Thyroid Uptake Measurements with I-123: Problems and Pitfalls: Concise Communication

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The measurement of radiolodine uptake is generally considered to be straightforward and accurate. However, during the past two decades, discrepancies in "normal" thyroid uptake values have been noticed between Montefiore Hospital and Medical Center and the Hospital of Albert Einstein College of Medicine. These differences were attributed to differences in patient population. Further investigation revealed that the persisting uptake discrepancies arose from neck-phantom differences and variations in procedure. Differences in presumably standardized neck-phantom attenuation characteristics have been shown to cause large variations in count rates from I-123 and I-131 standard capsules. The effect of high-voltage fluctuations on phantom count rates is more pronounced with I-123 than with I-131. In constant levels of high-energy contaminants in I-123 also affect the uptake measurements. Large errors in the measurements of thyroid uptake values may result from seemingly unimportant variations in technique. A stable high-voltage power supply, precise high-voltage adjustment, careful selection of energy window, and the use of a standardized neck phantom with generally accepted attenuation characteristics are absolutely essential if RAIU values are to be compared and appropriate therapeutic doses are to be administered based on these measurements.

J Nucl Med 23: 667-670, 1982

The measurement of thyroid uptake of radioiodine was one of the earliest clinically useful procedures in diagnostic nuclear medicine. In spite of its success, several sources of inaccuracy and inconsistency have been recognized over the years (1). Construction of the thyroid neck phantom to simulate the absorption and scatter characteristics of a human neck was one of the first steps towards adequate standardization of the thyroid uptake test. Differences in neck-phantom characteristics and HV fluctuation obviously may introduce significant errors into any thyroid uptake measurement, but even today the test is carried out in most laboratories with very little attention to these factors.

The introduction of I-123, a radionuclide with a shorter half-life than I-131 and better photon energies for gamma camera imaging, has accentuated the potential problems in thyroid uptake measurement. The effects of thyroid gland depth, incomplete dissolution of capsule filler, and radionuclide purity on I-123 thyroid uptake have been documented (2-5).

The present study was undertaken to investigate differences observed in the normal range for thyroid uptake in three large affiliated teaching hospitals. An extensive study was made of the thyroid neck-phantom characteristics, window settings and HV drift during the day, measurement techniques, and decay corrections. This

Received Feb. 5, 1982; revision accepted Mar. 22, 1982.

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FIG. 1. Cross sections of the three different neck phantoms used in the study, showing variations in capsule location. Phantom No. 1 = Picker Nuclear Neck Phantom 250002; Phantom No. 2, unmarked; Phantom No. 3 = Nuclear Associates 74-350.

investigation revealed the need to establish a set of simple but rigorous guidelines to help validate the uptake measurement values; it is the subject of this report.

MATERIALS AND METHODS

Three "IAEA neck phantoms" with identical outer dimensions but distinctly different capsule housing arrangements were used in the study (Fig. 1). The counting equipment in each case consisted of a NaI(T1) crystal, 5×5 cm, attached to a standard flat-field collimator (20 cm long and 7.6 cm diam) in conjunction with a singlechannel analyzer and scaler. Throughout the investigation the detector-to-phantom distance of 25 cm was held constant for the three phantoms. Iodine-131 was obtained as RAIU capsules. The I-123 was also obtained commercially and was found to contain I-124 as the only radioactive contaminant in detectable amounts. The proportion of I-124 to I-123 varied with each shipment, ranging from 3-5% at calibration time.

Several count determinations were made for both I-123 and I-131 under various experimental conditions and with different neck phantoms, in order to study the effect of high-voltage fluctuations during measurement and of high-energy gamma contaminants in I-123 on the indicated thyroid uptakes. These counts included measurement of the capsule in and out of the phantom, variation of the HV setting, different pulse height and window settings. Counts were taken for 1 min at HV settings varying from 1025 to 1100 V for each of the measurements, with the capsule inside and outside the phantom. The capsule was positioned outside the phantom and away from scattering media at the end of a stiff wooden rod such that the detector-to-capsule distance was identical to the distance when the capsule was counted inside the phantom.

The effects of these parameters on clinical thyroid uptake measurements were studied in eight patients who had thyroid uptake measurements after ingesting $100-\mu$ Ci I-123 capsules. All three neck phantoms were used to count the capsules in both differential (140–180 keV window) and integral mode (lower level discriminator at 140 keV). Each patient's capsule was counted both inside and outside the neck phantom while keeping the detector-to-capsule distance constant for each phantom. The ratio of phantom counts to air counts of the capsule was calculated both for the differential as well as integral counts. One of the capsules was set aside as a standard. Twenty-four hours after administration of an I-123 capsule to the patients, integral as well as differential counts were obtained from the neck and the standard capsule in all three phantoms and in air. The phantom-to-air count ratios for the standard were calculated as well as the uptake values.

The thyroid uptake was calculated with the following equation:

% uptake =
$$100 P_2 S_1 / S_2 P_1$$
, (1)

where P_1 = net capsule counts before administration, P_2 = patient neck counts, corrected for background counts obtained from the thigh, S_1 = net standard-capsule counts on the day of administration of capsule to patient, and S_2 = net standard-capsule counts on the day of neck counting.

RESULTS

Figure 2 shows the spectra of I-123 and I-131 both in air and in phantom as measured using the uptake probe, and illustrates the striking difference in the proximity



FIG. 2. Photopeaks and Compton scatter for I-123 and I-131, as seen with an uptake probe, with capsule in air and placed inside phantom. Shaded area shows scatter counts.

	Day of cal	ibration	24 hr after calibration		
	Differential counts (140-180 keV)	Integral counts (lower level at 140 keV)	Differential counts (140–180 keV)	Integral counts (lower leve at 140 keV)	
Phantom 1	0.92	0.92	0.95	0.99	
Phantom 2	0.93	0.94	0.91	0.98	
Phantom 3	0.79	0.80	0.83	0.88	

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of the Compton scatter peak to the total absorption peak for the two radionuclides when inside the phantom. It is obvious that a slight change in high voltage could shift the spectrum of I-123 in such a manner that an appreciable fraction of Compton scatter counts would be included in the selected window setting. The use of a wide window setting for I-123 would result in the inclusion of a significant amount of scatter. For example, with a 100-keV window, about 25% of the counts would be due to scatter from the phantom. In patient counting, this value would vary, depending on neck size and thyroid depth.

The complete spectrum of the I-123 capsule in the phantom was obtained using the uptake probe. Measurements were made on the capsule calibration date and 24 and 48 hr later. Although the amount of I-124 present is normally only 3 or 4%, the 511-keV annihilation peak and the 602-keV gamma peak were readily detected. Because of the longer half-life of I-124 (4.2 days), their contribution to the total count increases daily. If the I-123 capsule is counted in the integral mode, then the percent contribution of these high-energy photons, including their scatter from the phantom, would be as follows: calibration date, 5%; 24 hr after calibration, 10%; 48 hr after calibration, 19%. These figures could account for the differences between the narrow-window phantom-to-air ratios and the integral ratios as shown in Table 1.

Table 2 illustrates the phantom-to-air ratios of the I-123 and I-131 capsules using Phantom No. 3 when the high voltage was deliberately manipulated at a constant window setting. A significant variation has been noted during the course of the day after an initial HV adjustment of the pulse-height analyzer in the morning.

The thyroid uptake values in the first set of four patients, obtained by using the three phantoms, and the phantom-to-air ratios, are presented in Table 3A. Similar data are given in Table 3B for four more clinical cases studied with two phantoms and a different shipment of I-123 capsules. This is typical of variation in uptake measurements on different days.

DISCUSSION

There are inherent problems of inaccuracy and inconsistency in the measurement of thyroid uptake of

High oltage (V)	Actual window (keV*)	Phantom counts (cpm)	Air counts (cpm)	Phantom/ air ratio
. -131				
1050	340-440	7711	9249	0.83
1063	310-410	14184	15918	0.89
1075	270–370	14633	15902	0.92
1087	230–330	9325	8317	1.12
I-123				
1050	170–210	15226	19351	0.79
1063	140-180	24110	28603	0.84
1075	100-140	20723	21616	0.96
1087	70-110	12439	8145	1.53

[ABLE 3. THYROID UPTAKE VALUES WITH 123 CAPSULES OF TWO SETS OF PATIENTS USING DIFFERENT PHANTOMS*						
Patient	Phantom 1 %	Phantom 2 %	Phantom 3 %			
A. 1	20	21	24			
2	64	67	79			
3	23	24	28			
4	30	32	36			
B. 5	31		35			
6	68	_	78			
7	2.2	_	2.5			
8	3.3	_	3.8			

* The differences in thyroid uptake values obtained using different phantoms are reflected in the phantom-to-air ratios between phantoms. These range from 4% to 6% between Phantoms 1 and 2 and 20 to 23% between Phantoms 1 and 3.

TABLE 4. SUGGESTED PROTOCOL FOR THYROID UPTAKE MEASUREMENT WITH I-123

- 1. Use a well-stabilized high-voltage supply.
- Use the 250-keV range (higher gain setting in PHA) for counting I-123 and avoid using the 1-MeV range when using a singlechannel analyzer.
- 3. Perform high-voltage calibration every time the uptake probe is used.
- If a large window (100 keV) is used for high-voltage calibration, leave the I-123 capsule in the air and away from the neck phantom.
- 5. If the I-123 capsule is placed inside the neck phantom during high-voltage calibration use a (20-keV) window.
- 6. If a 6-mm solid plastic rod is used for distance determination, remove it during measurements, or replace it with a hollow rod or thin bar.
- 7. Do not use integral mode for counting I-123 because of scatter counts from high-energy contaminants.
- 8. Count all capsules before administration to the patients.
- 9. Do not use calculated counts (corrected for decay) when using I-123 because of the variation of scatter component with high-voltage fluctuation.
- 10. Use a standard neck phantom.
- 11. Calculate the thyroid uptake by using formula (1).

I-131, and these are aggravated by the use of I-123. Iodine-131, with its high-energy photons, offers certain advantages in overcoming these problems because of a fair degree of separation of the Compton scatter from the photopeak, whereas I-123, with primary photons of lower energy and long-lived impurities, introduces a different set of problems of attenuation and unpredictable scatter characteristics. The uptake measurements with I-123 have also been shown to be significantly influenced by variations of thyroid depth (2). This investigation focuses on the difficulty of reproducing phantom-to-air ratios for a standard I-123 capsule, as seen in the two sets of patients and raises the question of consistency in the accuracy of the thyroid values from day to day. There is a great need to standardize the neck phantom in terms of the depth of capsule housing and the resulting attenuation factor. The differences in the depths of the capsule in the three phantoms accounted for only one of the several complex factors that contributed to the differences in air-to-phantom count ratio, with the scatter function being the most unpredictable.

The magnitude of the error in RAIU measurements could be minimized and controlled by rigorous protocols in the measurement technique. These include use of a well-stabilized high-voltage power supply for the counting equipment, frequent HV calibration during the day to monitor variations in high voltage with changes of load on the power line during the day, use of standard neck phantoms, and adoption of a proper window selection at an appropriate gain setting for the pulse-height analyzer.

In conclusion, the recommendations to be scrupulously followed for thyroid uptake measurements using I-123 are listed in Table 4. It is imperative that an accurate intercomparison of phantoms be obtained in order to validate the uptake measurements between centers that serve the same patient population.

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