NEC: Some Coincidences Are More Equivalent Than Others

One of the most difficult tasks in medical imaging is the determination of image quality across the range of clinical imaging environments. Image quality is, of course, task dependent, and the ultimate metric is human observer performance; however, direct measurement of human observer performance is extremely arduous and may not even be possible if the clinical task cannot easily be modeled in a controlled experimental situation. In PET, a range of surrogate metrics for image quality has been used over the last 2 decades, including image signal-to-noise ratio (*1*), image contrast-to-noise ratio (*2,3*), and various numeric observers for lesion detectability such as the nonprewhitening matched-filter signal-to-noise ratio (*4*) and the channelized hotelling observer signal-to-noise ratio (*5,6*). However, by far the most commonly used surrogate metric is the noise-equivalent counting rate (NEC).

See page 1825

NEC was first introduced by Strother et al. (*7*) and was derived from the noise-equivalent-quanta concept, which originates from conventional photographic imaging. Briefly, noise-equivalent quanta describe the equivalent number of quanta or counts required by an ideal imaging system to produce the same noise characteristics as does an actual system that is degraded by noise. Similarly, in PET, NEC describes the equivalent coincidence counting rate that would have the same noise properties as the net true counting rate, corrected for spurious coincidences arising from 2 particular sources: random (accidental) coincidences and scattered events. NEC can also be seen as being directly proportional to the square of the signal-to-noise ratio of the acquired data.

NEC is fairly straightforward to measure and has become a standard metric for scanner performance provided by manufacturers and determined as part of acceptance testing for new equipment. NEC is most frequently (or invariably, in the case of acceptance testing) computed using a standard test object. The first such object accepted by the community for this purpose was a uniform water-filled cylinder of 20-cm diameter and 20-cm length (*8*). It was soon discovered, however, that the axial extent of the test object has a large impact on NEC—an impact that varies considerably with scanner design and acquisition mode—and a second test object, 20 cm in diameter but 70 cm in length, was proposed for NEC-based assessment of whole-body imaging performance (*9*). Watson et al. show in their article in this issue (*10*) that this configuration in turn has limitations as a predictor of whole-body NEC, and some workers have proposed test objects with a greater diameter (*11*).

As Watson et al. (*10*) also point out, there are other concerns about the use of NEC for image assessment. NEC is a raw-data–quality metric that does not take into account the impact of reconstruction algorithms or of spatial resolution effects. Although NEC is often used to compare systems or imaging techniques in PET (such as 2- and 3-dimensional modes (*12*)), such uses have not been validated in the context of, say, lesion detectability, and because spatial resolution and reconstruction methods frequently differ between systems or acquisition modes, NEC may not always track image quality in a meaningful way in these contexts.

Nevertheless, there remain scenarios in which NEC might reasonably be expected to give useful insights into image quality. One of these is presented by Watson et al. in this issue (*10*). Traditionally, the typical injected ^{18}F-FDG dose for whole-body PET is 370–550 MBq (10–15 mCi) for a 70-kg adult, and the dose may be adjusted to patient weight, allowing for a maximum dose of 740 MBq (20 mCi). This dose regimen, rather than being optimized for the imaging equipment used, was originally based on radiation dose restrictions. Direct determination of optimum injected dose for the typical oncologic task of lesion detection is nontrivial, because having the same patient rest on the scanner while the dose decays is time consuming (and the results would in any case be confounded by tracer redistribution), whereas imaging the same patient on successive occasions with differing quantities of injected radiopharmaceutical would be confounded by differences in the patient's metabolic state. Watson et al. describe a methodology that allows the transformation of an individual patient's single whole-body scan data to a patient-specific NEC curve, as if the study had been performed at a range of activities. In this case, concerns about object size are circumvented by computing NEC from the patient data directly. Because the patient is being imaged on the same

Received Aug. 31, 2005; revision accepted Sep. 14, 2005.

For correspondence or reprints contact: Magnus Dahlbom, PhD, Division of Nuclear Medicine, Department of Molecular and Medical Pharmacology, UCLA School of Medicine, 650 Charles Young Dr. S., AR-264 CHS, Los Angeles, CA 90095.

E-mail: mdahlbom@mednet.ucla.edu

scanner, with the same reconstruction method, it is reasonable to expect that NEC will thus give useful guidance on image quality, always provided that other parameters such as spatial resolution or contrast do not vary significantly with counting rate in the clinical regime (*13,14*).

The assumption that spatial resolution and contrast do not degrade with counting rate to any noticeable degree in the clinical environment is probably valid on scanners with a high rate capability, such as the lutetium oxyorthosilicate devices used by Watson et al. (*10*), although the validity of this assumption has yet to be explicitly demonstrated in the literature. Watson et al. recommend that the injected activity be such that NEC reaches 90% or 95% of the peak value. Because of the relatively flat shape of a typical NEC curve near its peak, this choice acts not only to significantly reduce the radiation dose to the patient but also to reduce the negative effects of excessive counting rate on the data.

Although the patient-specific curve can be determined only retrospectively, it can be used to determine optimum dose for follow-up studies, or it can be determined for a population and used to generate guidelines for scanning protocols based on, for example, patient weight. As shown in the paper by Watson et al. (*10*) and previously by Lartizien et al. (*15*) and Townsend et al. (*16*), the NEC varies for a single patient at different axial positions during a whole-body scan. Although not practical on the current generation of PET systems, image quality may improve if the acquisition time is varied axially. On PET/CT systems, adjustment of the PET acquisition time may be possible using CT-derived information on the amount of attenuation at the various scan positions.

Evaluation of the imaging performance of PET systems continues to be a complex and multifaceted problem, and a simple metric such as NEC is inadequate as a sole predictor of image quality and lesion detectability. However, to produce the best possible image quality, one needs to examine all aspects of how the PET image is produced, including the amount of administered activity, the acquisition parameters, and the reconstruction options. NEC, with an appropriate understanding of its limitations, remains a tool that can be used to address aspects of this problem.

Ramsey D. Badawi, PhD
UC Davis Medical Center
Sacramento, California

Magnus Dahlbom, PhD
David Geffen School of Medicine
at UCLA
Los Angeles, California

REFERENCES

1. Pajevic S, Daube-Witherspoon ME, Bacharach SL, Carson RE. Noise characteristics of 3-D and 2-D PET images. *IEEE Trans Med Imaging*. 1998;17:9–23.
2. Miyaoka RS, Kohlmyer SG, Lewellen TK. Hot sphere detection limits for a dual head coincidence imaging system. *IEEE Trans Nucl Sci*. 1999;46:2185–2191.
3. Wollenweber SD, Phillips KR, Stearns CW. Calculation of noise-equivalent image quality. In: *IEEE Nuclear Science Symposium and Medical Imaging Conference Record*. Vol 4. Piscataway, NJ: IEEE; 2003;2822–2825.
4. Moore SC, El Fakhri G, Badawi RD, Van den Abbeele AD, Zimmerman RE. Relative lesion detectability in 3D vs. 2D dedicated multi-ring PET. In: *IEEE Nuclear Science Symposium and Medical Imaging Conference Record*. Vol 3. Piscataway, NJ: IEEE; 2000:17/18–17/22.
5. Lartizien C, Kinahan PE, Comtat C, et al. A tumor detection observer study comparing 2D versus 3D whole-body PET imaging protocols. *Nuclear Science Symposium and Medical Imaging Conference Record*. Vol 3. Piscataway, NJ: IEEE; 2000:18/81–18/86.
6. El Fakhri G, Holdsworth C, Badawi RD, et al. Impact of acquisition geometry and patient habitus on lesion detectability in whole body FDG-PET: a channelized hotelling observer study. In: *IEEE Nuclear Science Symposium and Medical Imaging Conference Record*. Vol 3. Piscataway, NJ: IEEE; 2002:1402–1405.
7. Strother SC, Casey ME, Hoffman EJ. Measuring PET scanner sensitivity: relating countrates to image signal-to-noise ratios using noise equivalent counts. *IEEE Trans Nucl Sci*. 1990;37:783–788.
8. NEMA Standards Publication NU-2 1994. Washington, DC: National Electrical Manufacturers Association.
9. NEMA Standards Publication NU-2 2001. Washington, DC: National Electrical Manufacturers Association.
10. Watson CC, Casey ME, Bendriem B, et al. Optimizing injected dose in clinical PET by accurately modeling the counting-rate response functions specific to individual patient scans. *J Nucl Med.* 2005;46:1825–1834.
11. Surti S, Badawi RD, Holdsworth CH, Fakhri GE, Kinahan PE, Karp JS. A multiscanner evaluation of PET image quality using phantom studies. In: *IEEE Nuclear Science Symposium and Medical Imaging Conference Record*. Vol 4. Piscataway, NJ: IEEE; 2003:2425–2427.
12. Badawi RD, Marsden PK, Cronin BF, Sutcliffe JL, Maisey MN. Optimization of noise-equivalent count rates in 3D PET. *Phys Med Biol*. 1996;41:1755–1776.
13. Badawi RD, Domigan P, Johnson O, et al. Count-rate dependent event mispositioning and NEC in PET. *IEEE Trans Nucl Sci*. 2004;51:41–45.
14. Germano G, Hoffman EJ. A study of data loss and mispositioning due to pileup in 2-D detectors in PET. *IEEE Trans Nucl Sci*. 1990;37:671–675.
15. Lartizien C, Comtat C, Kinahan PE, Ferreira N, Bendriem B, Trebossen R. Optimization of injected dose based on noise equivalent count rates for 2- and 3-dimensional whole-body PET. *J Nucl Med*. 2002;43:1268–1278.
16. Townsend DW, Isoardi RA, Bendriem B. Chapter 4: volume imaging tomographs. In: Bendriem B, Townsend DW, eds. The Theory and Practice of 3D PET. Dordrecht, The Netherlands: Kluwer Academic Publishers; 1998:111–132.