An Ultrasensitive Total-Body PET Scanner: Application Feasibility Simulations

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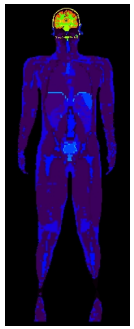
A PET scanner long enough to contain an entire human would possess a range of capabilities currently unavailable to the imaging community, including whole-body dynamic imaging with high temporal resolution, massively increased sensitivity and the ability to image at very low radiation doses. The objective of this study is to explore the potential application space of such a device using Monte Carlo simulations. We assess a range of applications and designs using noise-equivalent count-rates and lesion detectability.

1. Noise-Equivalent Count Rates

We used SimSET Monte Carlo simulations to estimate trues, randoms and scatter rates for a range objects intended to model adult whole-body, pediatric whole body, adult brain and the early frames of adult dynamic scans. We compared results for a Siemens mCT and for EXPLORER. Activity levels were set to model conventional and drug microdosing applications. ^{176}Lu activity, pile-up and system dead-time were modeled. NEC rates were calculated using TOF weighting (Conti et al 2006), adjusted for the actual distance subtended through the object by each line of response. Scanner parameters are given below:



	Siemens mCT	EXPLORER
Scintillator	LSO	LYSO
Crystal thickness (mm)	20	20
Ring diameter (cm)	84.9	78.6
Axial FOV (cm)	21.8	215.3
TOF resolution (ps)	530	530
Adaptive time-window?	No	Yes

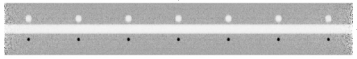
To mimic whole body scans we used a 27 cm diameter x 200 cm long uniform cylinder. To model a pediatric whole-body scan we used a 20 cm diameter x 70 cm long uniform cylinder. To model brain scans we used the VOXTISS 8 anthropomorphic phantom with activity ratio of 6:1 brain: whole-body, and included only LORs passing through the brain. To model the early frames of a dynamic scan we used the VOXTISS 8 phantom with all activity within the heart, and included only those LORs passing through the heart.

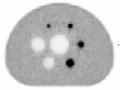
RESULTS

	mCT NEC (kcps)	EXPLORER NEC (kcps)	NEC Ratio	mCT NEC_{TOF} (kcps)	EXPLORER NEC_{TOF} (kcps)	NEC_{TOF} Ratio
Pediatric whole-body						
0.03 mCi	1.87	29.0	**15.5**	3.91	72.8	**18.6**
3 mCi	156	2,840	**14.1**	341	7400	**21.7**
Adult whole-body						
0.1 mCi	1.12	40.0	**35.7**	3.06	132	**43.2**
10 mCi	75.7	2,560	**33.8**	234	10,300	**43.9**
Brain						
0.1 mCi	2.20	7.89	**3.59**	2.93	12.0	**4.08**
10 mCi	176	597	**3.39**	250	1,060	**4.23**
Dynamic scan, initial frame						
0.1 mCi	7.49	24.6	**3.28**	7.77	28.5	**3.66**
10 mCi	479	1,580	**3.30**	549	2,310	**4.21**
20 mCi	613	1,910	**3.12**	792	3,750	**4.73**

2. Reconstruction Practicalities

The images below show a 2-meter long adaption of the NEMA image quality phantom. 600 M trues were simulated (no scatter or randoms) and reconstructed using list mode 3D OS-EM (5 iter 2 subs). Reconstruction time was 13.5 min per iteration with 16 2.4 GHz CPUs. For 10 mCi of activity in the phantom, then if randoms were included we estimate this would increase to ~4 hrs. Work on reconstruction acceleration is ongoing.





3. Lesion Detectability

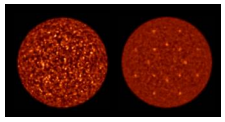
Our initial efforts to estimate lesion detectability gains are an extension of work described by Surti et al (2013), using a simplified EGS4 Monte Carlo model that ignores random coincidences in order to reduce the computational burden. Noting from our NEC simulations that for extended anthropomorphic scanning there is little advantage in accepting coincidences between detectors more than 50-100 cm apart in the axial direction, we compared a Philips Gemini TF-like scanner with a 72 cm long extended AFOV scanner.

	Gemini TF-like	Extended AFOV
Scintillator	LSO	LSO
Crystal size (mm3)	4.0 x 4.0 x 20.0	4.0 x 4.0 x 20.0
Ring diameter (cm)	84.3	84.3
Axial FOV (cm)	18	72
TOF resolution (ps)	600	600

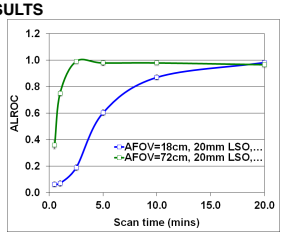
A 35 cm dia. x 100 cm long cylinder containing 16 hot spheres (1 cm diameter) was simulated. Sphere to background activity ratio was 3:1. 5 data replicates were generated. The activity level was set to 6.7 mCi corresponding to a 10 mCi injection and a 60 min uptake period. The scan time was set equivalent to a range of 30 sec to 20 mins for a 100 cm long scan. Lesion detectability was estimated numerically using a generalized scan statistics model (Popescu and Lewitt 2006) and the area under the LROC curve calculated (ALROC).

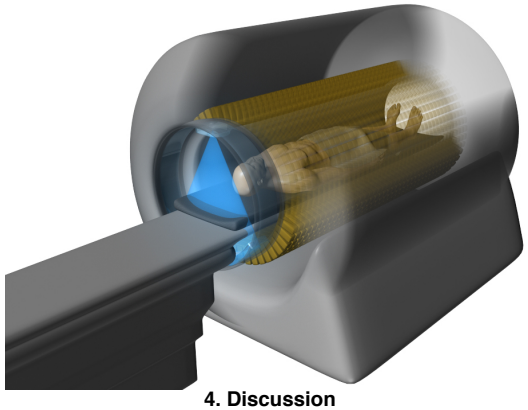
RESULTS

Images for the 2.5 min scans are shown to the left. ALROC curves are shown on right. The long AFOV scanner achieves the same ALROC value at 2.5 mins that the conventional scanner achieves at 20 mins.



18 cm AFOV 72 cm AFOV





4. Discussion

For whole-body static imaging, both the NEC data and the lesion detectability data demonstrate very substantial improvements for EXPLORER over conventional scanners. EXPLORER has the potential to:

- Realize the highest possible effective spatial resolution throughout the body for a given amount of administered radiation dose
- Detect low grade systemic disease in e.g. cancer, inflammation and infection
- Produce useful scan and kinetic data at low to extremely low radiation absorbed doses
- Record total body tracer kinetic information to produce whole body quantitative data/ parametric images
- Investigate interconnecting "systems" throughout the body e.g. brain-body

For the brain and for early frames of a dynamic scan an NEC_{TOF} gain of approximately 4 is obtained. This suggests that while EXPLORER will generate improved data quality for kinetic modeling compared to conventional scanners, the critical gain will be the ability to perform *whole-body* kinetic modeling rather than radically improved data quality for single organs.

For adults, TOF-weighted NEC results suggest that whole-body scans could be performed at 1/100 of the dose (~0.07 mSv) of current protocols provided a factor of 2 decrease in count density is considered acceptable. The data also suggest the potential to significantly reduce tracer mass. With a specific activity of 37 GBq/umol, for molecules of molecular weight less than ~10 kDa (FDG is ~0.2kDa), it would be possible use an injected mass below 1μgram. Of note, the regulatory threshold for toxicological concern for most non-pharmaceutical administrations is 1.5 μgrams/person/day.

In conclusion the results presented here suggest that the EXPLORER project has the potential to open up a wide range of important new applications for PET.

Conti *et al.*, IEEE *Trans. Nucl. Sci.* 53(3): 1188 – 1193; 2006
Surti *et al.*, *Phys. Med. Biol.* 58: 3995-4012; 2013
Popescu and Lewitt, *Phys. Med. Biol.* 51: 6225-6244; 2006

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