# Impact of Radiocontaminants in Commercially Available Iodine-123: Dosimetric Evaluation

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Iodine-123 ($^{123}$I) is considered by some to be the radionuclide of choice for thyroid scintigraphy because of its ideal physical and biological characteristics and low radiation absorbed dose to the thyroid. However, commercially available $^{123}$I (p,2n) and (p,5n) have radiocontaminants. The MIRD formalism was used to estimate the absorbed dose to the thyroid for various age groups receiving recommended administered activities at the time of delivery and at two half-lives assuming radiocontamination levels specified by the suppliers. The calculations demonstrate that an $^{131}$I uptake with a technetium-99m scan at the time of delivery results in less absorbed dose to the thyroid than an $^{123}$I (p,2n) scan and uptake. At two half-lives the absorbed dose triples and becomes equivalent to the dose from an $^{131}$I scan. The absorbed dose from an $^{123}$I (p,5n) scan at two half-lives is higher than that of an $^{123}$I (p,2n) scan at the time of delivery. Iodine-123 capsules should not be decayed down in order to obtain a recommended pediatric administered activity. There appears to be no dosimetric advantage of commercially available $^{123}$I for thyroid scintigraphy for adults or most children.

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Iodine-123 ($^{123}$I) is considered by some to be the radionuclide of choice for thyroid uptake and imaging because of its "ideal" physical and biological characteristics (*1–4*). Only the problems of high production costs and inefficient distribution systems prevent its widespread use. Its radiation absorbed dose to the thyroid is 1/100th that of $^{131}$I and is felt to be almost as low as technetium pertechnetate (*2,5,6*).

However, commercially available $^{123}$I (p,2n) and more recently $^{123}$I (p,5n) have long-lived radioactive contaminants—$^{124}$I and $^{125}$I, respectively. In addition, the administration of recommended activities of $^{123}$I to children is difficult since the smallest available capsule contains 100 $\mu$Ci. The capsule must be "decayed down" or a larger than recommended activity administered. Allowing the $^{123}$I to "decay down" results in a larger percentage of long-lived radioactive contaminants with time, resulting in a higher radiation absorbed dose to the thyroid for equal administered activities of $^{123}$I (i.e., 50 $\mu$Ci administered at the time of delivery (TOD) compared with 50 $\mu$Ci administered after two half-lives of radioactive decay). Although $^{123}$I (p,2n) in solution is commercially available, it must be purchased in units of 1 mCi. Iodine-123 (p,5n) in solution is not for human use.

This paper evaluates the radiation absorbed dose to the thyroid from commercially available $^{123}$I (p,2n) and (p,5n) at various ages using recommended administered activities at TOD and at two half-lives (26.6 hr) after delivery, comparing this with other commonly used thyroid radiopharmaceuticals, $^{131}$I and technetium-99m ($^{99m}$Tc) pertechnetate.

## MATERIALS AND METHODS

The MIRD formalism (*7*) was used to estimate the radiation absorbed dose to the thyroid based on data and recommendations of Kereiakes et al. (*8*) and the Task Force on Short-lived Radionuclides for Medical Applications (*9*). The $^{123}$I absorbed dose was based on the manufacturers stated maximum radiocontamination. The adult thyroid weight assumed for these calculations was 20 g, 15.8 g for the 15 yr old, 8.7 g for 10 yr old, 6.1 g for 5 yr old, 2.5 g for 1 yr old, and 1.9 g for the newborn (*8*). The assumed biological half-life of iodine in the thyroid was 65 days. A 25% uptake for iodine is assumed except for the newborn, where a 70% uptake is

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**TABLE 1**
**Recommended Administered Activity (*9*)**

| Age | $^{131}$I Uptake ($\mu$Ci) | $^{131}$I Scan ($\mu$Ci) | $^{123}$I Uptake ($\mu$Ci) | $^{123}$I Scan ($\mu$Ci) | $^{99m}$Tc Scan (mCi) |
|---|---|---|---|---|---|
| Adult | 6 | 30 | 20 | 200 | 5.0 |
| 15 yr | 2 | 25 | 20 | 170 | 4.2 |
| 10 yr | 2 | 18 | 10 | 120 | 3.0 |
| 5 yr | 2 | 13 | 10 | 86 | 2.2 |
| 1 yr | 2 | 9 | 10 | 60 | 1.5 |
| Newborn | 2 | 4 | 10 | 28 | 0.7 |

assumed. A 1.6% uptake of [$^{99m}$Tc]pertechnetate is assumed except for newborns, 3.5%.

Sodium iodide $^{123}$I* is accelerator produced by the tellurium-124 ($^{124}$Te) (p,2n) $^{123}$I reaction. The radioisotopic contaminants present in the final product are $^{124}$I (<5.0%) and sodium-24 ($^{24}$Na) (<0.5%) as specified by the manufacturer. The maximum amount of radiocontaminants, including traces of tellurium, and aluminum in the product at calibration time, is less than 6% of the nominal $^{123}$I activity present. The final radiopharmaceutical product contains a minimum of 94% of sodium iodide $^{123}$I. This is available in 100 $\mu$Ci capsules and 1 mCi solution.

Sodium iodide $^{123}$I† is produced by the $^{127}$I (p,5n) $^{123}$Xe → $^{123}$I reactions and contains 1.9% or less $^{125}$I as the only radionuclide impurity at time of calibration. At time of expiration (30 hr) the capsules contain not less than 91.2% $^{123}$I, not more than 3.4% $^{125}$I and not more than 0.4% all other radionuclides. This product is available only in 100 or 200 $\mu$Ci capsules. The supplier‡ of $^{123}$I (p,5n) for purposes of packaging in capsules and distributing states that $^{125}$I radiocontamination at processing is <0.1%. However, the radiocontamination at the usual time of calibration and delivery (45 hr) is usually 1.4–1.8% (*10*). Although $^{123}$I (p,5n) in solution can be delivered directly from the producer within 24 hr, it is not approved for human use.

Iodine-123 is now produced by the $^{124}$Xe (p,2n) $^{123}$Cs → $^{123}$Xe → $^{123}$I method§ with no detectable $^{124}$I or $^{125}$I; however, it is not approved for human use.

The recommended administered activity for average adult patients (70 kg) according to the manufacturer is 100 $\mu$Ci for uptake studies and 400 $\mu$Ci for thyroid imaging. This was judged to be higher than commonly used or required; therefore, our data is based on an adult administered activity of 200 $\mu$Ci adjusted by age according to Webster's rule: adult dose × (age + 1)/(age + 7) (*11*). The administered activities assumed in this paper for young children for dosimetric calculations are lower than used in many laboratories.

In this paper, dose is defined as the quantity of radiation energy deposited in the thyroid per g of tissue. The unit of absorbed dose is the rad. Activity refers to the amount of administered activity of the radionuclide in units of mCi or $\mu$Ci, indicating the rate of radioactive decay.

## RESULTS

Table 1 lists the recommended administered activity according to age (*8,9*). The calculated radiation absorbed doses to the thyroid for both uptakes and scans using $^{131}$I, $^{123}$I (p,2n) and (p,5n) assuming manufacturer's stated radiocontaminants, and $^{99m}$Tc are shown in Table 2. Figure 1 compares the radiation absorbed dose (rad) to the thyroid from various thyroid scans including $^{131}$I, pure $^{123}$I, $^{123}$I (p,2n) and (p,5n), and $^{99m}$Tc for different ages. Figure 2 compares the absorbed dose from an $^{131}$I uptake and $^{99m}$Tc scan to that from $^{123}$I (p,2n) and (p,5n) scans with uptakes at time of delivery (TOD) and two half-lives (Day 2) for different ages. Figure 3 compares the absorbed dose (rad) to the thyroid from a $^{99m}$Tc scan with an $^{131}$I uptake to a $^{99m}$Tc scan with $^{123}$I uptakes (p,2n) and (p,5n) at TOD and Day 2.

## DISCUSSION

Iodine-123 has several advantages over $^{131}$I for thyroid uptake and imaging. The 159 keV photon emitted from $^{123}$I is ideal for modern gamma cameras in con-

**TABLE 2**
**Radiation Absorbed Dose to Thyroid**

| | | Age (yr) | | | | |
|---|---|---|---|---|---|---|
| | Adult | 15 | 10 | 5 | 1 | Newborn |
| $^{131}$I Uptake | 6.60 | 3.20 | 4.40 | 7.60 | 16.00 | 32.00 |
| $^{131}$I Scan | 33.00 | 40.00 | 40.00 | 49.00 | 73.00 | 64.00 |
| $^{123}$I (Pure) Uptake | 0.22 | 0.32 | 0.21 | 0.40 | 0.83 | 1.62 |
| $^{123}$I (p,5n) Uptake | 0.58 | 0.85 | 0.55 | 1.04 | 2.20 | 4.27 |
| Day 2 (p,5n) Uptake | 1.52 | 2.24 | 1.44 | 2.74 | 5.76 | 11.19 |
| $^{123}$I (p,2n) Uptake | 1.12 | 1.65 | 1.06 | 2.02 | 4.24 | 8.25 |
| Day 2 (p,2n) Uptake | 3.25 | 4.79 | 3.07 | 5.85 | 12.31 | 23.93 |
| $^{123}$I (Pure) Scan | 2.20 | 2.70 | 2.60 | 3.30 | 4.90 | 4.50 |
| $^{123}$I (p,5n) Scan | 5.80 | 7.12 | 6.85 | 8.70 | 12.92 | 11.86 |
| Day 2 (p,5n) Scan | 15.20 | 18.65 | 17.96 | 22.80 | 33.85 | 31.09 |
| $^{123}$I (p,2n) Scan | 11.20 | 13.75 | 13.24 | 16.80 | 24.95 | 22.91 |
| Day 2 (p,2n) Scan | 32.50 | 39.89 | 38.41 | 48.75 | 72.39 | 66.48 |
| $^{99m}$Tc Scan | 1.00 | 1.50 | 1.40 | 1.70 | 2.00 | 2.40 |

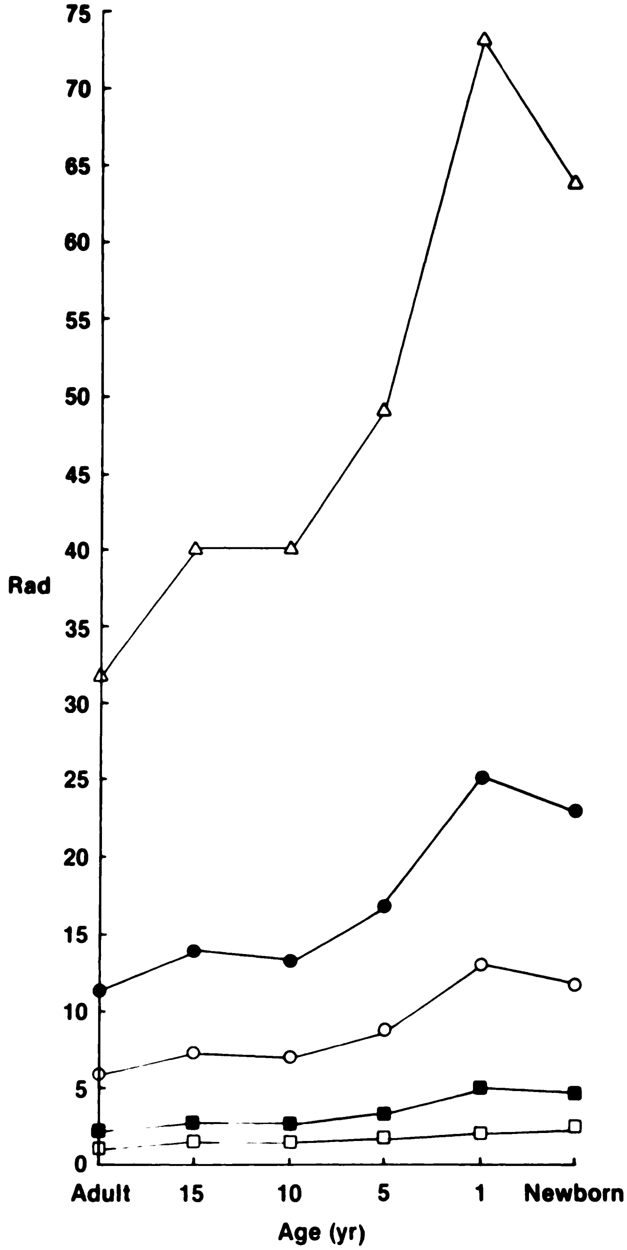


**FIGURE 1**
Radiation absorbed dose (rad) to thyroid from various thyroid scanning radiopharmaceuticals using recommended administered activities at different ages. Although absorbed dose to thyroid is low for both pure $^{123}$I (■) and $^{99m}$Tc (□), pure $^{123}$I results in twice the thyroid absorbed dose. However, pure $^{123}$I is not commercially available. $^{123}$I (p,2n) has been most widely available and used (●). Its absorbed dose is five times that from pure $^{123}$I, while dose from $^{123}$I (p,5n) (O) is half that of $^{123}$I (p,2n). Thyroid dose from $^{123}$I (p,2n) scan is 9–12 times and from $^{123}$I (p,5n) scan 5–6 times that of $^{99m}$Tc scan. By comparison, $^{131}$I (△) results in 3 times the absorbed dose of $^{123}$I (p,2n).

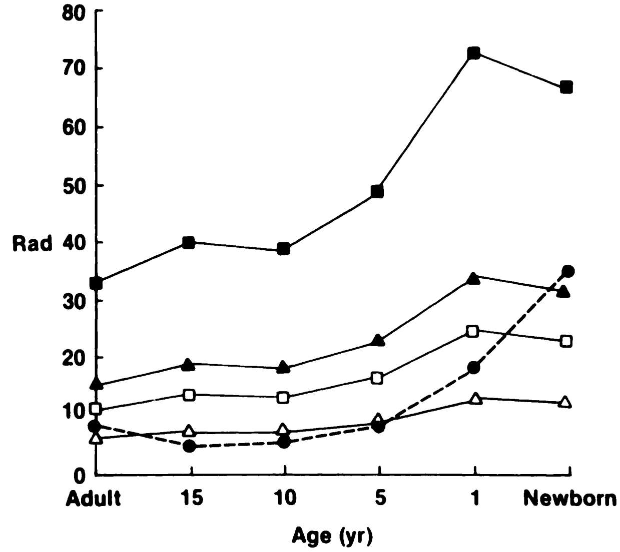


**FIGURE 2**
Common clinical request requires uptake and scan. Here $^{123}$I (p,2n) and (p,5n) scans and uptakes at time of delivery (TOD) and at two half-lives (Day 2) are compared to $^{99m}$Tc scan with $^{131}$I uptake. Note that radiation absorbed dose from $^{99m}$Tc scan with $^{131}$I uptake (- - -, ●) is considerably lower than that from $^{123}$I (p,2n) at TOD (□) except in newborn (which assumes low recommended administered $^{123}$I activity of 28 μCi). Even $^{123}$I (p,5n) at TOD (△) offers no dosimetric advantage over $^{99m}$Tc scan with $^{131}$I uptake in terms of rad to thyroid except for 1 yr old and newborn. If $^{123}$I (p,2n) or (p,5n) are not administered at TOD, but 1 day later (i.e., two half-lives or 26.6 hr) (Day 2), absorbed dose to thyroid due to long-lived radiocontaminants increases considerably. Absorbed dose from $^{123}$I (p,5n) at Day 2 (▲) is now considerably higher than that from $^{99m}$Tc scan and $^{131}$I uptake at all ages, except for newborn where it is equivalent. $^{123}$I (p,2n) absorbed dose at two half-lives (■) triples from TOD (□) and becomes equivalent to the dose from $^{131}$I scan. Note that absorbed dose from $^{123}$I (p,5n) on Day 2 (▲) is higher than absorbed dose from $^{123}$I (p,2n) at TOD (□).

trast to the high-energy 364 keV photons of $^{131}$I, although contamination of the $^{123}$I (p,2n) by the high energy photons of $^{124}$I degrades image quality. Numerous studies have confirmed the superiority of $^{123}$I images and emphasized the lower radiation absorbed dose to the thyroid (*5,12,13*). Technetium-99m is widely used for thyroid scintigraphy because of its excellent thyroid images, ready availability, low cost and low radiation absorbed dose to the thyroid (*6,14*). Studies have shown similar results and superior images when using $^{99m}$Tc compared with $^{131}$I (*15,16*) and others have found no significant advantage of $^{123}$I over $^{99m}$Tc in most cases (*17*), although rare discordant results due to a disparity between trapping and organification have been reported (*18–20*).

With the radiation absorbed dose frequently presented in rad/μCi in textbooks and published papers (1–2 rad/100 μCi $^{123}$I, 100–200 rad/100 μCi $^{131}$I, 0.2 mrad/μCi $^{99m}$Tc), the actual dose to the thyroid from a particular administered activity adjusted to age or weight, is not always immediately apparent. The $^{123}$I

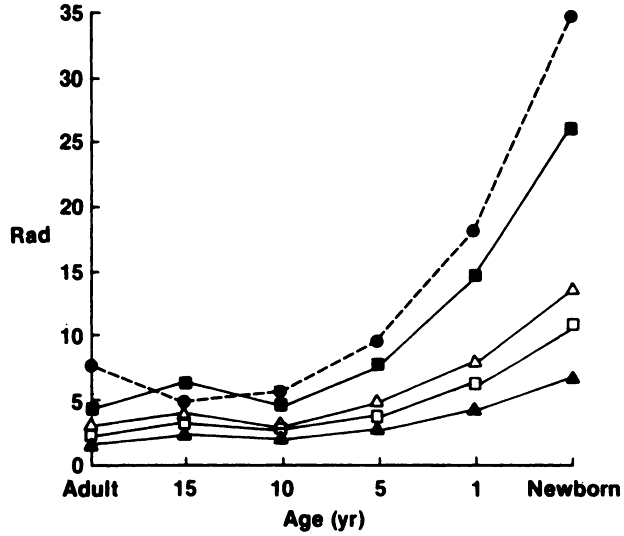


**FIGURE 3**
**This graph illustrates radiation absorbed dose to thyroid from combination of $^{99m}$Tc scan with various iodine uptakes including $^{131}$I, $^{123}$I (p,2n), and (p,5n) at TOD and at two half-lives (Day 2). $^{123}$I (p,2n) *uptake* at TOD (□) with $^{99m}$Tc scan produces less absorbed dose than $^{99m}$Tc scan with $^{131}$I uptake (- - -, ●). However, an $^{123}$I (p,2n) uptake and $^{99m}$Tc scan at two half-lives (■) offers little advantage over $^{131}$I uptake and $^{99m}$Tc scan. $^{123}$I (p,5n) uptake with $^{99m}$Tc scan, whether at TOD (△) or at Day 2 (▲) appears to be ideal combination, although dosimetric advantage occurs mainly in ages 5 through newborn. However, $^{123}$I (p,5n) in solution is not available for human use.**

dosimetry frequently quoted is for pure $^{123}$I (1–2 rad/100 $\mu$Ci). This is misleading, since it is not commercially available. Iodine-123 (p,5n) results in 2.9 rad/100 $\mu$Ci[†‡] and I-123 (p,2n) 6 rad/100 $\mu$Ci[*] to the adult thyroid. Baker et al. (*21*) demonstrated how the percentage of radiocontaminants of $^{123}$I (p,5n), (d,n), and (p,2n) increase with time from production resulting in increased rad/$\mu$Ci to the patients. However, they concluded that there was only marginal reduction in radiation dose when using the most "pure" as opposed to the least "pure" $^{123}$I. Keyes et al. (*22*) also emphasized the presence of impurities in $^{123}$I and estimated the thyroid absorbed dose in an adult from $^{123}$I (d,n) at TOD and 24 hr later. They recommended that it be used only on the day of calibration because of the high radiation dose to the thyroid.

Although there appears to be a linear nonthreshold risk for thyroid cancer from radiation exposure, the risk of thyroid nodules and thyroid carcinoma from diagnostic doses of $^{131}$I appears to be quite small (*23*). After 35 years of use there is only one report of thyroid cancer after low dose $^{131}$I exposure (*24*). However, it still seems prudent to keep the dose as low as possible.

We agree with others who state that there is no place for $^{131}$I thyroid imaging except in the follow-up and therapy of thyroid cancer (*2,4,6*). However, our results show than an $^{131}$I uptake with a $^{99m}$Tc scan results in less absorbed dose to the thyroid than an $^{123}$I (p,2n) scan, except in the newborn when a recommended activity of 28 $\mu$Ci is administered (Fig. 2). This is probably half of what is commonly used. Iodine-123 (p,2n) should never be used at two half-lives, because of unacceptably high absorbed dose from $^{124}$I contamination. The only dosimetric advantage of $^{123}$I (p,5n) over a $^{99m}$Tc scan with $^{131}$I uptake would be at TOD for children less than 5 yr old (Fig. 2). Iodine-123 (p,5n) is preferrable to $^{123}$I (p,2n) in terms of dosimetry by a factor of 2. Even the $^{123}$I (p,5n) scan gives an excessive radiation dose to the thyroid at two half-lives (33 rad for a 1 yr old) (Fig. 2) when the same clinical information can be usually obtained with a $^{99m}$Tc scan and $^{131}$I uptake at considerably less absorbed dose. Note that the $^{123}$I (p,5n) scan dose at two half-lives is greater than the $^{123}$I (p,2n) scan dose at TOD (Fig. 2).

Using $^{123}$I for uptake measurements in conjunction with a $^{99m}$Tc scan would be ideal from a dosimetric standpoint. However, pediatric recommended administered activities are not possible with 100 $\mu$Ci capsules. The capsule form is preferred by many (except for small children) because of its convenience, radiation handling safety and cost. Figure 3 demonstrates that there is little or no dosimetric advantage for a $^{123}$I (p,2n) uptake at two half-lives compared to $^{131}$I uptake. Even the $^{123}$I (p,5n) uptake absorbed dose is significantly less than $^{131}$I only in the 5 yr old and younger age groups (Fig. 3). Unfortunately, $^{123}$I (p,5n) in solution is not available for human use.

We have found that the $^{123}$I capsules can be easily opened and the semisolid sugar filler scooped out and calibrated to the desired activity. Mixing with water (not dissolvable) then allows easy administration to children.

To summarize, we have demonstrated that the radiation absorbed dose from radiocontaminants in commercially available $^{123}$I is significant and that the time from calibration of administered $^{123}$I is a major determinant of the overall radiation absorbed dose to the thyroid. Iodine-123 should never be decayed down in order to obtain a recommended pediatric administered activity. If $^{123}$I is clinically indicated for a young child (i.e., ectopic or lingual thyroid), $^{123}$I in solution should be administered as promptly as possible on the day of delivery. There appears to be no dosimetric advantage of commercially available $^{123}$I for thyroid scintigraphy for adults or most children.

## FOOTNOTES

* Medi-Physics, Emeryville, CA.

† Benedict Nuclear Pharmaceuticals, Inc. (BNPI), Golden, CO.

‡ Crocker Nuclear Laboratory, Davis, CA.

§ Atomic Energy of Canada Limited, Ontario, Canada.

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