

# Radioactive $^{131}\text{I}$ Iodine Body Burden and Blood Dose Estimates in Treatment for Differentiated Thyroid Cancer by External Probe Counting

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## Abstract

Radioactive<sup>131</sup> iodine (RAI) body burden is estimated in thyroid cancer patients by a) exposure rate meter and b) external probe counting. A calibration factor of 301 cpm/MBq ( $d = 16$  cm) is used for the probe for estimates of whole body activity. Patients sit in a rotating stool with their center corresponding to the field of view for estimation of whole body RAI. Radioactive counts are obtained for anterior posterior (AP) and postero anterior (PA) geometries. Whole body retention factor is expressed as a ratio against assayed activity administered to the patient on day 1. With exposure rate measurement, for off-thyroxine (hypothyroid) patients, the retention factors were  $0.148 \pm 0.12$  ( $n = 211$ ) and  $0.07 \pm 0.08$  ( $n = 68$ ) at 48 h and 72 h, respectively. For recombinant TSH (rhTSH) (euthyroid) group, the retention factors were  $0.089 \pm 0.06$  ( $n = 24$ ) and  $0.05 \pm 0.05$  ( $n = 19$ ) at 48 h and 72 h, respectively. By probe counting method, the obtained retention factors were  $0.081 \pm 0.013$  (range: 0.071–0.096) (off-thyroxine group) and  $0.039 \pm 0.03$  (range: 0.008–0.089) for the rhTSH group at 48 h. The 72 h retentions in the off thyroxine (hypothyroid) group and the rhTSH (euthyroid) group were  $0.048 \pm 0.024$  (range: 0.016–0.076) and 0.005, respectively. The radioactive body burdens at 48 h were in the range of 290–315 MBq (7.8–8.5 mCi) for the off-thyroxine group and 44–286 MBq (1.2–7.7 mCi) for the rhTSH group. The calculated residence times in whole body were  $21.97 \pm 3.8$  h (range: 17.1–27.1) for off-thyroxine group and  $14.28 \pm 2.75$  h (range: 9.97–19.46) showing high statistical significance ( $P < 0.001$ ). The specific blood doses were  $0.118 \pm 0.025$  mGy/MBq (range: 0.083–0.172) for the off-thyroxine group (females  $n = 23$ );  $0.87 \pm 0.028$  mGy/MBq (range: 0.057–0.130) (females  $n = 13$ ),  $0.080 \pm 0.013$  mGy/MBq (range: 0.069–0.098) (males  $n = 5$ ) and  $0.080 \pm 0.028$  (range: 0.059–0.118 for rhTSH patients (males  $n = 4$ ). The mean mGy/MBq for blood was higher in females—about 10% for the rhTSH group compared to 40% higher for the off thyroxine (THW) group. The dose to blood was “inversely proportional” to the body weight, both in the off-thyroxine group and the rhTSH group but the dependence was not very strong with rhTSH administration because of less residence time of the radioactive iodine. There was no correlation between administered activity and retained body burden at 48 h or 72 h.

**Keywords:** Blood dose in iodine<sup>131</sup>, differentiated thyroid cancer, iodine kinetics, radioactive iodine, whole body retention

## Introduction

Radioactive  $^{131}\text{I}$  iodine (RAI) administrations continue to be in practice for the management for differentiated thyroid cancer (DTC), with adequate thyroid stimulating

hormone (TSH) stimulation for subsequent ablations. The commonly followed method is to achieve this by endogenous TSH stimulation by the withdrawal of thyroxine.<sup>[1]</sup> Large doses ranging from 1.85 GBq to 7.4 GBq (50–200 mCi) are administered. Numerous studies worldwide have reported comparable results with recombinant thyroid stimulating hormone (rhTSH)

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intervention as a conventional thyroxine hormone withdrawal.<sup>[2]</sup> The mean radiation dose to blood, individual risk organs, and the whole body depends on the rate of clearance of radioactive iodine (<sup>131</sup>I) and therefore, has a direct correlation to the retained part of administered radioactivity.

The European Association of Nuclear Medicine (EANM) dosimetry committee indicates pretherapeutic blood and bone marrow dosimetry and issued standard operating procedures (SOPs) and advice to perform pretherapeutic or therapeutic patient-specific absorbed dose calculations.<sup>[3]</sup> Usually, an estimate of retention time is quantified with a pretherapeutic dose either using a gamma camera conjugate view imaging or by using external probe (sodium detector with crystal) and patient distance of 2 m. The Society of Nuclear Medicine (SNM), USA<sup>[4]</sup> and the American Thyroid Association<sup>[5]</sup> have stipulated the need for written instructions to the discharged patients describing methods to limit the radiation dose to the public not exceeding 1 mSV (100 mRem). Patient-specific calculations need to be performed with several assumptions to provide specific recommendations.

The retention patterns in the whole body at the time of discharge varies from patient to patient, and depends on the individual body's functional variations and extent of hydrations. The patterns of retention are relevant to calculate a) the mean blood and bone marrow dose b) the number of days these patients should follow safety guidelines at home, and c) to estimate the likely doses to the other inmates at their residences. Most of the centers measure body burden using external exposure assessment with a Geiger-Müller type or ionization type survey instruments. Generally, exact body retained activities are not quantified. In the Royal Hospital, since the year 2005 differentiated cancer thyroid treatments are being carried out in I-131 isolation wards. Radiation safety applications call for the need to understand radioactive <sup>131</sup>I (RA<sup>131</sup>I) clearance pattern to estimate whole body doses. If individualized retention pattern is available, it might help in estimating blood and bone marrow doses.

## Materials and Methods

### Study approvals

The Medical Ethics and Scientific Research Committee of the Royal Hospital, Ministry of Health, Oman in its document MESRC No. 14/2014 dated April 6, 2014 has approved the research study to obtain data on the residual body burden of radioactivity in patients. This committee has legal scope to approve human studies following the Helsinki Declaration 1975.

## Methods

The available exposure rate data in the Department of Nuclear Medicine, Royal Hospital (about 250 patients) were reviewed to calculate the body burden and retention of whole body at 48 h and 72 h. Based on a method recommended in an earlier report<sup>[6]</sup> iodine-131 remnant whole body radioactive burden was estimated using a calibrated thyroid probe spectrometer. (AtomLab 950, Biodex) with 2" x 2" NaI crystal.

The thyroid probe/spectrometer operation was checked with a Cs-137 check source in terms of high voltage calibration and "photo peak calibration" for spectrometer setting. Using decayed unused I-131 capsules, the calibration factor of the thyroid probe (counts/min per MBq) was estimated under "scatter conditions" using water phantom. The field of view (FOV) of the conical collimator of thyroid probe was determined, and the covering field to encompass the whole body of the patients was ensured. The estimated field of view (FOV) for a count rate variation within 8% obtained for our counting setup was 65cm, which was of the same order as indicated in previous studies. The calibration factors for the probe with neck phantom (1 cm depth) was 974 cpm/MBq. Calibration factor with water phantom was 406 cpm/MBq (11 cm source depth) and 301 cpm/MBq (16 cm source depth) respectively (refer calibration in Figure 1).

The patient who was about to be discharged from the ward when going for gamma camera scan was asked to sit before the thyroid probe counter at a distance of 2.2 m. Radioactive counting was carried out for 6 min (2 × 180" counts) anterior counts and 6 min (2 × 180" counts) posterior counts were recorded. Background counts for the same amount of time were determined and net counts per minute (cpm) for the patient were determined. The geometric mean of cpm was estimated and using the

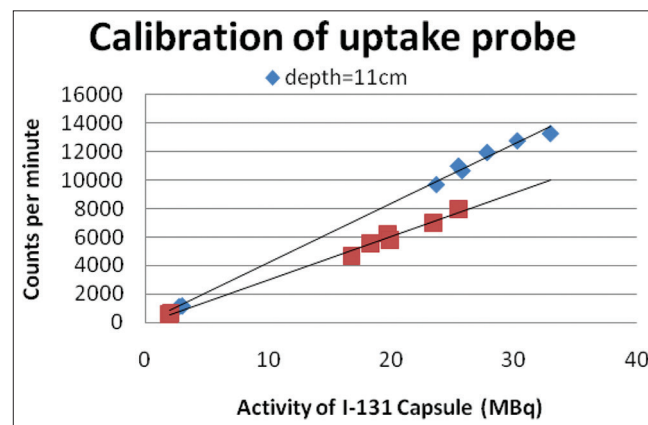


Figure 1: Counts/min for different I-131 activity surrounded by water at depths 11 cm, 16 cm

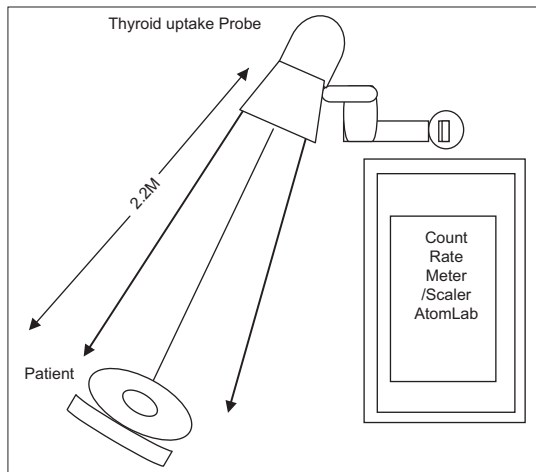
“probe calibration,” patients’ whole body I-131 activity was calculated. The geometry of measurement is shown in Figure 2.

Percentage retention was expressed with respect to the administered (assayed) activity to the patient on the first day, from equation 1. As the discharge of the patients took place on the second day (48 h) and third day (72 h), the retention fractions at 48 h and 72 h were used to calculate the “residence time” using the equation 2.

$$\text{Whole body retention}_{48h} = \frac{\text{Estimated I-131 activity in MBq}_{48h}}{\text{activity administered}_{0h}} \quad [1]$$

$$\text{Whole body residence time in hours} = 48 \text{ h} / \ln [100 / \% \text{retn.}_{48h}] \text{ or } 72 \text{ h} / \ln [100 / \% \text{retn.}_{72h}] \quad [2]$$

Empirical formulas in the literature<sup>[7]</sup> for calculation of “patient’s blood volume” using height (H) in cm and weight (W) in kg are available (equations 3 and 4). Using the value of whole body residence time, the specific dose  $D_{BL}$  and  $D_{BM}$  per MBq administered  $A_0$  were calculated using equations 5 and 6 substituting the calculated retention time and the value of the estimated time at 48 h or 72 h.



**Figure 2:** Location of the patient in a sitting position for estimation of whole body retained I-131 activity

$$BLV_{male} = \{31.9 \times \text{height (H)}\} + \{26.3 \times \text{weight (W)} - 2402\} \quad [3]$$

$$BLV_{female} = \{56.9 \times \text{height (H)}\} + \{14.1 \times \text{weight (W)} - 6460\} \quad [4]$$

$$D_{BL} / A_0 = \left[ \left\{ \frac{15.12}{BLV_{ml}} \right\} + \left\{ \frac{0.0188}{W_{kg}^{3/2}} \right\} \right] \times \text{residence time in hours} \quad [5]$$

$$D_{BM} / A_0 = \left[ \left\{ \frac{8.54}{BLV_{ml}} \right\} + \left\{ \frac{0.0106}{W_{kg}} \right\} \right] \times \text{residence time in hours} \quad [6]$$

### Patients

Exposure rates at 1 m measured from the total number of 244 patients using ‘beta gamma survey instrument’, were retrospectively analyzed. Tables 1 and 2 show the details of patients studied with the external counting method.

### Results

Table 3 illustrates the retention factor measured with sequential external exposure rates obtained from the patients at 1 m. These retention factors were compared with earlier publications<sup>[6,8]</sup> using diagnostic and therapeutic radioactive iodine administrations. The present results were comparable to earlier reported values. Table 4 shows the estimated retention factors, residence time of I-131 in the whole body, and the whole body activity by the external counting method. The whole body residence time for the off-thyroxine group was  $21.54 \pm 3.62$  h (in the range of 16.7–27.9 h) compared to the rhTSH group where it was  $17.22 \pm 6.14$  h (in the range of 9.97–32.4 h). The residence time in the rhTSH group was less compared to the off-thyroxine group, with a high statistical significance ( $P < 0.001$ ). Figure 3 shows the comparison of estimated residence times in these two groups of patients. The obtained residence time in the present study was comparable to the earlier reported values (8)  $24.1 \pm 7.8$  h for the THW group and  $17.3 \pm 3.9$  h for the rhTSH group. The 48 h retentions ranged between 0.071 and 0.096 with mean  $0.081 \pm 0.014$  (for off-thyroxine patients) and 0.008–0.15 with mean  $0.045 \pm 0.04$  (for recombinant TSH patients). The 72 h retentions in THW patients were almost equal

**Table 1: Details of I<sup>131</sup> activity administered, weight, height, blood volume**

Gender	Body weight (kg)	Height (cm)	Activity GBq	Blood volume
Males				
THW-5	90.5±18.4 (70-116)	176.4±5.1 (172.0-185.0)	5.09±0.84 (3.83-5.51)	5432±462 (4990-5906)
rhTSH-4	86.4±15 (69-103)	171.8±4.9 (168.0-179.0)	3.83±0.83 (3.23-5.06)	5348±521 (4846-6014)
Females				
THW-23	68.4±13.0 (40-100.5)	157.0±6.6 (144.0-169.0)	4.24±0.76 (3.52-5.51)	3396±513 (2810-4526)
rhTSH-13	75.5±13.3 (59.4-106)	158.3±8.6 (149.0-179.0)	4.08±0.78 (3.52-5.06)	3448±304 (2977-3941)

THW: Thyroxine hormone withdrawal; rhTSH: Recombinant thyroid stimulating hormone

to 48 h retentions in rhTSH patients. The comparison of retention factors at 48 h for rhTSH patients and at 72 h for THW patients is illustrated in Figure 4. Estimated radioactive body burden at 48 h was in the range of 290–365 MBq (7.8–9.9 mCi) for the off-thyroxine group and 44–570MBq (1.2–15.4 mCi) for the rhTSH group. The 72 h radioactive body burden in THW patients was almost equal to the 48 h remnant activity in rhTSH patients [refer Figure 5].

Table 5 shows the calculated specific blood and bone marrow dose in mGy/MBq, and the total dose due to the I-131 administrations. Considering males and females together, the specific dose to blood was 0.111 mGy/MBq

for THW patients ( $n = 28$ ) and 0.086 mGy/MBq for rhTSH patients ( $n = 17$ ); ( $P < 0.012$ ). Figure 6 shows the reduced specific blood dose values in rhTSH patients vis-à-vis THW patients. As the blood volume in females was less than that of male patients, the mGy/MBq value were more for female subjects compared to male subjects. For the THW group, the specific dose of blood in females was  $0.118 \pm 0.025$  mGy/MBq (ranging from 0.083 to 0.172). For the rhTSH group, in females the specific dose to blood was  $0.087 \pm 0.028$  mGy/MBq (ranging from 0.067 to 0.129). For the THW group, the specific dose to blood in males was  $0.080 \pm 0.013$  (ranging from 0.069 to 0.098). For males in the rhTSH group, the specific dose to blood was  $0.080 \pm 0.028$  (ranging from 0.048 to 0.112). It was seen that in males the mGy/MBq was almost the same with both THW and rhTSH protocols.

Grouping males and female cases together, the specific dose to bone marrow was 0.053 mGy/MBq in the THW group and 0.041 mGy/MBq in the rHTSH group, constituting about 50% of the dose to blood. For the THW group, the specific dose to bone marrow in females was  $0.057 \pm 0.012$  mGy/MBq (range: 0.04–0.125 mGy/MBq). For females in the rhTSH group, the specific dose to bone marrow was  $0.042 \pm 0.013$  mGy/MBq (range:

**Table 2: TSH values in the two groups (THW and rhTSH protocols) of patients**

Off-thyroxine group <i>n</i> =28	Recombinant TSH (rhTSH) group <i>n</i> =14	
Elevated TSH value following thyroxin hormone withdrawal (THW) in the preparation period. (mU/L)	Initial value of TSH on the day of admission (mU/L)	TSH after 2 daily injections of thyrogen 0.9 mg (rhTSH) (mU/L)
88.3±36.2 (range: 28.5-206.4)	4.7±7.4 (range: 0.003-23.3)	108.3±30.3 (range: 68.3-170.9)

THW: Thyroxin hormone withdrawal; TSH: Thyroid stimulating hormone

**Table 3: Retention factors from external exposure rates**

Treatment protocol	Whole body retention		Ladenson <i>et al.</i> <sup>[8]</sup> (at 48 h)	Sisson <i>et al.</i> <sup>[6]</sup> (at 48 h)	Hanchied <i>et al.</i> <sup>[9]</sup> 48 h
	At 48 h	At 72 h			
Off thyroxine	0.148±0.12 ( <i>n</i> =211)	0.07±0.08 ( <i>n</i> =68)	Mean 11.3%	0.144±0.074 ( <i>n</i> =43)	0.140±0.108 ( <i>n</i> =27)
recombinant TSH (rhTSH)	0.089±0.06 ( <i>n</i> =24)	0.05±0.05 ( <i>n</i> =19)	Mean 5.0%	0.056±0.050 ( <i>n</i> =10)	0.069±0.057 ( <i>n</i> =27)

TSH: Thyroid stimulating hormone

**Table 4: Estimated residence time and whole body retention by probe counting method**

Patients group	Estimated whole body residence time (h)	Estimated retention factor at		Whole body activity retained (MBq) at	
		48 h	72 h	48 h	72 h
		Off thyroxine <i>n</i> =28	21.54±3.62 (16.7-27.9)	0.081±0.014 (0.071-0.096)	0.038±0.024 (0.016-0.076)
recombinant TSH (rhTSH) <i>n</i> =17	17.22±6.14 (9.97-32.4)	0.045±0.04 (0.008-0.15)	0.06±0.05 (0.01-0.12)	160±83.5 (43.4-570)	24.8

TSH: Thyroid stimulating hormone

**Table 5: Dose to Blood and bone marrow from external counting method**

Patient group	Number of patients	Absorbed dose to blood		Absorbed dose to bone marrow	
		Specific dose mGy/MBq	Total dose mGy	Specific dose mGy/MBq	Total dose mGy
THW	Males 5	0.080±0.013 (0.069-0.098)	441.3±112.1 (280-575)	0.036±0.01 (0.031-0.045)	199.2±50.8 (126-261)
	Females 23	0.118±0.025 (0.083-0.172)	535.3±145.3 (341-864)	0.057±0.012 (0.039-0.125)	257.2±69.5 (160-415)
rhTSH	Males 4	0.080±0.028 (0.059-0.118)	318.2±91.9 (223-442)	0.056±0.021 (0.042-0.082)	129.8±20.3 (102-147)
	Females 13	0.087±0.028 (0.057-0.130)	376.4±133.0 (254-682)	0.042±0.013 (0.027-0.070)	183.3±60.8 (120.9-325.3)

THW: Thyroxin hormone withdrawal; rhTSH: Recombinant thyroid stimulating hormone

0.032 to 0.10 mGy/MBq). For the THW group, the specific dose to bone marrow in males was  $0.036 \pm 0.006$  mGy/MBq (range: 0.031–0.045 mGy/MBq). For males in the rhTSH group, the specific dose to bone marrow was  $0.037 \pm 0.013$  mGy/MBq (range: 0.042–0.082 mGy/MBq). Females received higher bone marrow doses compared to males, by similar magnitude as seen with absorbed dose to blood between them. Table 6 shows the present results as against a previous report;<sup>[8]</sup> it was observed that there was good agreement.

Figure 7 shows the plot of specific dose to blood and bone marrow against residence time. The dose per unit activity is directly proportional to the residence time. Specific doses to blood and red bone marrow are less in the case of recombinant TSH protocol because of reduced residence time. In Figure 8, the variations of blood dose (cGy) estimates for all the patients have been plotted and shown against body weight. It can be seen that blood dose is inversely proportional to body weight. Figure 9 shows the relation between the body

burden estimated activity based on external exposure rate measured at 1 m and the activity determined by the external probe method. It can be seen that external exposure rate underestimates the body burden even by a factor of 2. In Figure 10, the residual activity estimated in the patients against administered activity at  $t = 0$  h is shown at an elapsed time of 48 h and 72 h. It is very clear that there is no correlation of residual body burden with the activity administered. Table 7 shows the details of activity administered to a patient who had repeat administration for a metastatic spread and the calculated cumulative blood doses. For a total cumulated activity of 33.5 GBq, the cumulative blood dose was 3745 mGy over a period of 3 years.

### Discussion

The present work has outlined a simple method to quantify residual radioactive I-131 body burden in the patients treated for DTC. The method is based on

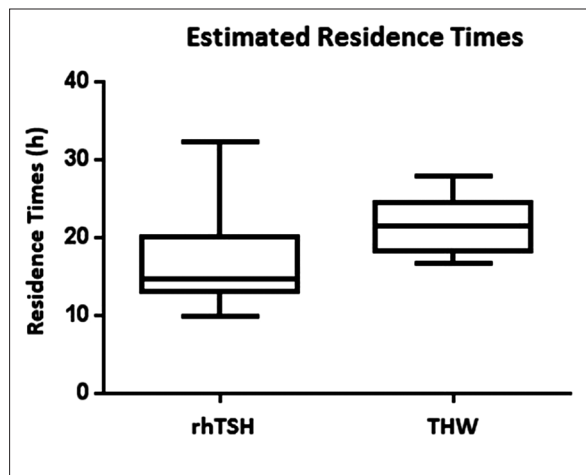


Figure 3: Estimated residence times in rhTSH and THW protocols

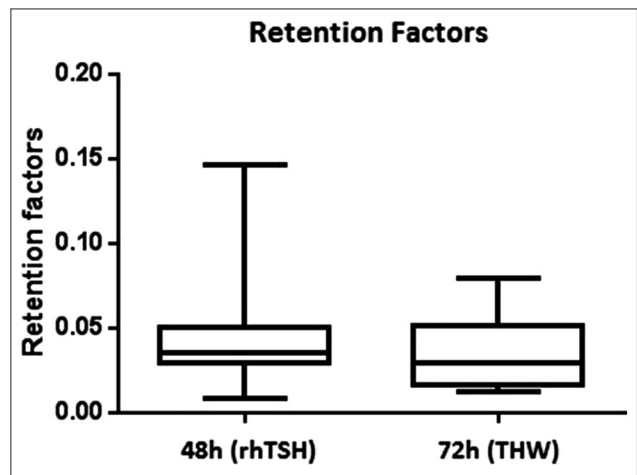


Figure 4: Comparison of whole body retention factors of I-131 against administered activity for two protocols of treatment

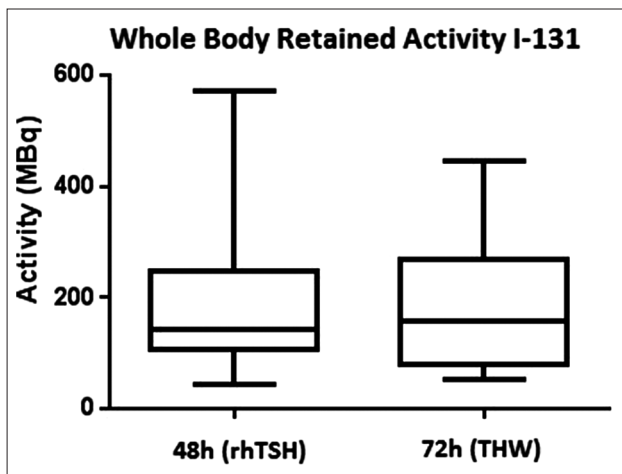


Figure 5: Whole body retained activity in rhTSH and THW patients expressed in MBq estimated by external probe counting

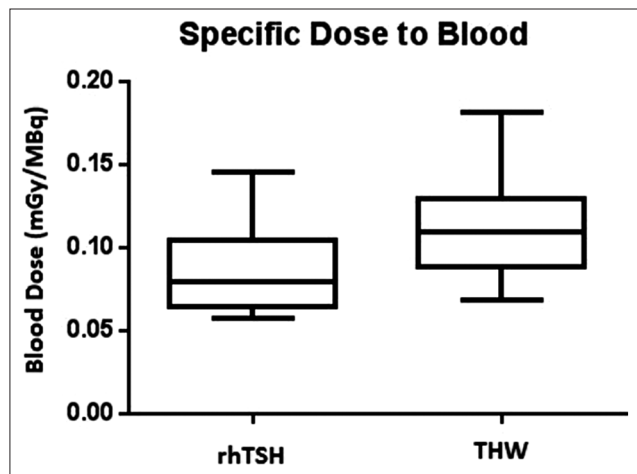


Figure 6: Higher value of specific blood dose seen THW group of patients compared to rhTSH patients

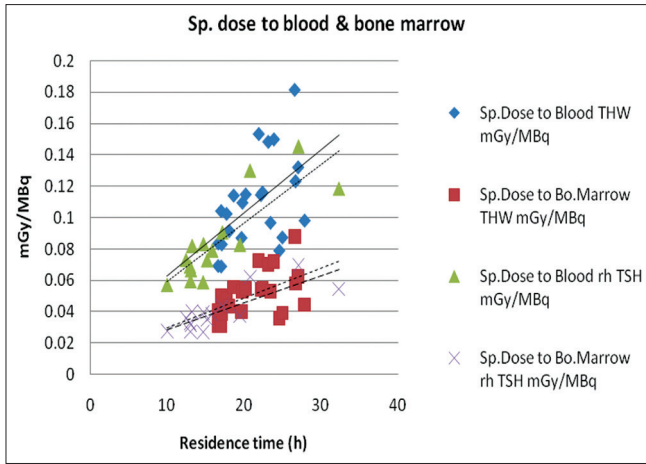


Figure 7: Variation of specific dose to blood and marrow related to residence time

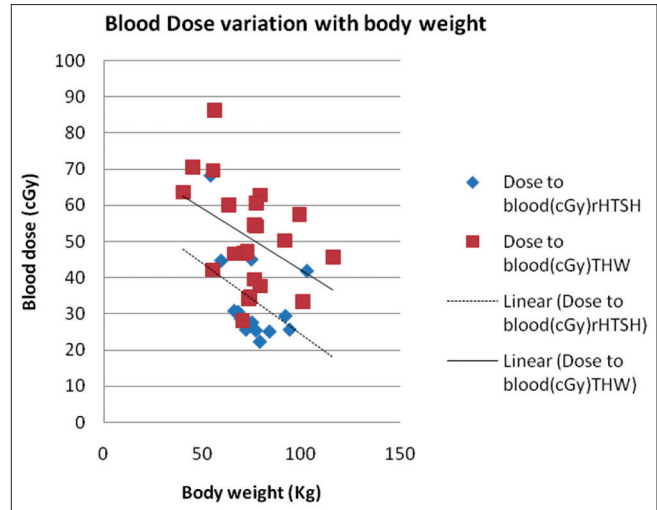


Figure 8: Variation of blood dose estimates against body weight

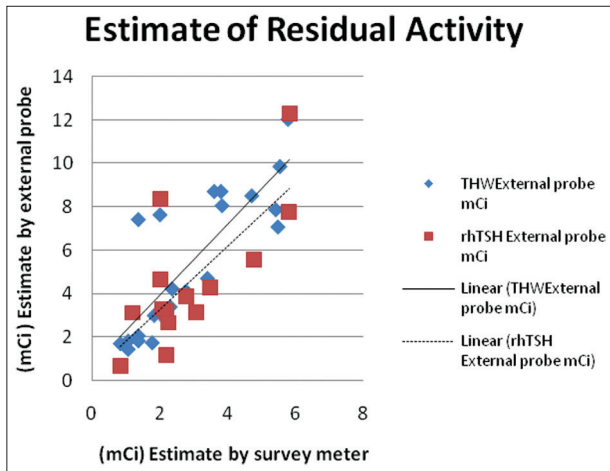


Figure 9: Radioactive body burden estimates by survey meter and external probe methods

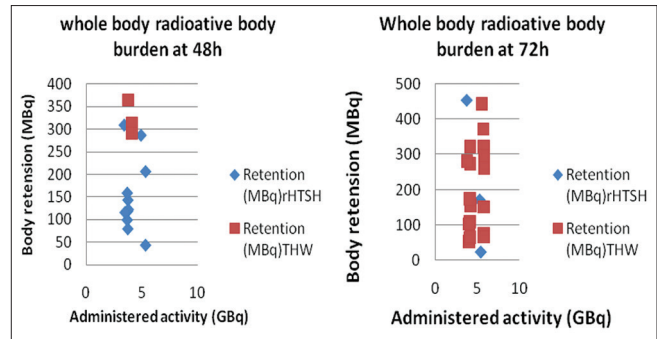


Figure 10: The whole body measured activity estimates at 48 h and 72 h in THW and rhTSH protocols

Table 6: Specific dose to blood  $D_{\text{Blood}}/A_0$  (by probe counting) compared with other reports

Patient group	Specific dose to blood mGy/MBq (present work)	Specific dose blood mGy/MBq Hanscheid et al. <sup>[8]</sup>		
		Vessel 0.2 mm radius	Vessel 0.5 mm radius	Refined method
THW	0.080±0.013 (0.069-0.098)	0.107±0.036	0.158±0.059	0.167±0.061
Males				
Females	0.118±0.025 (0.083-0.172)			
rhTSH	0.080±0.028 (0.059-0.118)	0.072±0.017	0.104±0.026	0.109±0.028
males				
females	0.087±0.028 (0.057-0.130)			

THW: Thyroxin hormone withdrawal; rhTSH: Recombinant thyroid stimulating hormone

obtaining whole body counts by a calibrated thyroid probe at 2.2 m distance. In this method, about ±10–15% accuracy is expected in estimating radioactive body burden, because of some uncertainties. An earlier work<sup>[6]</sup> outlined a similar counting for estimating residual body

burden using reference whole body counts at 2 h after the administration of I-131 activity capsule without voiding urine. We have taken ratio with respect to administered measured activity. The TSH value of patients in the off-thyroxine group was  $88.3 \pm 36.2$  mU/L (range: 28.5–206.4) ( $n = 28$ ) and for the rhTSH group was  $108.3 \pm 30.3$  mU/L (range: 68.3–170.9) ( $n = 14$ ) on the day of therapy capsule administration.

The measured retention factors in Table 3 were comparable to earlier reports in the literature. Table 4 shows the retention factors obtained from the external probe method at 48 h  $0.081 \pm 0.014$  (0.071–0.096) for the THW group and  $0.045 \pm 0.04$  (0.008–0.15) for the rhTSH group compared to the entries in Table 3, viz.,  $0.148 \pm 0.12$  ( $n = 211$ ) for the THW group and  $0.089 \pm 0.06$  ( $n = 24$ ) for the rhTSH group. This is because in Table 3 the patients who were discharged at 72 h were also included in measured exposure rates at 48 h, whereas in Table 4 the patients who stayed longer till 72 h were not counted at 48 h.

The residence times  $21.54 \pm 3.62$  h (range: 16.7–27.9 h) ( $n = 28$ ) for THW protocol and  $17.22 \pm 6.14$  h (range

**Table 7: Cumulative blood dose estimates in repeat I-131 administrations**

THW/date rHTSH	Activity GBq	1 m exp. rate		Time (h) elapsed	Retn. (%)	Residence time (h)	Blood dose	
		Initial	Final				mGy/MBq	mGy
		$\mu\text{Sv/h}$						
7-3-12 THW	4.220	112	8.6	72	7.68	28.04	0.148	623.5
2-9-12 THW	7.506	169	14.6	48	8.64	19.61	0.103	775.6
22-7-13 THW	7.670	161	22.0	48	13.70	24.11	0.127	974.4
1-4-14 rhTSH	7.032	138	13.7	48	9.93	20.78	0.110	770.0
18-11-14rhTSH	7.032	168	8.7	48	5.18	16.22	0.086	601.0
Total	33.460						Total	3745

THW: Thyroxin hormone withdrawal; rhTSH: Recombinant thyroid stimulating hormone

**Table 8: Observations in two protocols regarding  $^{131}\text{I}$  uptakes and clearance**

Compartment	THW protocol	rHTSH protocol
Thyroid remnant	More uptake	Less uptake
	Fast clearance	Long retention
Whole body	Slow clearance 1 <sup>st</sup> phase	Fast clearance 1 <sup>st</sup> phase
	Fast clearance 2 <sup>nd</sup> phase	Slow clearance 2 <sup>nd</sup> phase

THW: Thyroxin hormone withdrawal; rhTSH: Recombinant thyroid stimulating hormone

**Table 9: Summary of specific blood doses in males and females**

Specific blood doses mGy/MBq in	THW treatment protocol		rhTSH treatment protocol	
	mGy/MBq	Blood volume ml	mGy/MBq	Blood volume ml
Females	0.118 $\pm$ 0.025	3448 $\pm$ 304	0.087 $\pm$ 0.028	3448 $\pm$ 304
Males	0.080 $\pm$ 0.013	5432 $\pm$ 462	0.080 $\pm$ 0.028	5348 $\pm$ 521

THW: Thyroxin hormone withdrawal; rhTSH: Recombinant thyroid stimulating hormone

9.97–32.4 h) ( $n = 17$ ) for rhTSH protocol were comparable to  $24.1 \pm 7.8$  h ( $n = 27$ ) for THW protocol and  $17.3 \pm 3.9$  h ( $n = 27$ ) for rhTSH protocol reported by Hanschied *et al.*<sup>[9]</sup> [Figure 7] that clearly brought out that residence time was the dominant factor deciding the whole body dose and hence, dose to blood. In Figure, eight doses to blood (in cGy) based on the administered activity demonstrated a negative slope for dose to blood against body weight. Though the body weight dependence holds good for both THW and rhTSH patients, the body weight dependence was less significant due to fast clearance in the first phase (within the first 48 h). Dose to bone marrow [Table 5] had the same pattern like irradiated blood except for less magnitude (about 70% of blood dose). Specific dose to bone marrow was around 0.036–0.057 mGy/MBq for THW patients which was in the same order reported by the I 131 manufacturer, 'GE Healthcare'.<sup>[10]</sup> It reported that for adults, red marrow dose was 0.035 mGy/MBq, 0.054 mGy/MBq, 0.086 mGy/MBq, and 0.12 mGy/MBq for thyroid uptakes 0%, 15%, 35%, and 55%, respectively. In Table 6, our presently reported values of dose to blood were compared to the theoretical dose estimates by an earlier reference for different blood vessel radii.<sup>[9]</sup>

A guidance value of 0.17 mRem/h at 1 m distance from 1 mCi body retention was indicated in an earlier report.<sup>[5]</sup>

Based on this value, if the exposure rates in the patients for whom probe estimation of body burden was carried out, the comparison of activities are shown in Figure 9. Exposure rate measurements underestimate the residual body burden even by a factor of 2 compared to external probe estimations. The attenuation offered by body tissue may not be true and therefore, the true activity in terms of exposure rate might be overestimated. In a previous report[6] the first measurement was taken at 2 h after administration without voiding urine, after the I-131 capsule got dissolved in the stomach and was available in the blood circulation. This might be representing true activity equivalent administered to the patient.

Figure 10 indicates that 48 h and 72 h of residual radioactivity in the whole body does not have any correlation with "administered dose" (GBq) of iodine-131. Therefore, discharging patients on the 2<sup>nd</sup> day and 3<sup>rd</sup> day have no relation to the activity administered. Most of the patients with rhTSH administration had a residual activity of less than 150 MBq (4 mCi) at 48 h, whereas THW patients had about 200 MBq (5.5 mCi) at 72 h.

### Residence time and specific dose to blood and bone marrow

In Figure 7, the trend lines show that both THW and rhTSH protocol patients overlapped indicating that there was no separate mechanism for absorbed dose to blood because of endogenous TSH stimulation or by external administration of TSH. Larger residence time in THW protocol gave rise to more absorbed dose to blood. The magnitude of less residence time in rhTSH patients was brought out in our previous study.<sup>[11]</sup> It is clearly shown in Table 4 with a high statistical significance ( $P < 0.001$ ); two thyrogen injections in euthyroid patients had given fast clearance compared to THW patients. A recent publication<sup>[12]</sup> has discussed that in THW protocols, whole body I-131 activity is eliminated 35–75% in the first 24 h and about 80% is eliminated in 48 h. In this present work, it is brought out from body burden measurements, that a mean retention of whole body at 48 h is 8.1% in THW patients (eliminated portion: 91.9%) vis à vis 3.9% (eliminated portion: 96.1%) in rhTSH patients.

In Table 8, the clearance patterns have been brought out for the two protocols from the present study, and previous works.<sup>[11,13,14]</sup> If the biophysical kinetics are considered, we have two phases of clearances differing in THW and rHTSH patients. We tried to explain this based on the clearances of two types of iodines, viz., inorganic iodine and organic iodine excreted from body with both of these containing radioactive <sup>131</sup>I. Sustained presence of TSH is responsible for a higher uptake in remnant thyroid cells (THW group), increased organification followed by fast whole body clearance in the 2<sup>nd</sup> phase. Transient presence of TSH (rHTSH) is responsible for less uptake in thyroid, slowed down organification with slowed down elimination (with prolonged clearance time in the later phase).

### Dose to blood in males and females

Table 9 summarizes the results of mGy/MBq in both THW and rhTSH protocols in males and females. Dose to the blood was higher in females compared to males because the blood volume was less in females for an equivalent value of weight and height. Since packed cell volume (PCV) is lower in women, red cell volume (RCV) calculated in a study<sup>[15]</sup> was found to be lower in females, whereas plasma volume was the same in males and females. If there is increased organification in THW patients (due to sustained TSH value) and this organified iodine is carried by the RBCs, it will explain the increased mGy/MBq in females (because of less RCV). If we consider that organified iodine is less in case of rhTSH protocol patients (both males and females), the effect of RCV is not predominant in the both groups. This can explain as to why mGy/MBq was the same in both males and females in the rhTSH group irrespective of a large volume of blood present in males [refer to Columns 4 and 5, Table 9].

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### Conflicts of interest

It is declared that there are no conflicts of interests.

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