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RADIOIODINE-123 FOR APPLICATIONS IN DIAGNOSIS

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ABSTRACT

RADIOIODINE-123 FOR APPLICATIONS IN DIAGNOSIS.- The physical properties of 13-h I-123 make it the "ideal" radionuclide among the 30 nuclides of iodine for most uses in diagnosis. The 84% of 159-keV γ-rays have half-thicknesses in water of 4.7 cm, in NaI of 0.36 cm, in lead of 0.037 cm. The calculated photopeak detection efficiency in the 1.3-cm-thick NaI crystal of the Anger Camera is ≃ 90%, which is ≃ 3-fold greater than for the 364-keV γ-rays of I-131. Unfortunately, I-123 emits 5 additional γ-rays having energies in the 274-530-keV range, in ≃ 3% of the disintegrations.

Iodine-123 emits no β-particles, and the average energies of the conversion and Auger electrons are low relative to those of the β-particles of I-131; localized radiation exposures from I-123 cannot exceed several percent of those from I-131.

The 19-h average life closely matches the times usually involved in studies of iodine metabolism. Thus, not only is radiation greatly reduced further, but repetitive and confirmatory studies thereby are facilitated. Moreover, the low radiation from I-123 gives less cause for concern in conventional uptake studies; and even routine imaging of its distribution may be contemplated as an important additional advantage. Thus, much more informative thyroid "evaluation" studies become feasible, to supplant the limited usefulness of simple I-131 "uptake" measurements. Images made with the pinhole camera demonstrate superior resolution to those obtainable with I-131.

Iodine-123 lacks 4 of the neutrons of stable I-127. This "neutron deficiency" requires cyclotrons or other accelerators to generate it. These now are being used to produce I-123 in a variety of nuclear reactions, and in purities adequate for use clinically. One supplier bombards Te-122 (enriched to greater than 95%) with deuterons to provide I-123 that is contaminated at the time of calibration with only ≃ 2% of a combination of I-124, I-126, I-130, and I-131. A dose of 100

μCi of this I-123 and its contaminants, gives a maximum exposure of less than 6 rad to the thyroid gland and 20 mrad to the whole body.

INTRODUCTION

Iodine is least abundant among the 15 principal elements in "standard man", comprising only 2.13 X 10^{-6} at.% of him. By contrast, the number of iodine radionuclides is 29, which is more than twice that of any other "physiological" element [1]. The sole stable nuclide of iodine is I-127; and much of the 30 mg of it in us normally is present in the thyroid gland.

The ready availability now of Iodine-123 in adequate purity furnishes clinicians with opportunities to exploit its advantageous physical properties for many purposes [1]. Not only may physicians obtain superior information when they use I-123 for in vivo diagnostic procedures; but, very importantly, they may decrease radiation exposures to their patients simultaneously to as little as only a few per cent of those that result when they administer I-131 in comparable initial dosages.

TABLE I. PRINCIPAL PHYSICAL PROPERTIES OF IODINE-123 AND IODINE-131

	Iodine-123		Iodine-131
A. RATES OF DECAY			
Physical Half-Life	13 Hours		193 Hours
Average Physical Life	19 Hours		279 Hours
B. DECAY TYPES AND PARTICULATE RADIATIONS			
Modes of Decay	E.C.		β^-, γ
Chief Beta Particle	No β		90.4% 606 keV max. 192 keV ave.
Conversion Electrons	15.4% 127-158 keV		6.3% 46-363 keV
C. PRINCIPAL PHOTONS			
K X-Rays or γ-Rays (keV)	28 (av)	159 keV	364 keV
K X-Rays or γ-Rays (%)	92 %	84 %	82 %
Half-Thickness in Water	1.7 cm	4.7 cm	6.3 cm
Half-Thickness in Lead	0.0016	0.037	0.24 cm
Half-Thickness in NaI	0.020	0.37	1.45 cm
Photopeak Efficiency In:			
0.5-inch NaI(Tl)	99 %	87.4 %	29.8 %
1.0-inch NaI(Tl)	99 %	96.6 %	54.4 %
2.0-inch NaI(Tl)	99 %	98.0 %	80.7 %
D. OTHER PHOTONS			
High-Energy Gamma-Rays	≃ 3% 274-530 keV		6.8% 637 keV 1.6% 723 keV

ADVANTAGEOUS PHYSICAL PROPERTIES OF IODINE-123 OVER IODINE-131

Values for the pertinent physical properties of these radionuclides are listed in Table I, together with calculations based upon them, to facilitate intercomparisons of advantages of I-123 over I-131.

A. RATES OF DECAY.- The 19-h average life of I-123 closely matches the time required for most diagnostic procedures involving labeled iodide ion. It is less than 7 per cent of the unnecessarily and undesirably ≃ 15-fold longer 279-h average life of I-131. This factor alone leads to a large reduction in radiation exposure when I-123 replaces I-131 in procedures of long duration. Moreover, the

13-h $T_{1/2}$ of I-123 facilitates confirmatory and repetitive determinations; and it greatly lessens laboratory and environmental contamination.

B. DECAY MODES AND PARTICULATE RADIATIONS. - Iodine-123 decays solely by electron capture and lacks the abundant beta-particles emitted by I-131. Not only do these high-energy, short-range particles contribute principally to localized radiation exposure; but, also, they yield no useful information when I-131 is used for in vivo diagnostic studies.

The 192-keV average energy of the principal I-131 beta-particles exceeds the maximum energy of the conversion electrons of I-123, and they are more numerous [2,3]. Calculations based on the weighted abundances of the I-123 conversion electrons [3], gives ≃ 130-keV as their average energy. Hence, the ≃ 6-fold greater abundance of the beta-particles of I-131, when multiplied by the ratio of the average energies (192-keV/130-keV), indicates that the localized radiation exposure from only the chief beta-particles of I-131 will be ≃ 9-fold greater than from the conversion electrons emitted by I-123. When this ratio is multiplied further by the ≃ 15-fold longer average life of I-131, the difference in exposure during complete decay of a localized accumulation (in processes having long biological half-periods) becomes ≃ 135-fold greater from I-131 than from I-123.

RELATIVE RADIATION EXPOSURES TO THE THYROID GLANDS OF CHILDREN. It is especially important to replace I-131 with I-123 in thyroid uptake and imaging studies in infants and children [1]. A more complete analysis [4], which includes estimates of exposure due to the photons absorbed in the gland, reveals that the total dose absorbed from I-131 will be 85 times greater than from I-123 in a 1-g infant thyroid having an 80% uptake and an effective elimination time of 6 days.

C. PRINCIPAL PHOTONS: I-123(84% 159-keV γ-Rays). An especially important advantage of Iodine-123 is the 159-keV energy of the principal photons it emits in 84% of the disintegrations, in comparison with the 364-keV γ-rays emitted by I-131 in 82% of the decays (Table I).

Penetration in Water. - The calculated "narrow-beam" half-thickness of these 159-keV γ-rays in water is 4.7 cm. Thus, they are quite adequately penetrating for in vivo studies, even from accumulations lying deep within the body. The half-thickness of the 364-keV γ-ray of I-131 is 6.3 cm.

Absorption in Lead. - The half-thickness of the I-123 159-keV γ-rays in lead is only 0.037 cm, while that of the I-131 364-keV γ-rays is 0.24 cm (6.5-fold greater). Directionalization by selective absorption in collimators made from lead is simplified and more effective with I-123 so that resolution is improved greatly. The septa of parallel-hole collimators for γ-ray cameras can be made thinner and the efficiency is improved and dosages need be less.

The focused collimators for rectilinear scanners also can be made more efficient. Additionally, their light weight can simplify mechanization and decrease inertial resistance to change of direction.

Directionalized hand-held detectors are conveniently light. Also, the lesser penetration of the I-123 159 keV γ-rays in lead simplifies protection of personnel by shielding.

Depth Estimation with I-123 159-keV γ-Rays and 28-keV (av) X-Rays. - Differences in attenuation of these photons in overlying soft tissues may be used to estimate depths of I-123 by comparing the ratios of the 159-keV γ-rays to the 28-keV X-rays with curves derived experimentally in water [1,5,6]. This use of a single nuclide has advantages over the use of the 28-keV X-rays of I-125 [1,7,8] in combination with the 364-keV γ-rays of I-131 for similar objectives [9].

Also, it is feasible to make two rectilinear scans simultaneously of the thyroid gland [5,6] by using two energy-discriminator circuits (one tuned to the 159-keV γ-ray and the other to the 28 keV X-ray) and two separate readout styluses.

Relative Absorption in Sodium Iodide in the Scintillation Camera. - The calculated photopeak detection efficiency of 159-keV γ-rays in the 0.5-in.-thick NaI(Tl) crystal of scintillation cameras is 87%, whereas it is only 29% for the 364-keV γ-ray of I-131 (Table I). This much greater efficiency for the 159-keV γ-rays was a principal consideration in the efforts in this laboratory to explore

the biomedical potential of Iodine-123 [10]. Obviously, this 3-fold detection enhancement makes a reduced dosage possible, or a greater detected photon rate, or a combination of these two factors.

D. OTHER PHOTONS. - Unfortunately, in ≃ 3 per cent of the disintegrations, I-123 may emit any one of five γ-rays (Table I) with energies in the 274-530-keV region, most of which are 530-keV γ-rays. However, even here, I-123 has advantages over I-131, because the latter emits almost three times more γ-rays having higher energies (637-723-keV).

THYROID IMAGING AND UPTAKE STUDIES WITH IODINE-123

Four scintiphotos of thyroid glands are shown in Fig. 1. Patients had ingested a capsule containing approximately 100 μCi of I-123-iodide about 4-6 hours before the images were made with a Nuclear-Chicago Pho/Gamma Scintillation Camera operated in the pinhole mode.

In Fig. 1A a large defect is delineated sharply in which the I-123 did not accumulate in the lateral part of the left lobe. Actually, resolution is sufficient that one can see the decreased uptake extends through the lobe to its medial aspect. Also, there appears to be a broad defect in the inferior aspect of the left lobe as well. The uptake was 24%.

Fig. 1B clearly demonstrates that I-123 uptake largely is lacking in almost all of the left lobe except along the medial one-third of it. Also, I-123 is seen clearly not to have accumulated uniformly in the lower half of the right lobe.

Fig. 1C shows an essentially normal thyroid gland morphologically except for an area of localized concentration of I-123 in the upper right aspect of the isthmus.

The resolution in Fig. 1D is adequate to demonstrate clearly a narrow extension of I-123 accumulation upward from the superior end of the right lobe which appears to be due to a developmental anomaly.

DISCUSSION

In the case of the thyroid gland shown in Fig. 1A, there was a 24% uptake of I-123; and, although this lies within the normal range, the image demonstrates a striking lack of homogeneity in distribution of the I-123-labeled iodide. This illustrates how images can provide important information that supplements uptake studies.

The greatly decreased radiation exposures involved in making images by means of I-123 should encourage clinicians to obtain this additional information on a routine basis to augment the simple uptake studies, which are only of limited value otherwise.

The 19-h average life of I-123 is sufficiently long for some methods of studying protein-bound iodine turnover. The low radiation exposures should encourage frequent repetition when indicated for confirmation or for the evaluation of treatment.

Since I-123 lacks 4 neutrons and I-131 has an excess of 4 neutrons in comparison with stable I-127, fundamental studies are contemplated to assess whether this large 8-neutron mass difference may result in an "isotope effect" and different biochemical behavior under some circumstances.

Radioiodine-125, with 60-d $T_{1/2}$ [7], has come into extensive use in radioimmunoassay and similar procedures [11]. Whenever these may be completed within a few hours, the sensitivity might be increased up to ≃ 100-fold by substituting 13-h I-123 [1].

Potential advantages of I-123 for labeling iodohippurate (Hippuran), rose bengal, iodinated proteins and similar substances, as well as for multiple labeling in conjunction with I-125, I-126 and/or I-131 were projected previously [1,8].

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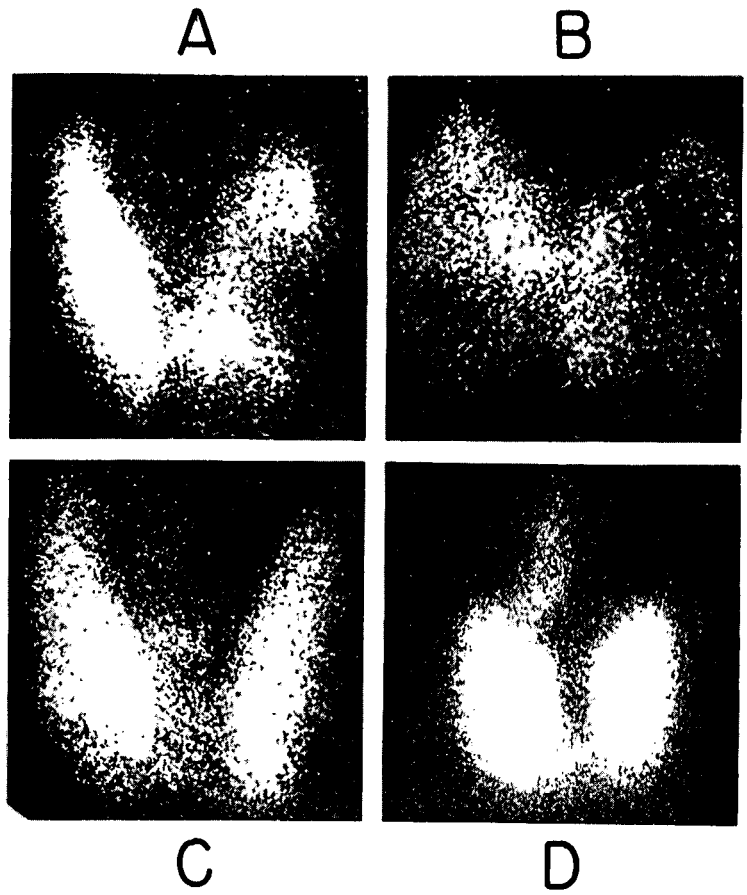

Fig. 1. Scintiphotos of thyroid glands made 4-6 hours after ingesting ≈ 100 µCi of I-123-iodide, with a Nuclear-Chicago Pho/Gamma Scintillation Camera equipped with a pinhole collimator.

A. Iodine-123 did not accumulate in a large defect in the lateral part of the left lobe. Also, a broad defect along the lower edge of the left lobe is present.

B. Iodine-123 is almost absent in the left lobe except the medial one-third, and has accumulated poorly in the lower part of the right lobe.

C. Morphologically normal thyroid except for increased concentration of Iodine-123 in the right upper aspect of the isthmus.

D. Iodine-123 is seen in a functioning developmental anomaly which extends from the superior end of the right lobe.

scintiphotos in Fig. 1 made by means of Iodine-123 in their patients.

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