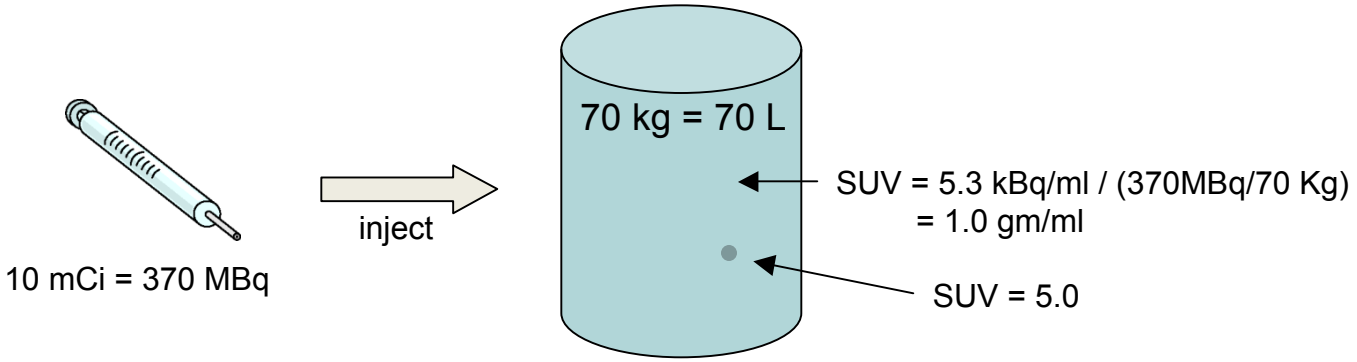
- When we use PET image analysis software
  - Is it reporting the values we expect it to?
  - How accurate are the reported values?
- Two main components to the calculation
  - What DICOM fields and formulas are used to calculate standardized uptake value (SUV)?
  - How is the ROI defined and what combination of voxels are used?

Standardized uptake value (SUV) - concept

- Normalize by amounts injected per volume (i.e. weight)
- Is a relative distribution with SUV = 1 for a uniform distribution

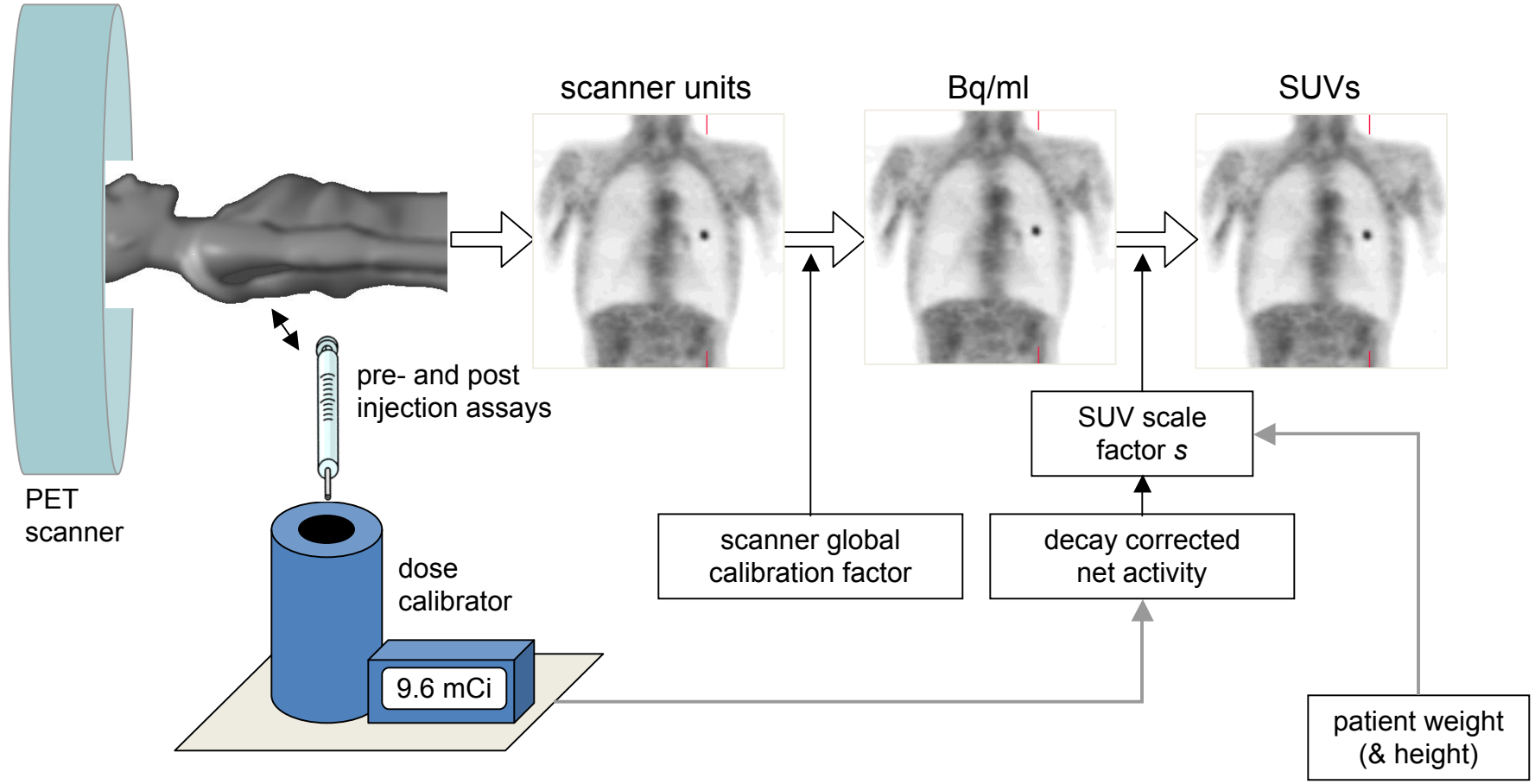
$$\mathrm{SUV} = \frac{\mathrm{PET}_{\mathrm{ROI}}}{D'_{\mathrm{INJ}} / V'}$$

PET = measured PET activity concentration
D′ = decay-corrected injected dose
V′ = surrogate for volume of distribution



A hot spot with 5x background uptake has the same SUV uptake values, independent of activity injected or volume of distribution (i.e. patient size)

SUV calculation chain for PET



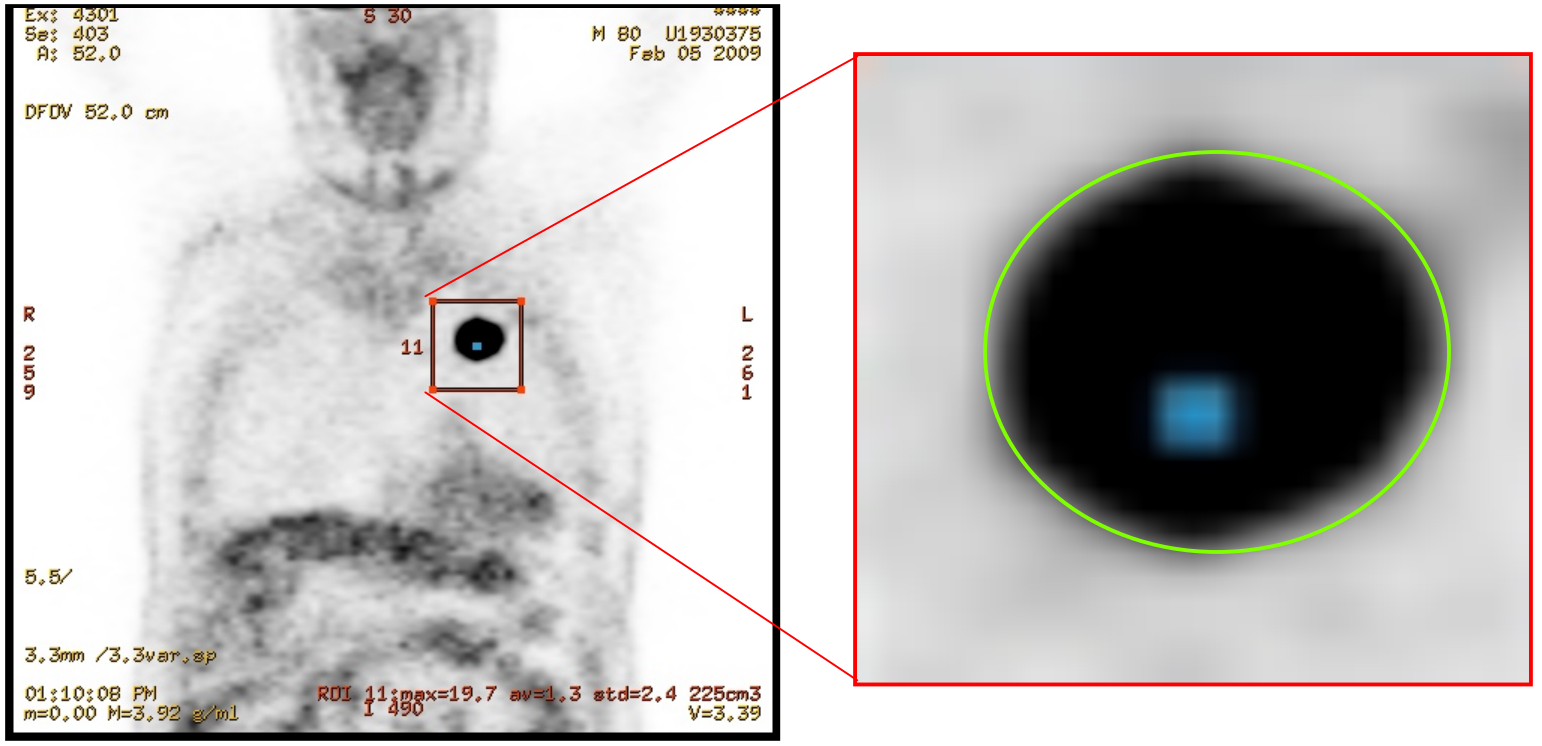
Standardized uptake value (SUV) - practice

- If the DICOM image meets <u>all</u> of the following
  - attenuation corrected (ATTN in DICOM field *Corrected Image* (0028,0051))
  - decay corrected (DECY in (0028,0051))
  - decay correction (0054,1102) is START
  - UNITS (0054,1001) are BQML (i.e Bq/ml)
- Then the SUV_{bw} scale factor, *s*, is given by

$$s = 1000 \cdot W \cdot A_1 \cdot 2\exp\left(\left(T_{1S} - T_i\right)/T_{1/2}^{18F}\right)$$

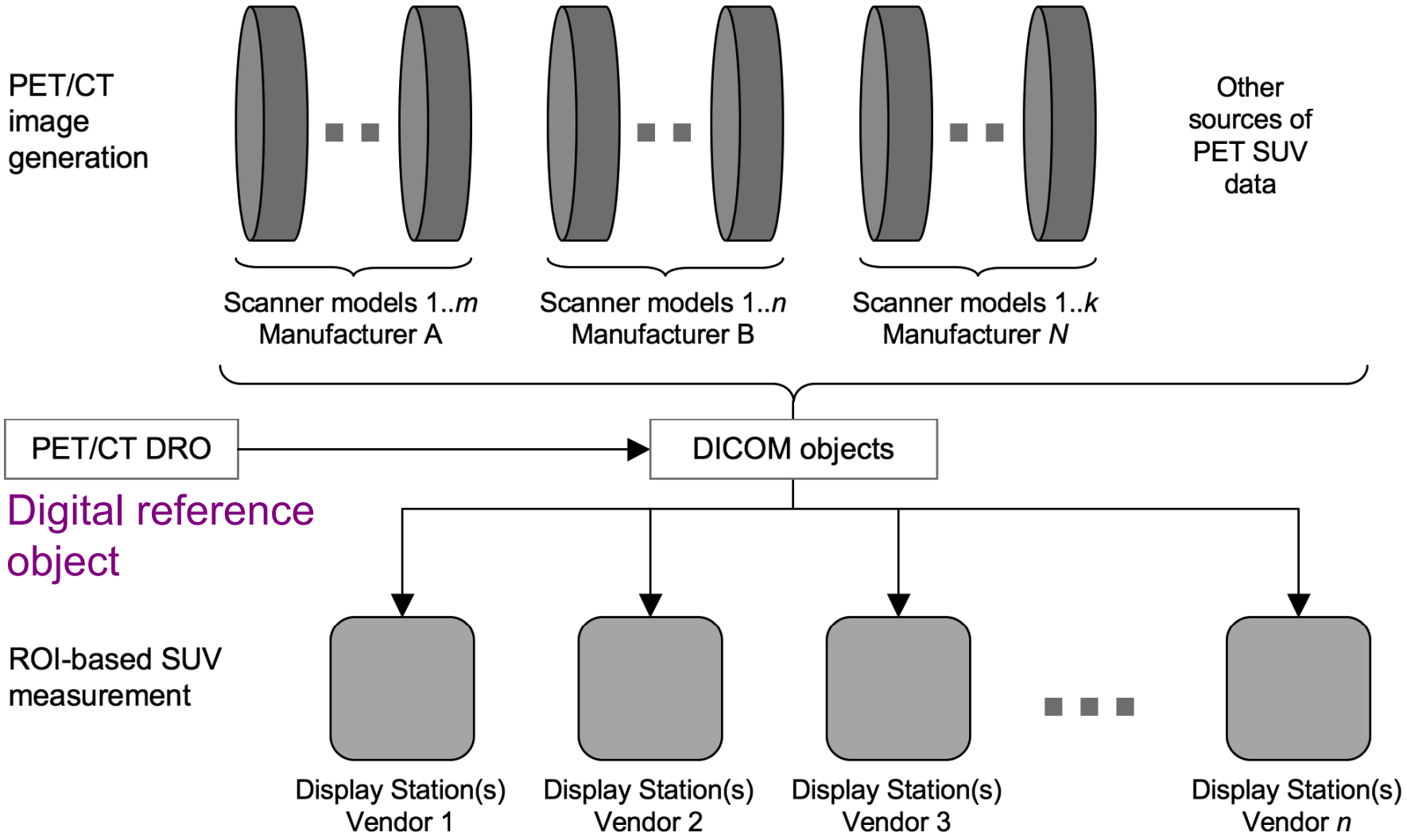
Variable	Symbol	DICOM field
Injection Time	T_i	(0054,0016)\(0018,1072)
Reference Time	T_R	
Injected Dose	A_i	(0054,0016)\(0018,1074)
^{18}F half life	$T_{1/2}^{18F}$	(0054,0016)\(0018,1075)
Patient's Weight	W	(0010,1030)

ROI analysis



- What pixels (or fraction) are included?
- Are the correct values reported?

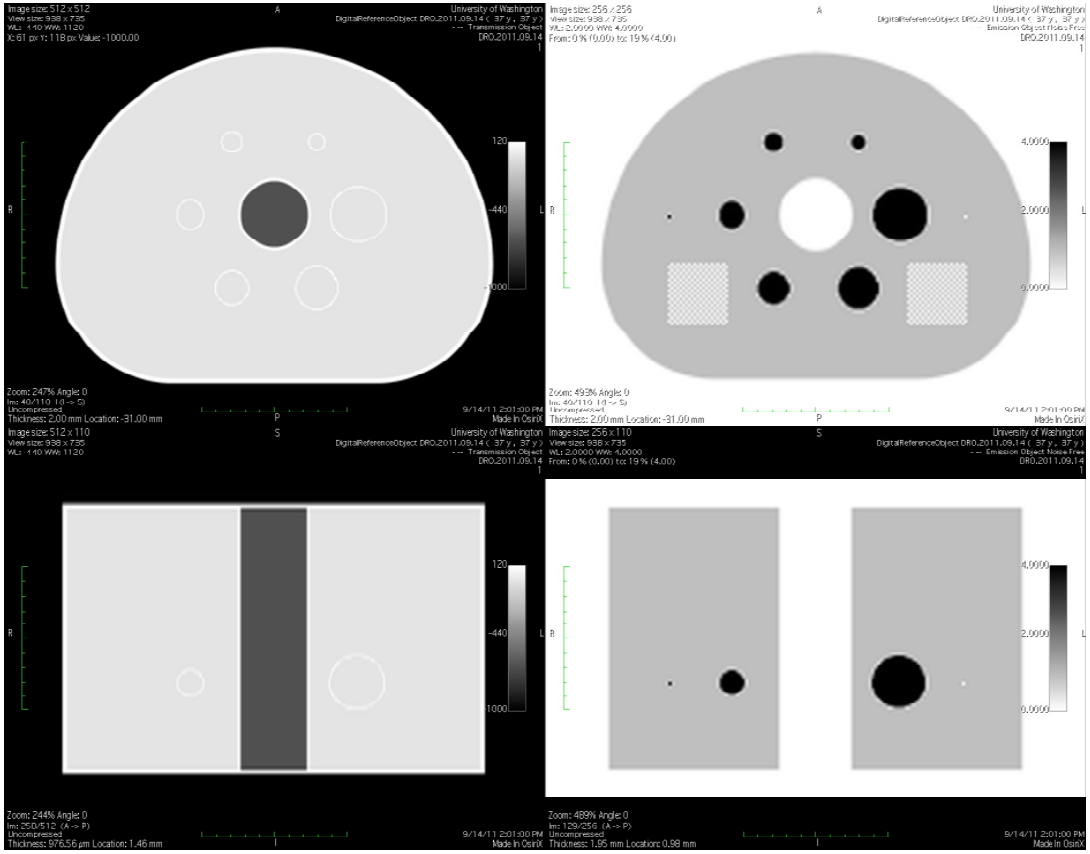
Data flow for DICOM PET/CT images



Digital reference object (DRO) specifications

- Based on the NEMA / MITA Image Quality phantom
  - PET and CT sets of DICOM images generated from scratch using dcmtk
  - DICOM fields populated with values appropriate for SUV calculations

CT (transmission) PET (emission)

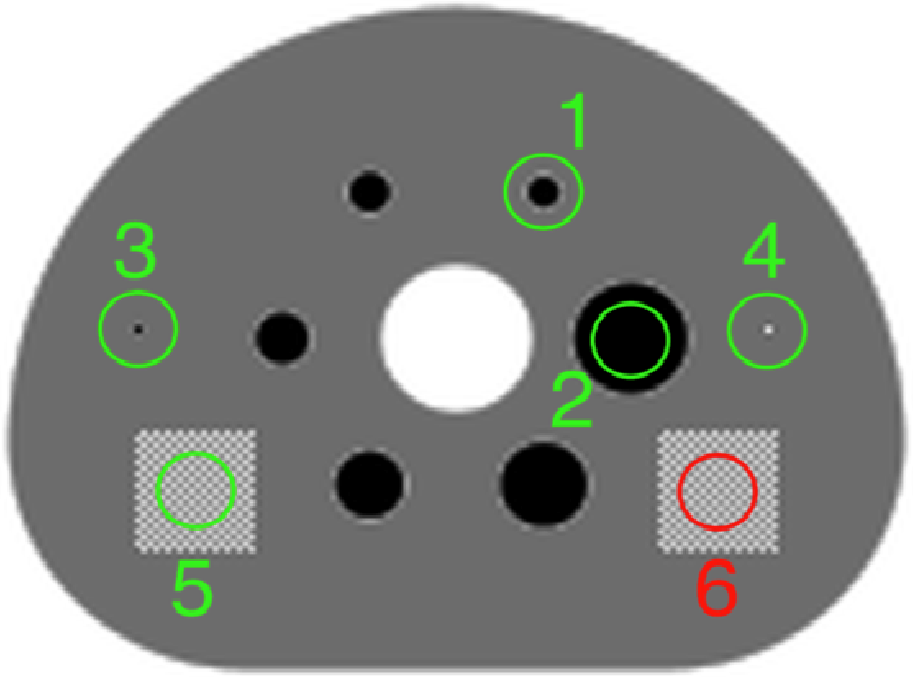


Can be generated with smoothing and/or noise

DRO Test Regions

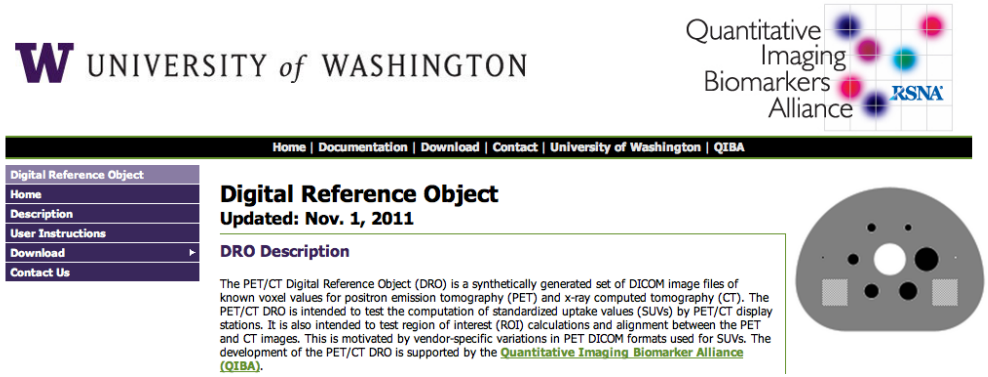
- SUV values in general are either 0, 1.0, or 4.0, except
  - A single voxel in ROI 3 is set to 4.11
  - A single voxel in ROI 4 is set to -0.11
  - A checkerboard pattern is used to provide a deterministic test for calculation of the standard deviation in 2D (ROI 5) and 3D ROI6)

ROIs 1-6 used for reporting values



DRO Analysis

- Download from depts.washington.edu/petctdro/
- Load into PET display / analysis system
- Perform ROI measurements
- Report values (or not)



ROI	Max	Min	Mean	STD	Diam or Area
ROI 1					
ROI 2					
ROI 3					
ROI 4					
ROI 5					
ROI 6					

Display systems tested

	Vendor	Platform	Version
1	GE	AW Volume Viewer	4.6
2	GE	Dynamic VUE	PDR_1.04-5c
3	GE	Volume Viewer	9.3.23
4	GE	Xeleris	1.1452
5	Hermes	Hermes Hybrid Viewer	PDR v 1.4C
6	Keosys	Keosys	N/A
7	MedImage	MedView	11.6.3
8	MedImage	MedView	12.0.3
9	MIM	MIM Software	5.1 (Build AC-18-00)
10	MIM	MIM Software	4.1.3 Patch D
11	MIM	MIM Software	5.3.0
12	MIM	MIM Software	5.4.2
13	OsiriX	OsiriX	v 4.0
14	Philips	EBW Fusion Viewer	V4.5.2.6032
15	Philips	EBW Fusion Viewer	V4.5.3.40140
16	Philips	EBW Fusion Viewer	V4.0.2.145
17	PMOD	PMOD	3.208
18	Segami	Oasis	1.9.2HF4
19	Siemens	syngo.via MMonco	VA11
20	Siemens	syngo MI	VA60A

Results: 13 sites, 20 different display systems

blue = okay, **yellow** = ?, **pink** = borderline, **red** = wrong

different sites/systems

results for each of the 6 ROIs

ROI Information																
SUV Type (BW, LBM, BSA)	BW	BW	BW	BW	BW	BW	LBM	BW	BW	BW	BW	BW	?	BW	BW	BW
Decimal places reported	1	1	3	2	1	1		maximimum	1	2	2	6	6 to 8	6	1 decimal Pla	2
ROI type (2D, 3D)	3D	2D	2D	2D	2D	2D (ROIs 1-5	3D	2D Circle SUV	2D	2D	2D	2D & 3D	2D	2D	2D	3D
ROI Area or Diameter?	Diameter	area	Diameter	Area	Diameter	Area	22 mm	Diameter for	Diameter	diameter	Area	Volume	4.900146cm	DIAMETER	Area	AREA/VOLUM
ROI Measurements																
ROI 1 Max	4.0	4.0	4	4.00	4.0	4.0	4.0000095	4	4	4.00	4	4.000019	4	4	4.0	4.00
ROI 1 Min	0.5	0.5	0.52	0.52	0.5	0.5	0.5199092	0.52	0.5	0.52	0.52	0.519943	0.52	0.622	0.5	0.52
ROI 1 Mean	1.1	1.4	1.36	1.33	1.4	1.4	1.2212964	1.396	1.3	1.39	1.73	1.390698	1.341	1.296	1.4	1.36
ROI 1 STD			0.939	0.91	1.0	1.0	0.7435832	0.974	0.9	0.97	1.223	0.968925	0.917	0.847	N/A	0.93
ROI 1 Diam / Area	24mm diame	492.1 mm2 a	25 mm	4.82 cm^2	25.0	443.7 mm^2	22 mm	R = 12.3	25.0 mm	25	5.11cm	0.984192	4.900146cm	25mm	490 mm2	484
ROI 2 Max	4.0	4.0	4	4.00	4.0	4.0	4.0000095	4	4	4.00	4	4.000019	4	4	4.0	4.00
ROI 2 Min	0.6	4.0	4	4.00	4.0	4.0	4.0000095	4	4	4.00	4	4.000019	4	4	4.0	4.00
ROI 2 Mean	3.9	4.0	4	4.00	4.0	4.0	4.0000095	4	4	4.00	4	4.000019	4	4	4.0	4.00
ROI 2 STD			0	0.00	0.0	0.0	2.61E-07	0	0	nan	0	0	0	0	N/A	NaN
ROI 2 Diam / Area	24mm diame	492.1 mm2 a	25 mm	4.82 cm^2	25.0	443.7 mm^2	22 mm	R = 12.3	25.0 mm	25	4.95.91cm	0.991821	4.900146cm	"	490 mm2	493
ROI 3 Max	4.1	4.1	4.11	4.11	4.1	4.1	4.1099997	4.11	4.1	4.11	4.11	4.110001	4.11	2.555	4.1	4.11
ROI 3 Min	1.0	1.0	1	1.00	1.0	1.0	0.99998724	1	1	1.00	1	0.999922	1	0.999	1	1.00
ROI 3 Mean	1.0	1.0	1.021	1.02	1.0	1.0	1.0042257	1.024	1	1.02	1.02	1.023846	1.022	1.01	1	1.02
ROI 3 STD			0.256	0.25	0.3	0.3	0.11473396	0.275	0.3	0.28	0.27	0.271721	0.26	0.126	N/A	0.25
ROI 3 Diam / Area	24mm diame	492.1 mm2 a	25 mm	4.81 cm^2	25.0	443.7 mm^2	22 mm	R = 12.3	25.0 mm	25	5.04cm	0.991821	4.900146cm	"	490 mm2	497
ROI 4 Max	1.0	1.0	1	999.94 mSUV	1.0	1.0	0.99998724	1	1	1.00	1	0.999922	1	0.999	1	1.00
ROI 4 Min	0.0	0.0	-0.1	-109.88 mSU	1.0	1.0	-0.1098776	-0.11	-0.1	0.00	-0.11	-0.109877	-0.11	0.445	0	-0.11
ROI 4 Mean	1.0	1.0	0.992	992.44 mSUV	1.0	1.0	0.9984767	0.991	1	0.99	0.99	0.99145	0.992	0.996	1	0.99
ROI 4 STD			0.094	91.23 mSUVI	0.0	0.0	0.04091707	0.098	0.1	0.09	0.096	0.096593	0.092	0.044	N/A	0.09
ROI 4 Diam / Area	24mm diame	492.1 mm2 a	25 mm	4.82 cm^2	25.0	439.9 mm^2	22 mm	R = 12.3	25.0 mm	25	5.04cm	0.999451	4.900146cm	"	490 mm2	494
ROI 5 Max	1.0	0.9	0.9	899.97 mSUV	0.9	0.9	0.99998724	0.9	0.9	0.90	1	0.899985	0.9	0.95	0.9	0.90
ROI 5 Min	0.1	0.1	0.1	99.97 mSUVI	0.1	0.1	0.10000705	0.1	0.1	0.10	0.1	0.099977	0.1	0.549	0.1	0.10
ROI 5 Mean	1.0	0.5	0.5	492.02 mSUV	0.5	0.5	0.9307193	0.507	0.5	0.51	0.75	0.512289	0.492	0.75	0.5	0.50
ROI 5 STD			0.401	401.25 mSUV	0.4	0.4	0.22840944	0.4	0.4	0.40	0.378	0.399815	0.401	0.201	N/A	0.40
ROI 5 Diam / Area	24mm diame	492.1 mm2 a	25 mm	4.81 cm^2	25.0	443.7 mm^2	22 mm	R = 12.3	25.0 mm	25	4.888cm	0.991821	4.900146cm	"	490 mm2	484
ROI 6 Max	0.9	0.9	0.9	NA	0.9	0.9	0.8999599	0.9	0.9	0.90	0.9	0.89999	0.9	0.499	0.9	0.90
ROI 6 Min	0.1	0.1	0.1	NA	0.1	0.1	0.10000705	0.1	0.1	0.10	0.1	0.099977	0.1	0.499	0.1	0.10
ROI 6 Mean	0.5	0.5	0.5	NA	0.5	0.5	0.49820703	0.505	0.5	0.50	0.5	0.489707	0.5026	0.5	0.5	0.51
ROI 6 STD			0.53	NA	0.4	0.4	0.39997247	0.4	0.4	0.40	0.4	0.399874	0.4013	0	N/A	0.40
ROI 6 Diam / Area	24mm diame	492.1 mm2 a	25 mm	NA	25.0	5.52 cm^3	22 mm	25.0	25.0 mm	27	5.11cm	7.720947	1.7986cmA3	"	490 mm2	8360

Summary

- In general most (but not all) systems correctly calculated SUVmean and SUVmax
- There were increasing levels of problems with SUVmin, standard deviation and area
- There were anecdotal reports of software changes in response to tests performed with the PET/CT digital reference object (DRO)
- The PET/CT DRO is a useful method for testing the validity of PET SUV calculations

Thanks to the DRO Testing team and the QIBA FDG-PET Technical Committee

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