SOCIETY OF NUCLEAR MEDICINE AND MOLECULAR IMAGING
CLINICAL TRIALS NETWORK

PAT Uniform Phantom Analysis

The Uniform Phantom Analysis is meant to provide five distinct measures of scanner performance. These are relevant for daily clinical performance as well as qualifying a scanner for use in trials.

1. Scanner Quantitative Calibration Accuracy
2. Uniformity in the axial (across planes) direction
3. Uniformity in the radial (within planes) direction
4. Spatial resolution in the axial direction
5. Spatial resolution in the radial direction

Phantom Data Acquisition and Reconstruction

This phantom study is meant to quantify some of the most fundamental metrics associated with your PET scanner performance. To get accurate measures this test is meant to be performed using:

1. A lengthy two-bed position (at least) scan of your 20 cm diameter uniform phantom (15-30 minutes per bed position). The phantom is tilted on a slight incline (front edge raised approximately 2 cm) so that spatial resolution can be accurately assessed from the edge of the phantom given that its physical edge occurs at a gradual progression of y-locations (floor to ceiling) in different axial slices. The long acquisition minimizes statistical noise.

2. Your standard clinical oncology reconstruction to get an accurate assessment of resolution using your clinically-used reconstruction algorithm and parameters.

Software Functioning

The software expects the uniform phantom data to be acquired on a slight incline. It understands the cylindrical geometry of the phantom and analyzes the images to determine the 3D equation of the central axis of the cylinder. Given this information, a series of measurements is made without requiring user interaction.

- **Calibration Accuracy:** A large cylindrical VOI is placed in the center of the phantom (avoiding edge effects).
- **Uniformity in the Axial Direction**: Individual approximately 15 cm diameter circular ROIs are placed in the center of each axial slice.
- **Uniformity in the Radial Direction**: Five individual circular regions of interest approximately 4 cm in diameter are placed in each axial slice anterior, posterior, left, right, and center.
- **Spatial Resolution in the Axial Direction**: An edge profile is drawn for the central axial slice, and several slices in front and several slices behind. Using the measured phantom axis angle to calculate fractional offset of the adjacent edge curves, a highly sampled edge response curve can be pieced together. A mathematical function is fit to this curve in order to measure the axial resolution.
- **Spatial Resolution in the Radial Direction**: An edge profile is drawn on the central coronal slice and several slices to the left and right. In a manner similar to the previous step, piecing these several profiles together creates a highly sampled edge response function that can be used to assess the radial resolution.

Caveats

The software expects the phantom data to be collected at a slight incline. If it is not, and the scan is performed with the phantom parallel to the axis of the scanner then all measurements will still be valid EXCEPT the resolution measurements, which require the higher sampling afforded by the inclined phantom.

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PAT Uniform Phantom Analysis

Understanding the Report

Report Header

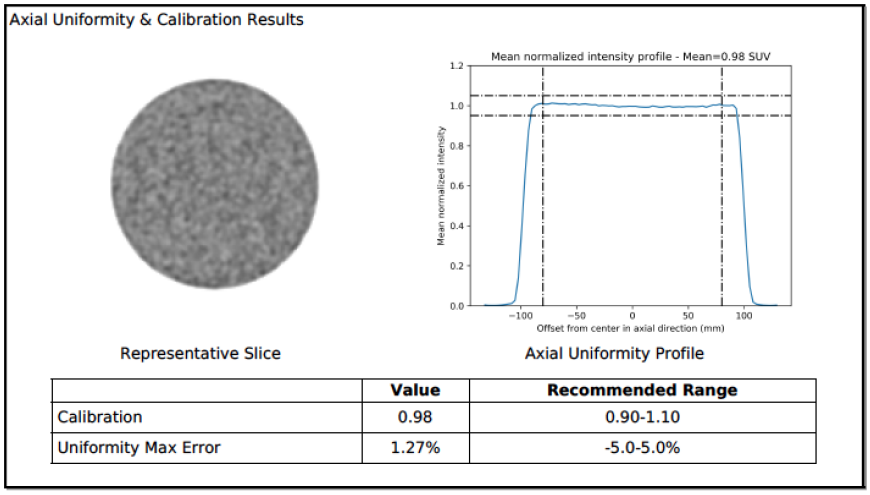
The header of the report is at the top of the first page. Example below.

Facility: University of Iowa Hospitals	Phantom: Uniform Concentration: 0.21µCi/ml
Scanner Model: SIEMENS Biograph64_Vision 600	Scan: 08/02/2019 Time Per Bed: 3.0min.
Reconstruction: PSF+TOF 4i5s Gauss3.00	

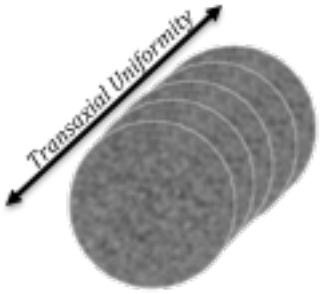
This Section reads the facility name, scanner make and model, reconstruction, scan date, and time per bed position from the DICOM Tags. It also reports the actual concentration in the phantom based upon the reported activity injected into the phantom, and the phantom volume.

Scanner Calibration and Axial Uniformity

The scanner calibration accuracy is reported at the bottom of the first box. The "Calibration" reported is the PET measured concentration from a large cylindrical VOI automatically placed on the image data, divided by the actual concentration at scan time as determined by the decay corrected concentration as calculated from the data entered into PAT (activity injected into the phantom, time of dose measurement, the phantom fill volume). The Calibration reported should ideally be 1.00 with an acceptable range between 0.90 -1.10 (within ±10% of actual concentration).



	Value	Recommended Range
Calibration	0.98	0.90-1.10
Uniformity Max Error	1.27%	-5.0-5.0%



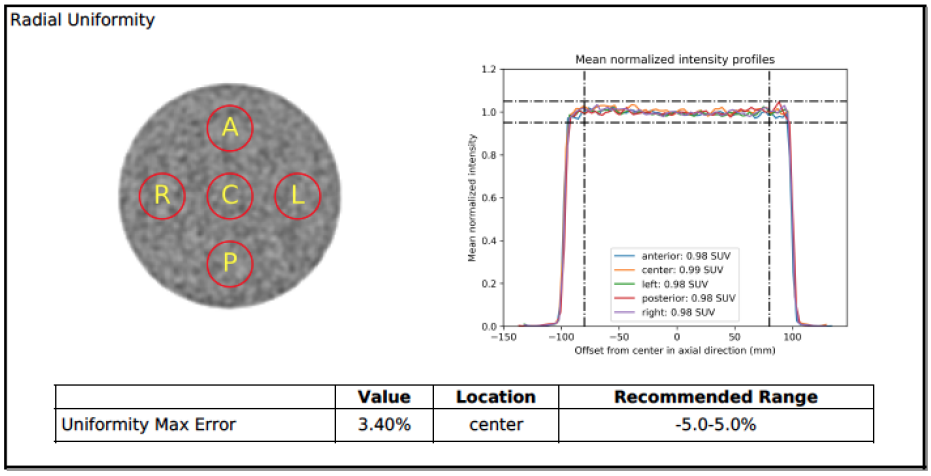
Axial uniformity is reported both graphically as a profile through all axial slices of the scanner, and numerically in a downloadable spreadsheet available from PAT. For purposes of uniformity (but not of accuracy) the plot is normalized to the mean measured across the scanner's axial field of view, and will always be centered around 1.0. A circular region of interest of approximately 15 cm is centered in each slice around the centroid pixel to determine the mean concentration per slice.

For purposes of uniformity assessment, only the central 80% of slices are analyzed (designated by two dotted vertical lines in the plot) so as to avoid edge/resolution effects. Two horizontal dotted lines are provided at ± 5%. Typically, a scanner should have uniformity that stays within that ± 5% window. The largest deviation from 1.0 is reported in the first box underneath the Calibration

measure. One should *not* observe a gradient from front to back (or vice versa), and this would be evidence of a problem, even if it were to stay within the ± 5% boundaries.

Radial Uniformity

Radial uniformity is reported both graphically and numerically in the second box as a profile through all axial slices of the scanner. For this measurement, five individual circular regions of interest approximately 4 cm in diameter are placed in each axial slice anterior, posterior, left, right, and center to assess radial uniformity in each slice. Like the first box, this plot is normalized to the mean measured across the scanners axial field of view, and so will always be centered around 1.0.



	Value	Location	Recommended Range
Uniformity Max Error	3.40%	center	-5.0-5.0%

For purposes of uniformity assessment, only the central 80% of slices are analyzed (designated by two dotted vertical lines in the plot) so as to avoid edge/resolution effects. Two horizontal dotted lines are provided at ± 5%. Typically, all five regions should have uniformity that stays within that ± 5% window, however because these are smaller regions, noise may result in excursions slightly above and below the 5% line, which is to be expected and is likely of no consequence. Here we are looking for geometric bias. Is the anterior region systematically different than the posterior region? Is the left different than the right? Is the center region higher or lower than the peripheral regions (as might be seen if either attenuation or scatter corrections are not being performed appropriately)? It is up to the reader to make these determinations, as no automated detection of regional bias is performed. The largest deviation from 1.0 is reported in the first box underneath the Calibration measure, along with which region this occurred in.

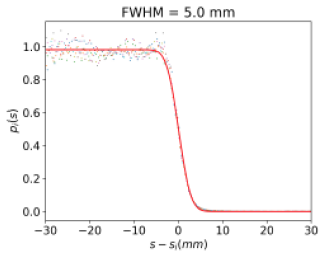
Resolution Measurement

Spatial resolution measurements of PET scanners have historically been performed using point sources of F-18 in air reconstructed using filtered back-projection. This is the NEMA approach, which has the explicit purpose of measuring the *intrinsic* resolution of a PET scanner; it does not, however, provide a meaningful measurement of resolution under clinical scanning conditions.

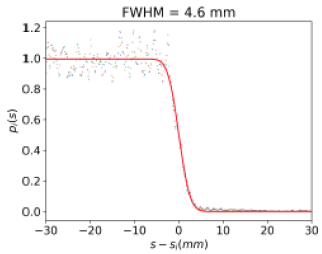
The PAT approach targets providing sites with a meaningful measure of spatial resolution under more clinically relevant conditions. PAT implements an algorithm developed by Lodge[1] that uses the edge response function measurement from the uniform phantom acquired at a slightly oblique

angle to measure both axial and radial resolution. This approach uses the phantom data reconstructed with the site's clinical reconstruction method in the presence of scatter and attenuation material to generate a clinically meaningful measurement of resolution.

The table provided in the PAT report includes the composite edge response function for the radial and axial planes, along with the functional fit to the data. The table below documents the axial and radial resolution measurements. The dots indicate the data and the curves indicate the function fit from which the resolution measure is derived.



Radial Resolution



Axial Resolution

	Value	Recommended Range
Radial Reconstructed Resolution	5.0mm	<9mm
Axial Reconstructed Resolution	4.6mm	<9mm

DICOM and Fill Information

Relevant DICOM header and fill information is displayed in fourth box. This is provided to provide a simple means to check the fill and reconstruction information.

Name	Value
Institution	University of Iowa Hospitals
Phantom	Uniform
Series Description	PET WB ultraHD
Scan Date	08/02/2019
Scan Time	14:58:07
Assay Time	14:32:00
Background Volume	6303.0g
Background Activity	1.59
Uptake Time	26.1
Minutes per Bed	3.00
Voxel Dimensions	1.65x1.65x3.00mm
Matrix Dimensions	440x440x88
Scanner Make and Model	SIEMENS Biograph64_Vision 600
Reconstruction Method	PSF+TOF 4i5s
Reconstruction Parameters	
Reconstruction Filter	XYZ Gauss3.00

References

Measuring PET Spatial Resolution Using a Cylinder Phantom Positioned at an Oblique Angle.
Lodge MA, Leal JP, Rahmim A, Sunderland JJ, Frey EC. J Nucl Med. 2018 Jun 14