

NEMA and clinical evaluation of a novel brain PET-CT scanner

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DISCLOSURE

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ABSTRACT

The aim of this study was to determine the performance of a novel mobile human brain/small animal PET-CT system, developed by Photo Diagnostic Systems Inc. The scanner has a 35.7-cm diameter bore and a 22-cm axial extent. The detector ring has 7 modules each with 3×4 cerium-doped lutetium yttrium orthosilicate crystal blocks, each consisting of 22×22 outer layer and 21×21 inner layer crystals, each layer 1 cm thick. Light is collected by 12×12 SiPMs. The integrated CT can be used for attenuation correction and anatomical localization. The scanner was designed as a low-cost device that nevertheless produces high-quality PET images with the unique capability of battery-powered propulsion, enabling use in many settings. **Methods:** Spatial resolution, sensitivity and noise-equivalent count rate (NECR) were measured based on the National Electrical Manufacturers Association NU2-2012 procedures. Reconstruction was done with tight energy and timing cuts: 400-650 keV and 7ns, and loose cuts: 350-700 keV and 10ns. Additional image quality measurements were made from phantoms, human, and animal studies. Performance was compared to a reference scanner (ECAT Exact HR+) with comparable imaging properties. **Results:** The full-width half-max transverse resolution at 1 cm (10 cm) radius is 3.2 mm (5.2 mm radial, 3.1 mm tangential) and the axial resolution is 3.5 mm (4.0 mm). For tight (loose) cuts, a sensitivity of 7.5 (11.7) kcps/MBq at the center increases to 8.8 (13.9) kcps/MBq at a 10 cm radial offset. The maximum NECR of 19.5 (22.7) kcps was achieved for an activity concentration of 2.9 kBq/ml. Contrast recovery for 4:1 hot cylinder to warm background was 76% for the 25 mm diameter cylinder, but decreased with decreasing cylinder size. The quantitation agrees within 2% of the known activity distribution and concentration. Brain phantom and human scans have shown agreement in SUV values and image quality with the HR+. **Conclusion:** We have characterized the performance of the NeuroPET/CT and shown

images from the first human studies. The study shows that this scanner achieves good performance when considering spatial resolution, sensitivity, count rate, and image quality along with a low cost and unique mobile capabilities.

Key Words: PET/CT, instrumentation, NEMA standard

INTRODUCTION

Positron Emission Tomography (PET) has proved to be a powerful tool for diagnosis of dementia (1) and diagnosis and monitoring of brain tumors (2). It can also be used to measure responses to stimuli. Renewed interest in brain imaging is leading to the development of dedicated head scanners with a low cost while still maintaining high sensitivity and spatial resolution.

The NeuroPET/CT is a full-ring mobile brain PET-CT (computed tomography) scanner developed by Photo Diagnostic Systems, Inc. (PDSi) (3,4). It is the first ever dedicated brain PET-CT scanner. While developed primarily for brain imaging, it can also be used for animal and pediatric imaging. Because all PET data are acquired in list mode, it is easy to create dynamic sequences and reconstruction. The NeuroPET/CT is self-propelled on battery-powered wheels, such that it can be driven to multiple locations. Due to its mobility and ability to use any standard power outlet, the NeuroPET/CT can be used in a flexible manner. Instead of a motorized bed moving through the bore, as with typical scanners, the NeuroPET/CT moves on treads to collect CT data, and can be used with any bed that can be adjusted to the appropriate height. A NeuroPET/CT scanner was installed at Massachusetts General Hospital (MGH) in 2011. After a period of studies on its performance, the scanner is now used for clinical and pre-clinical research studies. Figure 1 shows a picture of the scanner with major components labeled.

We evaluated the imaging characteristics of the PET component of the NeuroPET/CT scanner using the National Electrical Manufacturers Association (NEMA) standards measurements (5), and with additional phantom, animal, and human studies.

MATERIALS AND METHODS

PET Specifications

NeuroPET/CT was designed to achieve high sensitivity and good spatial resolution. The PET detector consists of 1-cm long cerium-doped lutetium yttrium orthosilicate (LYSO) crystals divided into modules and blocks. The physical specifications of the NeuroPET/CT are summarized in Table 1, along with specifications for the ECAT Exact HR+ scanner, which is currently used at MGH for brain imaging. Event positions are determined using the centroid from the SiPM array on each block. While the offset inner and outer crystal layers will eventually be used to determine the depth of interaction (DOI), they are currently treated as a single layer with a single characteristic conversion depth. The 22-cm axial extent of the PET rings allows the human brain to be imaged in a single acquisition.

PET data are taken in list mode and reconstruction software creates sinograms with randoms, scatter, and attenuation corrections for multiple temporal frames. A dead time correction is applied based on a paralyzable model at the block level. Singles rates for each block are collected every 6 seconds during an acquisition and used in the dead time correction. Delayed data used for the randoms correction have offline cuts and live fraction applied before sinogram binning. Smoothing is applied prior to subtraction from the prompts. Radioactive decay is corrected on a per-frame basis. For scatter correction, the standard "single scatter simulation" method (6) is used. To correct for inhomogeneity and variations in the coincidence channels (i.e., lines of response), a two hour normalization scan is taken of a thin (low scatter) 30.5 cm long annulus with inner (outer) diameter of 27.9 cm (29.2 cm) filled with ~18 MBq of ^{18}F . The data are binned into sinograms and randoms are subtracted. Normalization data are corrected for differences in the activity distribution and are variance reduced before being used as a normalization correction during reconstruction. Attenuation correction is done using a

low-dose CT scan taken with each PET scan. The bilinear scaling method is used to convert CT images in HU to μ -values at 511 keV (7,8).

Iterative maximum likelihood expectation-maximum and filtered back projection are reconstruction options. Reconstructions are done in 2-D after Fourier rebinning (9). The projection operator is a line integral calculated on the fly, where the integrand is determined by performing a bi-linear interpolation in image space at fixed intervals along the line. The reconstruction uses a maximum ring difference that is half of the axial field of view (FOV). The hardware coincidence time window is 10 ns, but can be reduced in the software. Similarly the energy window can be set to anywhere between 350 keV and 750 keV. Within this paper, “tight cuts” refers to an energy window of 400-650 keV and timing window of 7ns. “Loose cuts” refers to an energy window of 350-700 keV and timing window of 10 ns. The reconstructions in this paper use $256 \times 256 \times 92$ image space bins for $1 \times 1 \times 2.3$ mm³ voxels or $256 \times 256 \times 184$ image space bins for $1 \times 1 \times 1.17$ mm³ voxels. Images are calibrated to radioactivity concentrations in Bq/mL using a 6L cylindrical head-sized source of known activity concentration.

CT Specification and Safety Assessment

The CT has 3264 detector channels with 8 axial slices at spacing of about 1.25 mm. The X-ray source, capable of 100, 120, or 140 kVp at 2.0 to 7.0 mA, can rotate at 60 rpm for 1440 views/sec. The system is capable of taking full axial FOV helical CTs in under 15 seconds. Low dose CT scans deliver a dose of less than 100 mrem.

The limiting factor for the mobility of the NeuroPET/CT is the external radiation produced during CT operation. Scatter dose rates were measured with a 20 cm diameter, 27 cm length cylindrical water phantom at CT isocenter. Rates were measured for low

dose CT scans (2 mA tube current), and higher dose, higher quality, scans (7 mA). All scans were 220 mm axially at 120 kVp, with 2-second resolution. At 1.5 m from the scanner and at 1.2 m height, the maximum dose received at a 45 degrees angle from patient axis is 308 (1076) μrem for a low (high) dose scan. The worst-case exposure at 3 m, with the scanner running at the highest dose settings, is 140 (470) μrem .

PET Performance

Spatial Resolution. The spatial resolution was measured using three plastic-encased 5 μCi ^{22}Na point sources less than 1 mm in all dimensions. The point sources were placed at two axial positions, the center of the FOV and 8.5 cm from the center, and scanned for 15 minutes each. For each axial location, the sources were placed at three (x,y) positions: (1 cm, 0), (0, 10 cm), and (10 cm, 0). The data were reconstructed using filtered back projection with $1 \times 1 \times 1.17 \text{ mm}^3$ voxel size, tight cuts, and no spatial smoothing. A parabolic fit was used to find the peak and then linear interpolation was used to find the full width at half maximum (FWHM) and the full width at tenth maximum (FWTM) of the point spread functions in all three cardinal directions, which were combined into radial, transverse, and axial results.

Sensitivity. Sensitivity was measured with a standard set of thin aluminum sleeves around a 70-cm line source filled with 6.81 MBq at the start of acquisition, resulting in negligible dead time. The line source was placed in the center of the transverse FOV, parallel to the scanner bore. Five aluminum sleeves with increasing inner diameter and constant wall thickness were added to the line source, and a 180 second acquisition was taken for each additional sleeve. Sinograms were corrected for decay and randoms and data were single slice rebinned (10). The sensitivity was calculated as the normalized sum of the corrected activity for each acquisition. Counting rates were plotted against

accumulated aluminum thickness. The absolute sensitivity was obtained by extrapolating the data to zero thickness (no attenuation) using linear regression. The analysis was performed with both tight and loose cuts. The procedure was repeated, but with the setup at 5 cm and at 10 cm from the center of the FOV.

Noise Equivalent Count Rate. The noise equivalent count rate (NECR) is the ratio of the square of the true rate to the total rate (true + random + scatter): $T^2 / (T+R+S)$. It is proportional to the square of the signal-to-noise ratio in the reconstructed images. A 20-cm-diameter polyethylene scatter cylinder ($\rho=0.96 \text{ g/cm}^3$) with a length of 70 cm was used to measure NECR. A plastic tube was placed through the full length of the cylinder at 4.5 cm from the center and filled with 173 MBq ^{18}F at the scan start. The cylinder was centered axially and transaxially in the scanner with the line source closest to the table.

The data were acquired over a 24-hour period as 20 frames of increasing length, from 79 seconds to one hour, each separated by 45 minutes. A “blank” scan was taken 44 hours later, with the phantom in place but no remaining activity, to measure the intrinsic LYSO background count rate. Sinograms were created for each frame using both tight and loose cuts. The sinograms were analyzed according to the NEMA instructions and noise equivalent count event rates were calculated for each acquisition.

Scatter Fraction. The scatter fraction was calculated with NECR data based on the methods described by Watson et al. (11). For each activity concentration, i , the scatter fraction, SF , was calculated according to the equation $SF_i = R_{\text{scatter}} / (R_{\text{true}} + R_{\text{scatter}})$, where R_{scatter} was calculated by subtracting the delayed estimated random event rate, the true rate R_{true} , and the intrinsic true rate (measured from the “blank” scan) from the total rate calculated within a 12 cm radius.

Dead Time Correction. The NECR measurement data was used to assess the dead time correction by comparing the system singles rate with and without dead time corrections versus activity concentration.

Image Quality and Quantitation

Uniform phantoms. A uniform cylindrical water phantom of volume 6,283 ml was filled with 20 MBq of ^{18}F and scanned for 15 minutes. The data were reconstructed with tight cuts. An aliquot was used to measure the activity concentration with a well counter to compare to the image concentration. Images were examined for uniformity in axial and transaxial directions.

A contiguous grid of $10 \times 10 \text{ mm}^2$ regions of interest (ROI), all contained within a circle of radius 88 mm, was created for each slice. As a measure of concentration variability a coefficient of variation was determined by calculating the standard deviation of the means of the ROI counts, normalized by the mean of all ROI within each slice.

ACR Phantom. An American College of Radiology (ACR) accreditation phantom, with a section of wedges of cold rods of varying sizes (4.8, 6.4, 7.9, 9.5, 11.1, and 12.7 mm), a uniform section, and a section with cold and hot cylinders, was filled with ^{18}F such that the hot cylinders to background ratio was 4:1. The total activity of about 13 MBq corresponds to that expected from a 222 MBq injection to a 70 kg patient. The phantom was scanned for 15 minutes, and reconstructed with tight cuts. The cold and hot cylinders were compared to the background activity to measure contrast recovery. The same phantom, fill, and scan parameters were performed on the HR+ and the data were reconstructed using standard brain imaging settings (described below), but without the usual segmenting of the attenuation map, to avoid artifacts from over-correction of air pockets.

The contrast recovery coefficients for the hot cylinders were calculated as $CRC = (H/B-1)/(a-1)$ where H is the mean hot concentration in a single slice ROI with diameter corresponding to each cylinder diameter, B is the background concentration estimated from 60 ROI of the same size as the corresponding cylinder, and a is the true hot to background ratio. The cold cylinders' recovery coefficients were calculated as $(B-C)/B$ where C was the mean cold cylinder concentration.

Hoffman Brain Phantom. ^{18}F -FDG was added to a water-filled Hoffman 3-D brain phantom that was then shaken for several minutes and allowed to mix for another two hours. A 15-minute PET scan on the NeuroPET/CT was started when the phantom reached an activity of 27 MBq, slightly lower than the typical activity present in the FOV during an FDG scan. The same procedure was later repeated on the HR+. Both the HR+ and the NeuroPET/CT images were reconstructed with the same respective parameters as for typical brain studies (see below). For comparison purposes, the NeuroPET/CT images were rigidly registered to the HR+ images by minimizing the least squares difference in image intensities.

Human Scans. Over 50 human subjects have been scanned using the NeuroPET/CT at MGH. Each subject was injected with 190 ± 10 MBq of FDG. After 47 ± 6 minutes of uptake, the subject was scanned first on an HR+ for 15 minutes, and then 14 ± 6 minutes later on the NeuroPET/CT for a 15-minute PET. All human studies were approved by the MGH institutional review board and written informed consent was obtained.

The HR+ images were reconstructed as a single frame using the standard brain imaging settings: ordered subset expectation maximum algorithm with 3 iterations, 16 subsets, 2 mm Gaussian smoothing, and voxel size $2 \times 2 \times 2.4$ mm. The NeuroPET/CT images were reconstructed with maximum likelihood expectation-maximum, 100

iterations, 1.25 mm inter-iteration Gaussian smoothing, 1.85 mm Gaussian post-smoothing, voxel size $1 \times 1 \times 2.3 \text{ mm}^3$ and the tight set of cuts.

Thirty-three subjects scanned on the NeuroPET/CT and the HR+, and who also had an MR scan, were selected for analysis. FDG-PET image volumes were registered to each subject's MR image using the rigid-body registration algorithms in the Statistical Parametric Mapping software (12). The MR volume was then registered to the ICBM-152 MNI brain template (13) using non-linear registration. The resulting registration matrix was used to transform the two corresponding PET image volumes. Using the MNI structural atlas, the average Standardized Uptake Value (SUV) within each of 9 anatomical regions (caudate nucleus, cerebellum, frontal lobe, insular cortex, occipital lobe, parietal lobe, putamen, temporal lobe, and thalamus) was computed for each subject. A scatter plot to show the relationship between the measured SUVs on the HR+ and NeuroPET/CT was made for all 9 regions and 33 subjects.

To establish the linear relation between SUVs measured on these scanners, the within-patient SUVs from the two scanners were fitted to the linear model with blocked total least squares regression (TLS) (14)

$$\text{SUV}_{\text{NP/CT}}(i, j) = k \text{SUV}_{\text{HR+}}(i, j) + C_i,$$

where subscript i denotes subject and subscript j denotes region. This analysis yields a mutual regression slope, k , for all subjects and an intercept, C_i for each subject that accounts for subject-specific uptake and clearance rates. TLS was also performed for each subject separately and the mean and standard deviation of the slopes were calculated.

Animal Scan. In addition to the human brain studies, a low dose ^{11}C kinase tracer study was performed on a macaque monkey. The monkey was injected with 250 μCi at the start of PET acquisition, scanned for 15 minutes, and images were reconstructed

using the tight cuts with $1 \times 1 \times 1.17 \text{ mm}^3$ voxels. The MGH animal care committee approved all animal studies.

RESULTS

Spatial Resolution

The spatial resolution for each of the point source measurements is listed in Table 2 along with literature-based values for the HR+ (15,16) that were calculated using the same analysis method.

Sensitivity

Figure 2 shows the results of the sensitivity as a function of accumulated sleeve thickness for the NeuroPET/CT, and the sensitivity of the HR+. The center of the FOV has a sensitivity of almost 0.75% (i.e., 7.5kcps/MBq), increasing to 0.88% at a 10 cm offset. With the looser energy and timing windows, the sensitivity increased to 1.16% (1.39%) at the center (radial) placement. The sensitivity of the HR+ is much smaller—0.66% central and 0.72% at 10 cm offset.

NECR

Figure 3 shows the NECR versus activity concentration. With tight cuts, the maximum NECR of 19.5 kcps was achieved for an activity concentration of 2.9 kBq/ml. With the loose cuts, the peak NECR was 22.7 kcps.

Scatter Fraction

The mean scatter fraction (SF) at peak NECR was 42.7% for the tight cuts, and 44.4% for the loose cuts. This SF is slightly lower than the 46.9% measured for the HR+ (17).

Dead Time Correction

An extrapolation from a linear fit to the system singles at low count rate was used as an ideal case with no dead time. Relative to the extrapolated fit, the singles rate is under-corrected by 2.4% at peak NECR and at the typical human FDG singles rates, increasing to 5% at a rate of 40 Mcps and activity concentration of 7.1 kBq/ml.

Image Quality and Quantitation

Uniformity phantoms. The ^{18}F activity concentration measured in a 4233 ml ROI in the image was about 2% higher than the well counter measurements. There is a slight decrease of the activity towards the edges of the phantom. The coefficient of variation from the grid of ROI had mean and standard deviation across the slices of $7.4 \pm 1.1\%$.

ACR phantom. Figure 4 shows (A) a transverse view of the hot and cold cylinders, (B) the uniform section, and (C) the resolution using cold rods in a warm background. Rods in five of the six wedges are resolved. Contrast recovery results are in Table 3.

Hoffman Phantom. Images from the NeuroPET/CT scan show well-resolved structures and are visually comparable to those of the HR+. Given the differences in reconstruction algorithms, and the need for registration, it is difficult to say that either outperforms the other. Figure 5 shows a slice of the phantom from each scanner.

Human Studies. Human brain images on the NeuroPET/CT were overall of better quality, by visual inspection, than those of the HR+, despite a slightly lower activity concentration. Features of the gray matter are more distinct on the NeuroPET/CT images, although there is slightly more scatter into the white matter regions. An example human brain image is shown in Figure 6(A) for the HR+ and 6(B) for the NeuroPET/CT with $1 \times 1 \times 1.17 \text{ mm}^3$ voxels. Figure 6(C) shows 33 subjects with a global TLS fit and two example subjects highlighted. The mutual TLS regression slope of 1.04 ± 0.02 is close to 1. Similarly, the averaged slopes of 33 separate TLS regressions, 1.07 ± 0.18 , yield a p-

value of 0.36, suggesting that data obtained on the NeuroPET/CT are equivalent to those obtained with the HR+.

Animal Scan. PET/CT fused images of the monkey brain are shown in Figure 7 to demonstrate the capability of the scanner at very low activity levels. Features of the monkey brain are clearly visible in the PET tracer distribution.

DISCUSSION

The results presented above summarize the imaging capabilities of the NeuroPET/CT, with comparisons to the ECAT HR+. Many of the procedures followed were based on NEMA standards for a full body scanner. As such, we did expect some differences in objective results given that the NeuroPET/CT is a head scanner being compared to the full body HR+ scanner. Partly for this reason we also included the results of the human and monkey brain studies.

Spatial Resolution

Compared to the HR+ the NeuroPET/CT has superior resolution for all point source measurements. The spatial resolution away from the center of the scanner suffers somewhat due to the small ring size. While the smaller ring provides an advantage in sensitivity over the full-body sized HR+, it also creates additional uncertainty in the interaction position along the crystal. This disadvantage could be mitigated in the future by using depth of interaction information.

Sensitivity

The NEMA sensitivity is about 1.2 times of that for the HR+ for tight cuts, and 1.8 times for loose cuts (more similar to the HR+ settings). This higher sensitivity is because NeuroPET/CT has large solid angle and smaller gaps between the neighboring modules. The rate was normalized to the full line source of 70 cm. If instead it is

normalized to the length of the axial field, 22 cm, then the sensitivity calculation increases by a factor of 3.2, as noted in previous performance studies of head scanners (17).

NECR

The NECR curve for the NeuroPET/CT peaks at a fairly low activity concentration, but in that region its NECR is 5-20% higher (depending on the cuts used) than the HR+ NECR. The point of peak NECR corresponds to 63 MBq in the line source. Assuming about 1/3 is in the FOV that corresponds to 19.6 MBq. While it is somewhat lower than the activity level in a typical FDG scan (~28 MBq), it is not far outside clinical parameters, especially for longer scans. The high NECR at lower activities for the NeuroPET/CT indicates that lower doses can be used without sacrificing imaging quality in terms of signal-to-noise ratio.

Image Quality and Quantitation

Image quality and quantitation are suitable for the intended use of the NeuroPET/CT. The contrast recovery is comparable to that of the HR+—slightly better for the larger cylinders, and slightly worse for the smaller cylinders. Currently under investigation is why the NeuroPET/CT, with the better spatial resolution, has worse contrast recovery for the smaller cylinders. There is a high correspondence of SUV values within subjects measured with the HR+ and NeuroPET/CT. Some differences between the human images from the two scanners are expected, given the uncertainties from differences in FDG bio-distribution, scan time, and registration warping.

CONCLUSION

The device tested is the first mobile brain PET-CT scanner. In this work, we characterized the performance of the NeuroPET/CT scanner based on NEMA, phantom,

and human studies. Our study shows that the scanner has achieved a good combination of performance in terms of spatial resolution, sensitivity, count rate, and image quality, with the added advantage of mobility and flexibility of use.

DISCLOSURE

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FIGURE 1. The NeuroPET/CT scanner with outer components labeled. Treads (behind the metal apron) are used for precise scanner motion during CT scans, while wheels are used to transport the scanner to the scan location.

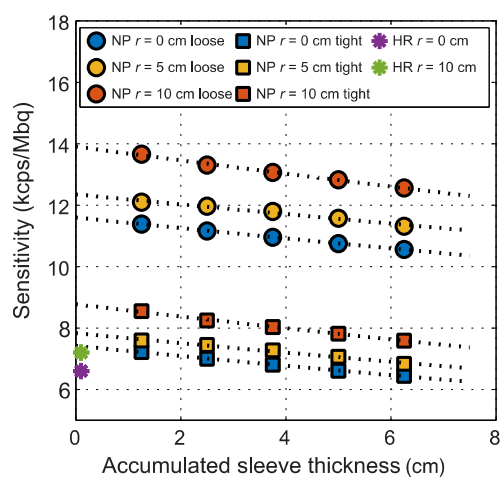


FIGURE 2. Sensitivity as a function of sleeve thickness for three different radial placements on the NeuroPET/CT. Loose cuts are shown with circles, tight cuts with squares. The lower HR+ sensitivity is shown for reference.

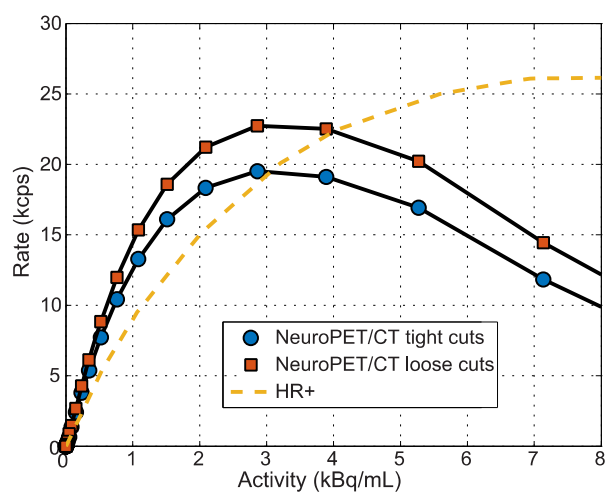


FIGURE 3. The noise equivalent count rate versus activity concentration for the NeuroPET/CT with tight and loose cuts, and for the ECAT HR+.

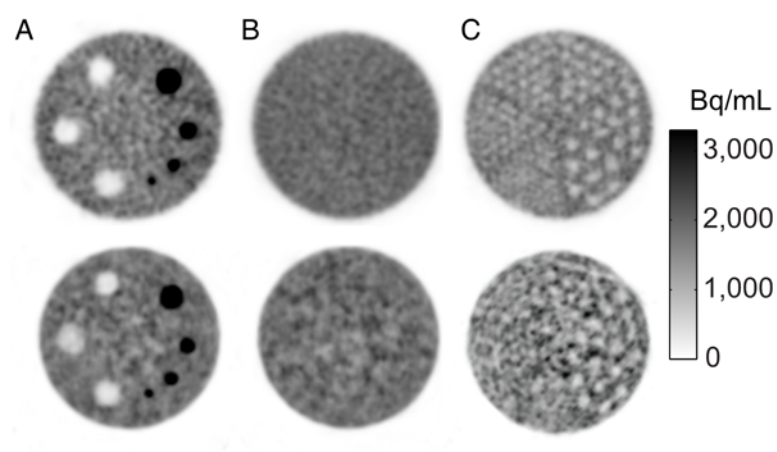


FIGURE 4. NeuroPET/CT (top) and HR+ (bottom) ACR-type phantom showing 10 mm transverse slices of the (A) contrast section with cold and hot cylinders (B) uniform section and (C) cold rod section for resolution, with the second smallest (6.4 mm) rods resolved for the NeuroPET/CT and the third largest (9.5 mm) rods resolved for the HR+, although lower resolution in the HR+ could be due to the proximity to the edge of the axial FOV. ACR: American College of Radiology

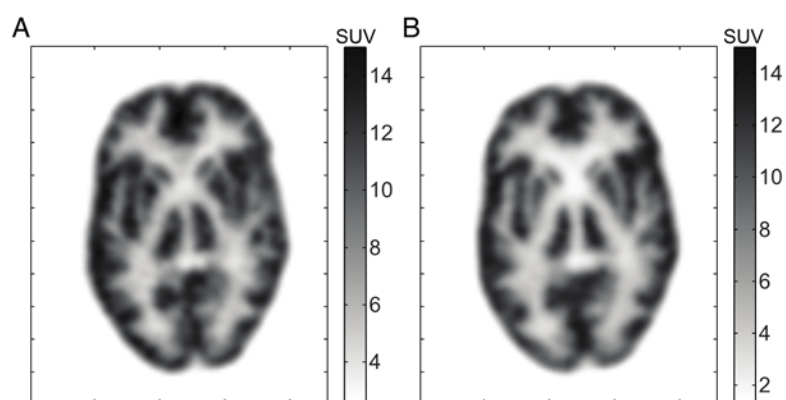


FIGURE 5. Transverse slice from Hoffman phantom for the (A) NeuroPET/CT and (B) HR+. Standardized uptake value (SUV) is based on a 70 kg patient.

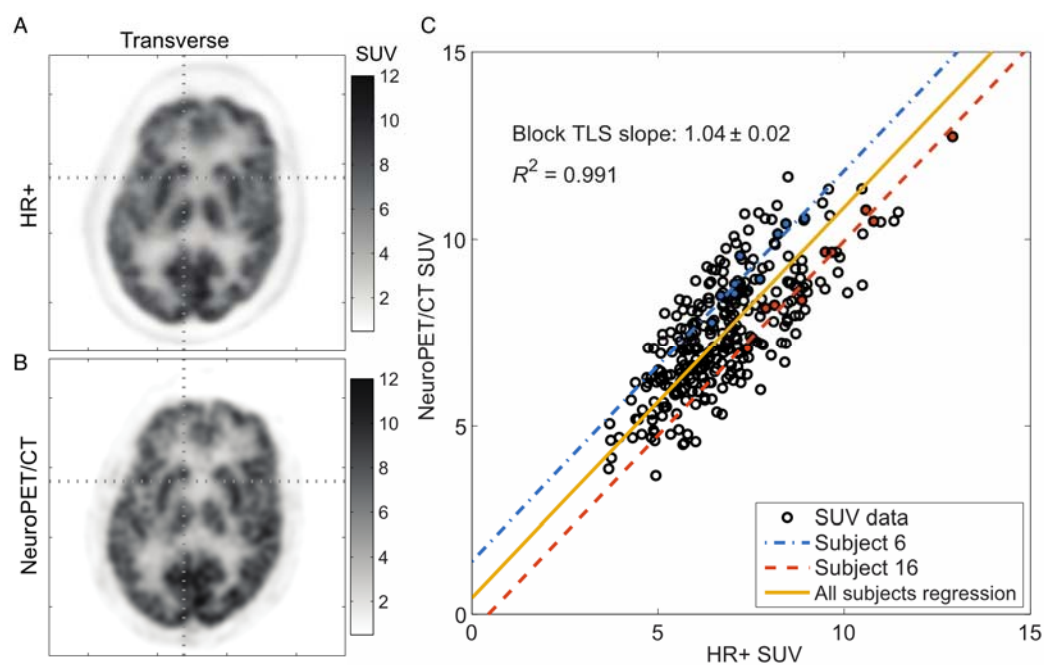


FIGURE 6. FDG images for an example subject scanned in (A) the HR+ and (B) the NeuroPET/CT, which show comparable visual quality. (C) The comparison between HR+ and NeuroPET/CT SUV of 9 regions in 33 subjects using blocked total least squares regression. Two example subjects are shown in blue and red while the averaged intercept was used for the yellow regression line. FDG: Fluorodeoxyglucose. SUV: standardized uptake value.

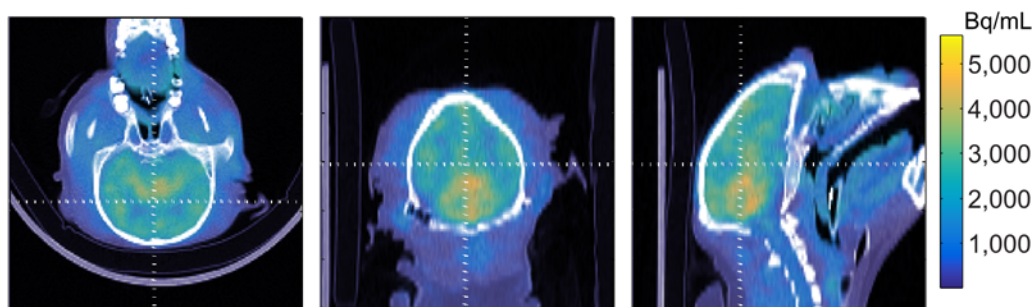


FIGURE 7. Transverse, coronal, and sagittal PET/CT views of a monkey brain scanned for 15 minutes after injection of 250 μ Ci of a ^{11}C kinase tracer that is under development.

TABLE 1

Design characteristics of the NeuroPET/CT with the HR+ for comparison

Characteristic	NeuroPET/CT value	HR+ value
Detector ring diameter	35.7 cm	82.4 cm
Detector material	LYSO:Ce	BGO
No. crystals	77,700	18,432
Modules	7	32 rings
Blocks/module	3×4	
Crystal size	$2.3 \times 2.3 \times 10$ mm (x 2 layers)	$4.05 \times 4.39 \times 30$ mm
Crystal array/block	22×22 outer, 21×21 inner	16 crystals/pmt
Transaxial FOV	25 cm	58.3 cm
Axial FOV	22 cm	15.5 cm
Coincidence window	Online 10.14ns (7ns offline)	12 ns
Energy window (keV)	Variable, default: 400-650	300-650

TABLE 2

NeuroPET/CT (NP) and HR+ spatial resolutions from point sources

Full width half/tenth max (mm)	Radial position: r = 1 cm		Radial position: r = 10 cm		
	Transverse	Axial	Radial	Tangential	Axial
FWHM NP	3.2	3.5	5.2	3.1	4.0
FWHM HR+	4.5	5.1	6.8	4.8	6.2
FWTM NP	6.0	6.8	8.3	5.5	8.3
FWTM HR+	8.2	11.2	12.2	9.9	13.5

TABLE 3

Contrast recovery coefficients (CRC) for hot and cold vials in the ACR phantom

Cylinder diameter	8 mm	12 mm	16 mm	25 mm	H ₂ O	Air	Bone
CRC NeuroPET/CT	0.32	0.50	0.66	0.76	0.80	0.80	0.90
CRC HR+	0.44	0.61	0.61	0.73	0.67	0.63	0.72



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