ACCURATE WHOLE-BODY QUANTITATION OF ^{131}I RETENTION BY COUNTING A SCATTER WINDOW

William D. Gibbs, Harold D. Hodges, Mildred Bailey and C. C. Lushbaugh

Oak Ridge Associated Universities, Oak Ridge, Tennessee*

Accurate relative or absolute quantitation of human ^{131}I content cannot be achieved by the spectral photopeak counting methods now used in whole-body counting because the radioisotope undergoes extreme changes in distribution with time, resulting in a variable detection efficiency. Studies by Haim and Dudley (*1*) and Miller (*2*) show that total Compton counts are less variable than photopeak counts although the total Compton counts also vary considerably when changes occur in radioisotope distribution within the body. The studies of Dudley and Miller suggest that a "minimum error window" may exist if the counts in some energy band of the ^{131}I spectrum are less affected by changes in bodily distribution than either those in the photopeak or the entire Compton spectrum. We have tested this hypothesis experimentally and then used the optimal scatter window we obtained for ^{131}I in clinical studies.

EXPERIMENTAL PROCEDURES

Our approach to this problem was to generate a complete set of whole-body count (200-MeV) spectra (WBCS) for photon emissions from a standard ^{131}I source when it was located in each of 33 different spatial positions within a humanoid water phantom (Fig. 1). A low-level background, whole-body counter system (*3*) with eight 5 × 4-in. NaI(Tl)-crystal detectors and a 200-channel pulse-height analyzer (PHA) with punched tape readout was used. The water-filled phantom, described previously (*4*), had 11 compartments: head, neck, chest, two arms, abdomen, pelvis, two upper legs and two lower legs. The photon emissions from a 5-μCi ^{131}I source, sealed in a small Lucite cylinder, were analyzed for pulse height when the source was located in three positions in each compartment: superficial (upper), medial (center) and posterior (lower).

The spectra were carefully standardized by analyzer drift control and gain adjustments to provide a constant energy range of 0.0–2.0 MeV across the 200 channels (10 keV/channel). A 4-min background WBCS was stored in the PHA system and automatically subtracted to obtain a net or background-free spectrum that was then read out of the analyzer on paper tape. The taped data comprising the 33 net spectra were then fed into an IBM-7090 computer programmed to find the spectral window where the least difference in net counts existed when all spectra from the 33 locations of the source were compared to the reference location (center of abdomen).

The steps in this computation were as follows:

1. Determine the total net counts in every possible continuous energy band (minimum band width 50 keV or 5 channels) within the energy range of 0–440 keV for each of the 33 spectra (a total of 820 bands or windows) and store these computations in the memory core.
2. Subtract the counts in each window for each source location from the counts obtained in the same window when the source was in the center of the abdominal compartment (the reference location).
3. Obtain percentage difference by dividing each difference obtained in Step 2 by the counts obtained with the source in the reference location and multiply by 100.
4. Add the percentage differences without regard for algebraic sign (absolute value) for each of the 820 energy bands. (This summed difference is the "variation index.")
5. Print out the variation indices in ascending order, addressed with the associated energy bands of the spectral window.

This analysis and ordering puts the spectral window where observed counts varied the least (minimum-variation window) when the source was moved throughout the phantom at the top of the list. No corrections for physical decay of ^{131}I were required since an entire experiment was completed in less than 3 hr.

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For reprints contact: W. D. Gibbs, ORAU Medical Division, P.O. Box 117, Oak Ridge, Tenn. 37830.

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TABLE 1. MINIMUM VARIATION WINDOWS COMPARED WITH PHOTOPEAK WINDOW FOR ^{131}I

	Lower channel (MeV)	Upper channel (MeV)	Variation index
Compton scatter windows	12	32	122
	12	31	124
	12	33	124
	11	33	125
	13	32	125
	12	30	126
	12	29	127
	11	32	127
	10	34	127
	13	31	127
Photopeak window	31	41	1,644

TABLE 2. OBSERVED COUNTS PER MINUTE PER MICROCURIE AT 0 TIME FOR EACH OF 10 PATIENTS FOR PHOTOPEAK AND MINIMUM VARIATION WINDOWS

Patient	Cpm/ μCi	Percent of mean	Photopeak	Percent of mean
1	15,296	99.9	8,967	105.7
2	15,360	100.3	7,532*	88.7
3	14,532*	95.3	7,861	92.6
4	15,715	102.7	9,029	106.4
5	15,188	99.2	9,098	107.2
6	15,084	98.5	8,284	97.6
7	15,002	98.0	7,588	89.4
8	15,944†	104.2	7,969	93.9
9	15,258	99.7	8,273	97.5
10	15,648	102.2	10,265†	120.9
Mean	15,308±600	100.0	8,487±1,500	100.0

* Minimum
† Maximum

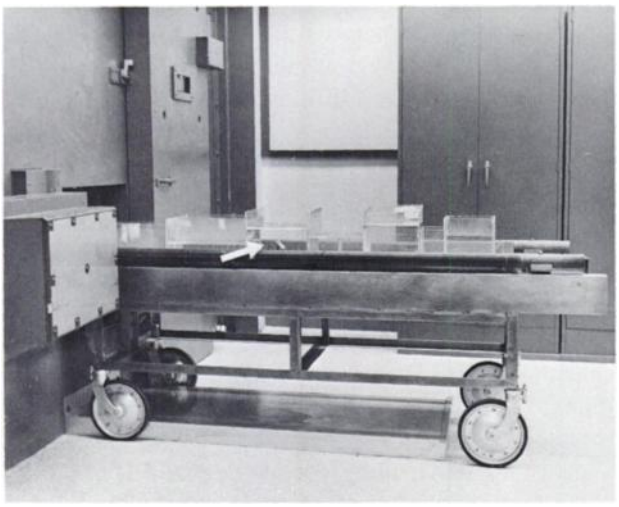

FIG. 1. The water-filled compartmented phantom containing ^{131}I source in pelvic compartment (arrow).

Clinical study. Ten patients were each given an oral dose of ^{131}I in the range of 4.2–9.1 μCi. Eight doses were in capsule form and the other two were given in liquid form. Each patient was counted immediately after administration of the dose and at 30-min intervals thereafter for 3 hr (total of 7 counts for each patient). The counting time was always 2 min. The patients refrained from voiding for the 3 hr required to do this study to keep the whole-body ^{131}I content constant (except for physical decay).

RESULTS

The first 10 computer-determined, minimum-variation windows from the water phantom study are listed in Table 1 in order of their variation index and compared with that of the photopeak. Obviously many spectral windows exist below the photopeak window where extreme changes in source location produce a relatively small variation index. However, the variation index of the photopeak window itself is large. Among the 820 windows analyzed by computer, only 51 had a larger variation index than the photopeak window and all of these had included all or part of the photopeak spectrum. Table 1 shows that some of the windows that result in small variation indices with extreme changes in source location are not really practical windows for everyday use because the window top (upper channel) is too close to the ^{131}I photopeak. Inclusion of any portion of the photopeak is a cause of unpredictable error when small electronic gain drifts occur and go uncontrolled. Therefore, the window with lower channel equal to 12 and upper channel equal to 31 (120–310 keV) was selected as the optimum window or most practical minimum-variation window for scatter counting everyday in patients.

Clinical results. The results of the studies are shown graphically in Fig. 2 for the photopeak window (310–410 keV) and the chosen minimum variation window (120–310 keV). The observed counts at each 0.5 hr are plotted as a percentage of the count obtained immediately after the dose was given. Because the patients were not allowed to void during the 3 hr covered by this study, the amount of ^{131}I in each patient was constant when corrected for physical decay. When the counts in the minimum-variation window (energy ranges 120–310 keV) were used, the maximum variation observed in the radioiodine content of any patient was less than 3%, but it was more than 35% when we used the photopeak window. During the 3 hr of the study the distribution of ^{131}I was changing rapidly and radically in these patients who were extremely variable from one another in stature. Figure 3 illustrates how variable iodine concentration is with time after dose.

It shows a series of profile scans made on one patient at approximately 1-hr intervals after a dose of ^{131}I. This patient was athyroid and, therefore, developed no neck concentration; however, during the 3-hr observation the ^{131}I distribution changed from essentially that of a small-volume source in the stomach to a diffuse distribution in blood and local distributions in the stomach and bladder. Figure 4 is a profile scan of a hyperthyroid patient showing four distinct areas of high concentration in addition to the blood distribution 3 hr after oral ^{131}I.

Table 2 contrasts the observed counts per minute per microcurie at 0 time for each of the 10 patients for the photopeak and the minimum-variation window. Counting efficiency is constant within ±5% with the minimum-variation window, but variations from the mean counts/microcurie are as large as 21% when the photopeak window is used.

DISCUSSION

This study shows that in whole-body counting of ^{131}I, the conventionally used photopeak counts have large variations independent of radioisotope quantity. These variations are related to body size and distribution of ^{131}I. However, a spectral window can be found where the observed whole-body count in man is constant within ±3% regardless of distribution of ^{131}I. The variation in observed counts per microcurie of ^{131}I is ±5% between subjects of extremely different size. Therefore, the accuracy of absolute quantitation of an unknown body burden of ^{131}I is greatly improved by using the minimal-variation window counting method described here. Absolute quantitation using the conventional photopeak-window counting method requires complex calibrations and extrapolations to correct both for body size and distribution of ^{131}I and is subject to large errors because the exact distribution is often difficult or impossible to determine and simulate in such calibration procedures.

The minimum-variation window that was determined for the whole-body counter used in this study is probably not directly applicable to other whole-body counters with different detector geometry. However, our experimental and analytical method described here can be used to determine this spectral window precisely for any whole-body counter.

We believe that a similar experimental approach

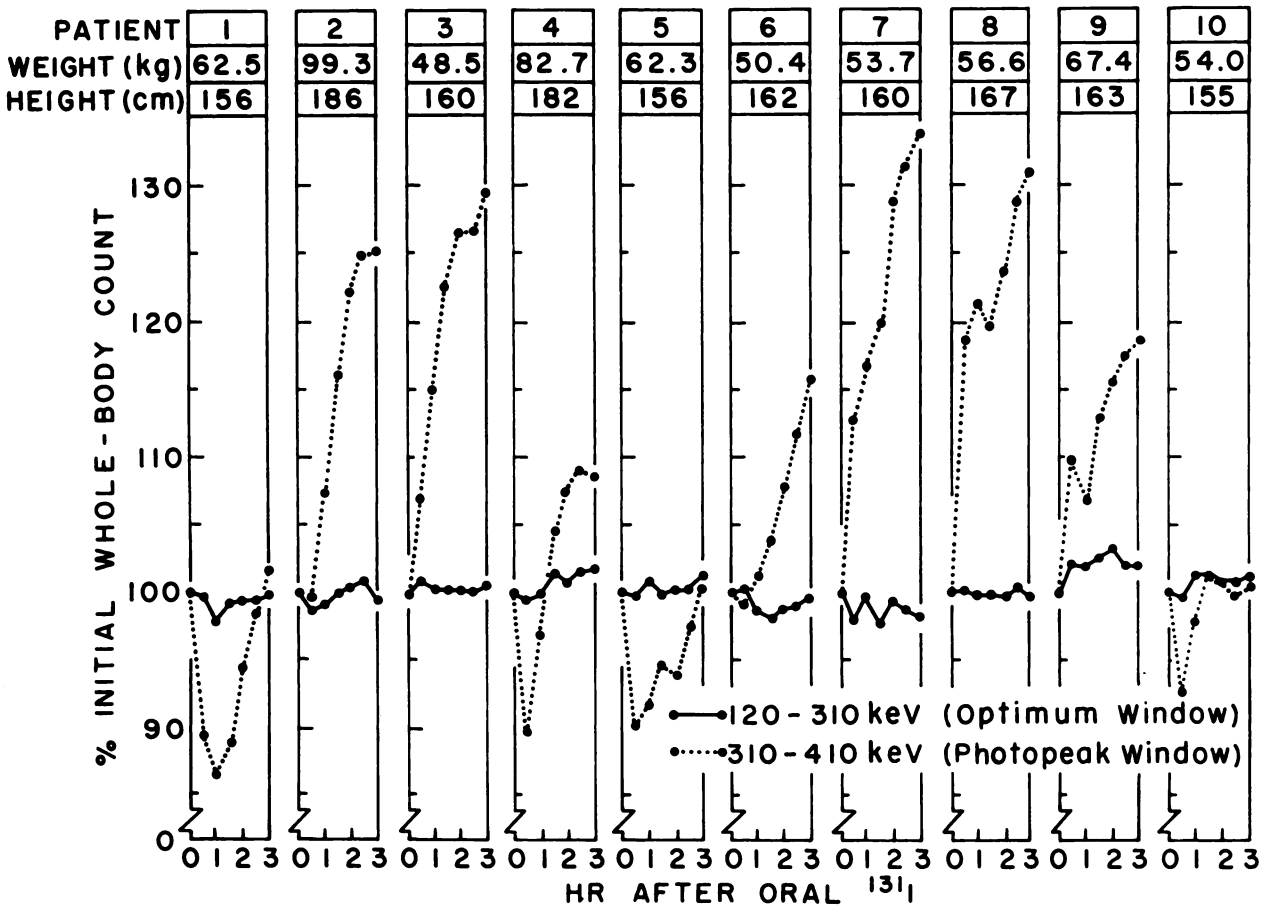

FIG. 2. Results of clinical studies with photopeak (310–410-keV) and optimum (120–310-keV) windows showing counting efficiency variations as large as 35% in photopeak window and less than 3% in optimum window.

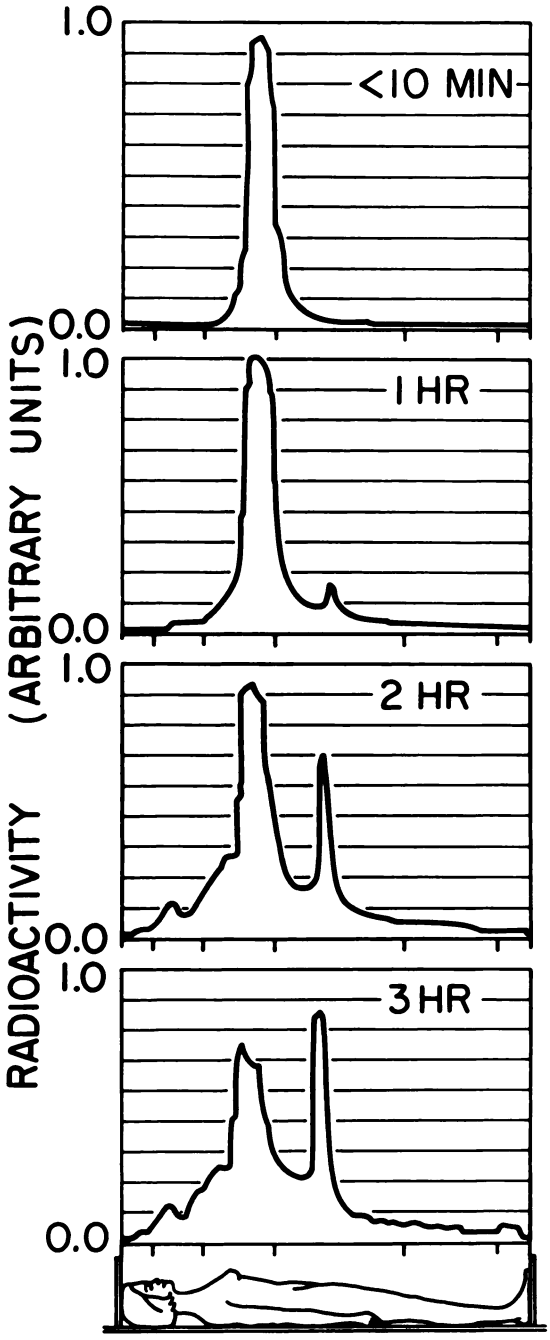

FIG. 3. Series of typical profile scans made on athyroid patient after oral dose of ^{131}I to show highly variable distribution of tracer that occurs in time.

with radioisotopes other than ^{131}I will produce minimum-error windows for each radioisotope that will enable more accurate relative and absolute quantitation than the photopeak windows now used. We are conducting these experiments and will report these results later.

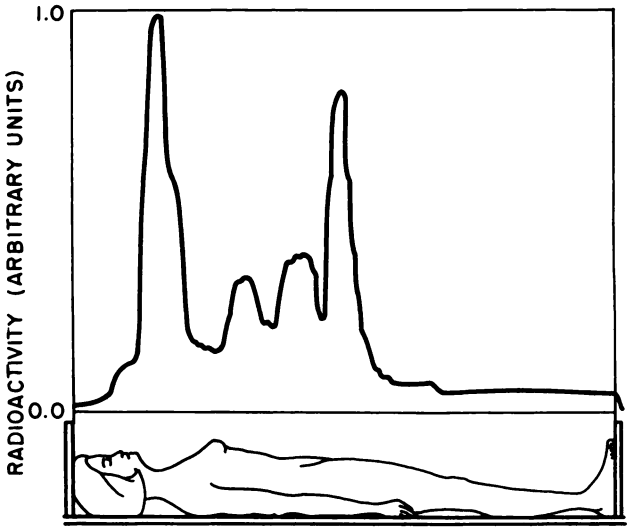

FIG. 4. Profile scan of regions of highest ^{131}I concentration 3 hr after oral dose in hyperthyroid person, showing in contrast with Fig. 3 extremely variable distribution of ^{131}I from patient to patient.

The minimal-variation window counting method and data presented here are not intended to suggest abandoning photopeak counting in all situations. All techniques that attempt to determine physical localization of ^{131}I (scanning, external organ counting, etc.), must use photopeak counting for optimum focus.

We doubt that our technique can be applied profitably to liquid scintillation or plastic detector whole-body counters where spectral resolution is poor, but probably for all whole-body counters with NaI(Tl) crystal detectors, minimum-variation windows can be found that will provide better quantitation than the use of the photopeak does. The degree of improvement obtained will be limited by the uniformity of the detector-to-subject geometry as determined by inverse-square characteristics.

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