Specification of Performance of Positron Emission Tomography Scanners

In the process of selecting a positron emission tomography scanner, we were hampered by the lack of standardized methods for measuring instrument performance. The assessment of resolution and sensitivity illustrates the problem.

Resolution is usually stated as the full width at half maximum (FWHM) of the count profile (line-spread function) through the reconstructed image of a line source (*1*). Several variables (often unspecified) can affect the FWHM. First, as the diameter of the experimental "line" source increases, the measured FWHM increases, since the observed line-spread function is the convolution of the true line-spread function with the rectangular function describing the width of the source. Second, the measured FWHM is less if the line source is imaged in air rather than in a scattering medium, both because of the lack of scattered radiation in air (which mainly increases the "tails" of the line-spread function) and because the positron range is greater. In air, the positrons are annihiliated either in the line source itself or at a great distance from it. In a scattering medium, annihilation events occur in and adjacent to the line source (*2,3*). The measured FWHM is less with the line source in air, since the observed line-spread function is the convolution of the true line-spread function with the positron range distribution function, which is much broader in a scattering medium. The use of a metal needle rather than plastic tubing for the line source also decreases the average positron range, decreasing the measured FWHM. The measured FWHM also depends on the radionuclide, which has a characteristic maximum positron energy. Lower-energy positrons have a smaller range in scattering material (*4*). The reconstruction algorithm itself affects the measured FWHM (*5*). For example, a ramp filter will provide maximum resolution, but will generate artifacts such as overshoot and ringing ("Gibbs phenomena") at borders of objects. Filters that do not produce artifacts yield a larger measured FWHM.

As a step in the direction of standardization, we recommend the use of plastic tubing with an inner diameter of 1 mm or less. The tubing should be filled with Ga-68 in water, since this radionuclide has an intermediate positron energy and is readily available, and placed in a plastic phantom with 20 cm o.d. filled with water. Since measured resolution is limited by the range of the higher-energy positron of Ga-68, a second measurement should also be done with F-18, which has a lower-energy positron. Measurements should be made with the line source at various positions that encompass the entire field of view. A Shepp and Logan filter should be used in the reconstruction, since it yields high resolution without artifacts. Both the full width at half maximum and full width at tenth maximum (as an indication of scatter) should be stated.

Sensitivity is usually expressed as the observed counts per second per microcurie per milliliter from a 20-cm-diameter phantom filled with water (*6*). As with resolution, several variables can affect this measurement, and it should be standardized. First, the phantom diameter should be specified as being the internal or external diameter, since this will affect the total amount of water and therefore the total amount of radioactivity in the phantom. Second, the wall thickness of the phantom should be standardized. The thicker the wall the greater the attenuation and the lower the observed count rate. Third, although the count rate is expressed "per microcurie per ml," measurements are usually made with lower concentrations of radioactivity. A lower concentration with a correspondingly lower count rate will yield more observed counts per second when normalized to 1 μCi/ml because dead-time problems will not be as great. The axial length of the phantom should also be standardized. The longer the phantom the more out-of-plane scatter radiation will enter the slice and increase the observed counts per second. Some describe sensitivity as the "raw" observed count rate; others normalize for differing detector efficiencies, and make scatter, coincidence, or attenuation corrections. Scatter and random coincidence corrections decrease the final count rate, but normalization and attenuation corrections increase it. Slice thickness (axial field of view per slice) also affects the measured sensitivity. As the slice thickness increases, the volume of water and therefore the amount of radioactivity increases, increasing the observed count rate without actually changing the "efficiency" of detection.

We recommend the use of a phantom with 1/8″ thick walls, filled with Ga-68 in water at a concentration of 100 nCi/ml. We prefer a phantom 15 cm in diameter for head scanners, and 25 cm in diameter for whole-body scanners. The phantom should be 2 cm longer than the axial field of view of the slice. The count rate should be the "raw" observed total coincidence rate, before normalization or other corrections. The count rate should be expressed on a "per axial cm" basis, using the measured axial FWHM of a line source in the plane of the slice to normalize the observed count rate.

Even if well standardized, resolution and sensitivity measurements are not sufficient to fully characterize the performance of a positron emission tomograph. Other specifications, such as accidental and random coincidence count rates as a function of total coincidence count rates, axial resolution, and quantitative linearity, are also needed. While we have not attempted to suggest standards for the specification of all parameters, standardization of certain fundamental measurements of performance could be of value.

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Comments on Specifying the Performance of a Positron Tomograph

The authors of the preceding letter have presented an excellent list of caveats for the potential user/buyer of a positron tomograph, and their suggestions for standardization are excellent as far as they go. It should be remembered, however, that the tomograph user/buyer must invest a great deal in the tomograph: either one to two years of his time if he builds it, or 0.5 to 2.0 million dollars if he buys it. Unless the user is primarily a builder/designer of instruments, he receives little or no scientific credit for building