Deadtime Error with Iodine-123 Thyroid Uptake Measurements

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Thyroid uptake measurements performed using iodine-123 (^{123}I) are subject to a systemic error due to deadtime loss when the standard is derived based on a decay factor. Higher deadtime loss with ^{123}I is due to using more activity along with its better detection efficiency, higher count rate, and shorter half-life compared to that of ^{131}I. The degree of error due to deadtime loss may range from insignificant to extreme, depending on a number of factors. Degree of error is related to the activity administered, the window settings, the age and energy resolution of the instrumentation, and the elapsed time between standard and patient counts.

Under certain conditions, thyroid uptake measurements performed with ^{123}I may be subject to a systematic error due to deadtime loss. Paradoxically, this systematic error is due, directly or indirectly, to the same characteristics that have been cited as the advantages of ^{123}I when compared to those of ^{131}I. Iodine-123 has been described as ". . .theoretically the best tracer for thyroid imaging. . ." because it is physiologic, has excellent physical characteristics, and delivers a comparatively low radiation dose to the patient (*1*). Counting efficiency is better than that with ^{131}I because the photon energy of ^{123}I is in the optimal range for photopeak detection efficiency with sodium iodide detectors (*2*). The dosimetry of ^{123}I is excellent compared to that of ^{131}I, due to the shorter half-life and the absence of beta emission. Textbook examples demonstrate that the radiation dose to the patient is less by a factor of nearly a hundred for a given activity and uptake (*3*). Due to these advantages, ^{123}I has become the recommended radioiodine for diagnostic thyroid studies (*4*).

These same characteristics combine to contribute to a systematic deadtime error. With the radiation dose to the patient no longer a limiting factor, more activity may be administered: up to 400 μCi of ^{123}I compared to the 100 μCi of ^{131}I (*5*). Higher activity combines with better detection efficiency to produce much higher count rates, and deadtime loss is related to count rate. The short half-life results in a significant count rate difference with time if the standard and the patient are counted at different times.

It has been demonstrated that deadtime error is insignificant when an equal activity standard is counted at the time of the uptake measurement (*6*). However, the procedure of "decaying the standard" (i.e., deriving a standard count by multiplying an initial count by a decay factor) has been described in a number of sources (*4,5,7,8*) and is in apparent widespread practice. To economize on ^{123}I, this procedure calls for a capsule to be counted before it is given to the patient. Then when the uptake measurement is performed, the so-called standard is derived from the initial count multiplied by the decay factor for the elapsed time. Thus, the two counts involve very different count rates and are, therefore, subject to different degrees of deadtime loss. The systematic error that is introduced may be insignificant to severe. The error is related to the inherent deadtime, age, and energy resolution of the instrumentation, the activity used, the window fraction effect, and to the elapsed time between the standard and patient counts.

MATERIALS AND METHODS

Iodine-123 used in this study was obtained from a commercial nuclear pharmacy in the form of 3.7 MBq (100 μCi) capsules. Deadtime effects were studied using three thyroid uptake systems*†‡. Characteristics of these three systems are shown in Table 1. Proper calibration of each instrument was confirmed prior to all measurements. System deadtime was determined using the two-source method (*9*). Deadtime measurements are plotted as the mean and standard deviation (SD) of five determinations. All other data represent the mean of triplicate measurements. Decay factors are based on a value of 13.22 hr for the half-life of ^{123}I, the current best estimate (Stabin M, *personal communication*, 1986).

Measurement conditions were intended to be representative of routine clinical practice. Capsules were counted in thyroid phantoms, with counting geometry identical to that used for

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TABLE 1. Characteristics of Three Thyroid Uptake Systems

Instrument	Age	FWHM ^{137}Cs	FWHM ^{123}I
A*	1 yr	7.9%	9.5%
B†	5 yr	9.0%	13.8%
C‡	9 yr	9.7%	21.8%

TABLE 2. Measuring Deadtime Loss*

Activity (μCi)	Initial Count	24-Hr Count Expected	24-Hr Count Measured	% Error
Instrument A Window: 20%				
100	370,128	105,189	106,399	1.2
200	740,298	210,389	215,435	2.4
300	1,091,082	310,080	321,019	3.5
400	1,405,126	399,330	426,087	6.7
Instrument B Window: 20%				
100	442,612	125,800	131,294	4.4
200	838,656	238,364	259,236	8.8
300	1,190,854	338,467	385,132	13.8
400	1,533,694	435,910	503,194	15.4
Instrument C Window: 20%				
100	280,041	79,586	99,631	25.2
200	432,943	123,040	181,584	47.6
300	512,834	145,745	249,535	71.2
400	554,311	157,533	304,589	93.3

*At a constant window setting, deadtime loss increases with activity. In every instance, the expected count rate at 24 hr, predicted by multiplying the initial count rate by the 24-hr decay factor, is less than the count rate actually measured at 24 hr.

routine standard counts. Activities of 3.7 to 14.8 MBq (100–400 μCi) were used, and elapsed times of 2–24 hr, corresponding to published procedures (*5*).

RESULTS AND DISCUSSION

Deadtime loss occurs because radiation detection systems require a characteristic resolving time between events if they are to be recorded as separate pulses. An event may not be recorded if it occurs before the processing of a prior event has been completed. The probability of deadtime loss increases with increasing count rate and may be a significant source of error at high count rates. Due to this loss, the observed count rate will be less than the true count rate (*10*).

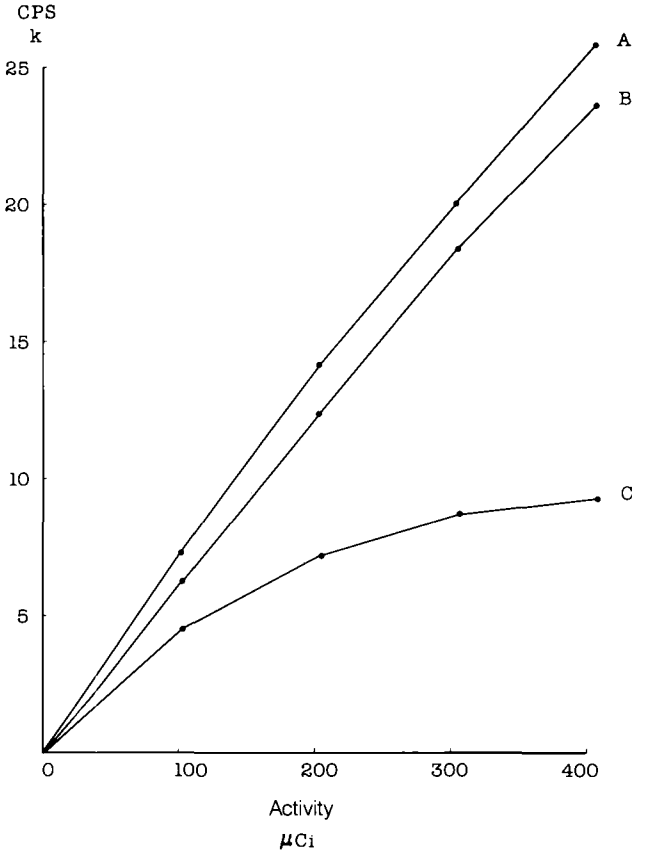

FIG. 1. Measured count rates for systems A, B, and C are not linear with activity in the clinically used range. Due to deadtime losses, the observed count rates are less than expected.

Greater deadtime loss is to be expected with ^{123}I due to the higher count rate. This effect is shown in figure 1, in which the observed count rates are not linear with activity. Each curve is concave downward, although there is a significant difference between machines.

The procedure of "decaying" a standard assumes that the standard count derived by multiplying an initial count by a decay factor is equivalent to an equal activity standard counted at a later time. Table 2 demonstrates that this assumption is not necessarily valid, because radioactive decay is not the only factor affecting the count rate. In every case, the count rate actually measured at 24 hr is greater than the count rate predicted from the initial count times the 24-hr decay factor. The initial count rates were much higher and subject to more deadtime loss. Derived standards based on decay factors are actually underestimates, and an uptake based on such a standard would be an overestimate.

The amount of error increases with activity. Window width also affects the error due to the window fraction effect. Table 3 shows that this amount of error is inversely related to win-

TABLE 3. Effect of Window Width on Deadtime Loss*

Window	Initial Count	24-Hr Count Expected	24-Hr Count Measured	% Error
Instrument A Activity: 100 μCi				
10%	306,039	86,975	88,718	2.0
20%	382,073	108,583	110,398	1.7
30%	410,122	116,555	118,453	1.6
40%	439,184	124,814	127,102	1.8
Instrument B Activity: 100 μCi				
10%	288,902	82,112	87,720	6.8
20%	442,612	125,800	131,294	4.4
30%	505,610	143,706	147,289	2.5
40%	534,474	151,909	156,222	2.8
Instrument C Activity: 100 μCi				
10%	140,210	39,847	52,788	32.5
20%	275,963	78,427	97,726	24.6
30%	337,277	95,852	115,714	20.7
40%	374,097	106,317	125,505	18.0

*At a constant activity, deadtime loss varies with window width due to the change of apparent deadtime loss (Fig. 2). The error is progressively worse with older equipment.

TABLE 4. Effect of Elapsed Time on Deadtime Loss*

Time Hr	Window Width	% Error 100 μCi	200 μCi	300 μCi	400 μCi
2	10	1.8		1.5	2.3
	20	—	—	—	0.2
	30	—	—	—	0.5
	40	—	—	—	0.6
6	10	2.5	4.9	3.7	4.9
	20	1.1	1.1	2.4	1.9
	30	0.3	0.9	1.7	1.6
	40	—	1.0	0.4	1.0
24	10	5.5	8.6	12.0	16.2
	20	3.3	5.2	8.9	11.9
	30	2.4	4.3	7.1	9.6
	40	2.1	3.9	4.9	8.0

*Error progressively increases with time as the count rate decreases due to radioactive decay, increasing the count rate difference in comparison to the initial count rate (Instrument B).

dow width, and the error is worse in older machines with poorer energy resolution (compare with Table 1). All events occurring within the detector contribute to deadtime loss whether or not they fall within the window. The apparent deadtime, or deadtime per event within the window, is longer than the real instrument deadtime measured with the total spectrum. The difference is related to the ratio of events occurring within the window to the total spectrum (*11*). A change of window setting alters this ratio. Figure 2 demonstrates that the measured deadtime decreases with a wider window.

Elapsed time is another factor. As expected, the error becomes progressively greater with time, due to the difference in count rates (Table 4). Deadtime error is insignificant at 2 hr, slight at 6 hr, but may be a significant problem at 24 hr.

The presence of long half-life contaminants would be expected to cause count rates at 24 hr to be higher than anticipated, but their effect is negligible. Results obtained with ^{124}Xe (p,2n) ^{123}I are virtually indistinguishable (data not shown) from the deadtime error measured using ^{124}Te (p,5n) ^{123}I, although the two types of ^{123}I differ markedly in contaminant levels.

CORRECTIVE ACTION

Some correction for deadtime losses is obviously necessary. The easiest and most straightforward solution would be to use a separate standard, counted at the same time as the patient.

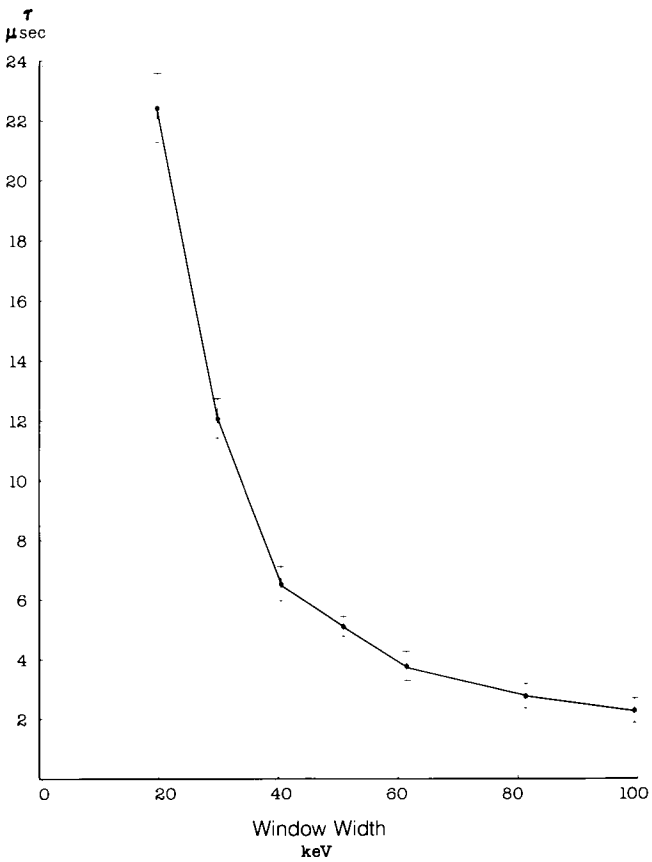

FIG. 2. Apparent deadtime (system B) varies inversely with window width due to the window fraction effect.

This eliminates radioactive decay as a variable. Depending of course on uptake, the patient and standard count rates would be much more comparable and subject to approximately equivalent deadtime losses. The error would partially cancel out when one count is divided by the other. However, use of a separate standard would be more expensive since more ^{123}I is used per procedure.

An alternate procedure that we have adopted makes use of a computer program to perform the deadtime correction. It is based on the approximate correction:

$$R_t = \frac{R_o}{1 - R_o\tau},$$

where R_t = true count rate, R_o = observed count rate, and τ = deadtime (*12*). The program converts patient and standard count rates into counts per second (cps) and corrects them for deadtime losses prior to any correction for background and radioactive decay. It is assumed that background count rates are low enough not to require deadtime correction. Percent uptake is calculated as:

$$\% \text{ uptake} = \frac{\frac{R_p}{1-R_p\tau} - R_{th}}{\frac{R_s}{1-R_s\tau} - R_b} \times \frac{100}{e^{-\lambda t}},$$

where

R_p = patient count rate (cps)
R_{th} = thigh count rate (cps)
R_s = standard count rate (cps)
R_b = background count rate (cps)
τ = deadtime (s)
$e^{-\lambda t}$ = decay factor.

A precise value of deadtime is essential. Once this is determined, however, the procedure is quite simple and provides an economical use of ^{123}I.

CONCLUSION

Deadtime loss introduces a systematic error into thyroid uptake measurements done with ^{123}I. Without a correction for this error, derived standards based on decay factors are underestimates, and the uptakes in turn are overestimates.

Error varies widely with different equipment and procedures. For any particular uptake system, the error may or may not be significant. However, it should not be taken for granted that it is not. This systematic error can be eliminated by use of either a separate standard or by use of a computer program.

NOTES

*Series 35 Plus (MCA), Canberra, Meriden, CT
†Spectroscalar 4R (SC), Picker, Highland Heights, OH
‡Model 300 spectrometer (SCA), ADAC, San Jose, CA

REFERENCES

1. Moses DC. Thyroid Scanning. In: Keyes JW, ed. *CRC Manual of Nuclear Medicine Procedures*, 3rd ed. West Palm Beach, FL: CRC Press, 1978:64.

2. Sorenson JA, Phelps ME. *Physics in Nuclear Medicine*, Orlando, FL: Grune and Stratton, Inc., 1987:326–327.

3. Early P, Sodee B, Razzak M, eds. *Textbook of Nuclear Medicine Technology.* St. Louis: CV Mosby Co., 1979:137.

4. Early P, Sodee B. *Principles and Practice of Nuclear Medicine.* St. Louis: CV Mosby Co., 1985:556–558.

5. Sodee B, Early P. *Manual of Nuclear Medicine Procedures.* St. Louis: CV Mosby Co., 1981:250–255.

6. Simpkin D. The effect of counting system deadtime on thyroid uptake measurements. *Med Phys* 1984;11:296–299.

7. Bernier D, Langan J, Wells D. *Nuclear Medicine Technology and Techniques.* St. Louis: CV Mosby Co., 1981:247–248.

8. Drew H. Thyroid imaging studies. *J Nucl Med Technol* 1987;15:83

9. Cember H. *Introduction to Health Physics.* New York: Pergamon Press, 1983:245.

10. Knoll GF. *Radiation Detection and Measurement.* New York: John Wiley and Sons, 1979:95–96.

11. Sorenson JA, Phelps ME. *Physics in Nuclear Medicine.* Orlando, FL: Grune and Stratton, Inc., 1987:256.

12. Knoll GF. *Radiation Detection and Measurement.* New York: John Wiley and Sons, 1979:96–99.