Considerations in Assigning Dose Based on Uncertainties from in Vivo Counting

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Lung counting is highly geometry dependent, especially at low photon energies. Monte Carlo simulations have been used to determine the magnitude of the errors obtained if it is assumed that the deposition is homogeneous, when in fact it is not. Simulation for a germanium lung counting system consisting of four, 70 mm x 30 mm diameter thick detectors have been performed for 70 deposition patterns. The detector efficiencies for 20, 40, 60, 120, 240, 660, and 1000 kiloelectron volts were calculated for a homogenous deposition and these efficiencies were used to estimate the bias when the deposition was heterogeneous. A bias of 80% was not unusual. Whole-body counting is prone to errors that can arise from the activity distribution and/or size of the subject. The latter are geometry dependent and, for example, a bias result of 200% can be obtained when measuring children in a chair geometry using a calibration factor based on reference man. Thyroid counting is the least prone to error. If the measurement is done correctly, biases can usually be kept below 20%. However, if the measurement is made with a collimator or if the detector is in contact with the subject’s neck, biases exceeding 200% can be obtained. — Environ Health Perspect 105(Suppl 6):1393–1395 (1997)

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Introduction

The dose estimate obtained from activity measurements from an in vivo count can only be as accurate as the results obtained from that measurement, and depending on the nature of the uncertainty the bias can be in either direction. Thus, if the in vivo measurement grossly underestimates the amount of activity present, then the dose will be underestimated by a corresponding factor and the resulting health risk prediction too low. If, on the other hand, the in vivo result is overestimated, the dose estimate will also be overestimated by a corresponding amount, and the health risk will be inflated. This could cause severe anxiety in the subject and, consequently, lead to other health problems.

The Human Monitoring Laboratory (HML), which acts as the Canadian National Calibration Reference Centre for In Vivo Monitoring (1), has been investigating the effect of counting geometry and activity distribution on the results obtained from an in vivo count. These uncertainties have been expressed in terms of bias. Bias, expressed as a percentage, is:

\[
Bias = 100 \left[ \frac{obs - true}{true} \right]
\]

where \(obs\) = observed value and \(true\) = true value.

Lung Counting

A lung counter is usually calibrated using a realistic torso phantom that contains lungs that have radioactivity distributed homogeneously. However, in occupational or accidental exposures the radioactive contaminant often is associated with aerosol particulates. These particulates do not deposit themselves homogeneously when inhaled. The deposition pattern is directly related to particle size, lung function, and working conditions.

Monte Carlo (2) simulations have been used to estimate errors that may be generated if it is assumed that the deposition is homogeneous, when in fact it is not. A virtual chest phantom was created and four germanium (Ge) detectors were modeled to correspond to the lung-counting system in the HML (diameter 70 mm x 30 mm thick). The lungs were loaded with activity corresponding to 65 deposition patterns and up to 5,000,000 photons were followed. The detector efficiencies for 20, 40, 60, 120, 240, 660, and 1000 kiloelectron volts (keV) were calculated for a homogeneous deposition and these efficiencies were used to estimate the bias when the deposition was heterogeneous (3). A summary of results is shown in Table 1 with some practical results obtained at Oak Ridge National Laboratory (ORNL) using a three-detector array. The detectors were the same size as those modeled. The HML provided the tissue substitute lung sets that contained radioactivity to ORNL. The radioactivity was distributed in the lung sets in the same geometry as those modeled in the Monte Carlo simulations.

Whole-Body Counting

The apparent activity determined by whole-body counting will be affected by activity distribution and/or size of the subject. These effects can be measured using Bottle Manikin Absorber (BOMAB) (Canus Plastics, Ottawa, Canada) phantoms (4). The accuracy of \(^{137}\)Cs activity determined from whole-body counting has been estimated from the Canadian Whole Body Intercomparison Programme (5) and the results obtained from the joint U.S. Department of Energy (U.S. DOE)–HML International Intercomparison Programme (6). Both projects have evaluated the performance of many different types of whole-body counters: scanning bed, scanning detector, static detector over prone or standing subject, shadow shield, chair, tilt chair, and arc. A summary of results is shown in Table 2 for systems that have measured a small (P4) and a large (PM95) phantom.

Thyroid Counting

The accuracy of the activity determined in thyroid counting depends on the following factors: neck detector distance, size of detector, collimation, thyroid size, amount
of overlaying tissue, precision of detector placement in the plane normal to the neck detector axis. These factors have been evaluated both practically and theoretically using Monte Carlo methods (7–10). A summary of results is shown in Table 3.

**Discussion**

The measure of inaccuracy used to evaluate lung counting, whole-body counting, and thyroid monitoring is bias. It is the ratio of the difference between the observed result and the true result, and often is expressed as a percentage.

Table 1 shows that lung counting can be a very inexact procedure, especially at low energy. Single detectors often missed the activity entirely (~100% bias) or overestimated the activity by a factor of 10 at 20 keV. An array of detectors performs better and the bias varies from ~96% to 231%, which means that the activity is underestimated by a factor of 25 and overestimated by a factor of 3.3. As the photon energy increases to 60 keV, the underestimation is a factor of 2.9 and the overestimation is a factor of 2.2.

Practical data collected by ORNL with a three-detector array (two on the right of the chest and one on the left side) showed similar results. At 17 keV, the activity was missed completely in some activity distributions and overestimated by a factor of 4.8 in others. The situation improves as the photon energy rises, and at 60 keV the activity was underestimated by a factor of 2.7 and overestimated by a factor of 3.4.

It is clear that lung counting should be performed with an array of detectors to minimize the effect of the heterogeneous deposition. The actual deposition of the inhaled radioactivity will remain unknown, so the data give an uncertainty interval that must be assumed to accompany the derived activity. Plutonium measurements (17 keV) are the most imprecise and carry the largest inherent uncertainty. Otherwise, lung counting can estimate the deposited activity to within a factor of 3.

Table 2 shows that interpretation of whole-body counting results must consider the size of the person being measured. If reference man calibration factors are used to estimate the activity in subjects of other sizes, uncertainty will be introduced into the result. Table 2 shows that the activity can be underestimated by a factor of 2 or overestimated by a factor of 3, depending on the geometry of the whole-body counter. Data in Table 2 are for the 661.6 keV photopeak of $^{137}$Cs, so similar results can be expected for higher energy emitters; however, as the photon energy decreases, these uncertainties could double.

Table 3 shows that thyroid counting can be the most exact of the three in vivo techniques if the counting geometry is optimized and other geometry effects are minimized (e.g., size of thyroid). There is no reason that activities of radiiodine cannot be measured to within 20% if the conditions in the last column of Table 3 are satisfied. If the situation lies between the columns, the activity obtained from a thyroid count will be probably within a factor of 2.

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