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Lesion-Wise Comparison of Pre-Therapy and Post-Therapy Effective Half-Life of Iodine-131 in Pediatric and Young Adult Patients with Differentiated Thyroid Cancer Undergoing Radioiodine Therapy

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Abstract

Purpose The effective half-life of radioiodine is an important parameter for dosimetry in differentiated thyroid cancer patients, particularly in children. We determined the pre-therapy and post-therapy effective half-life in different types of lesions, i.e., remnant, node, or lung metastases.

Methods Of 84 patients recruited, 27 were < 18 years (group 1) and the remaining 57 were between 18 and 21 years (group 2). A total of 114 studies were conducted and 253 lesions were analyzed. Serial whole-body scans were acquired at 24, 48, and ≥ 72 h after administration of iodine-131. Region of interests was drawn over lesions to determine counts in the lesion. Time versus counts graphs were plotted and mono-exponentially fitted to determine effective half-life.

Results The post-therapy effective half-life was found to be lesser than pre-therapy effective half-life in all types of lesions and in all groups. Median effective half-life was found maximum in intact lobe, minimum in the lung, and intermediate in remnant and nodes. In the assessment of all lesions together, pre- and post-therapy median and interquartile range (IQR) effective half-life were 59.8 (37–112) h and 48.6 (35.2–70.8) h ($p < 0.0001$) in group 1, 73.9 (46.2–112.7) h and 60 (57.4–85.9) h ($p < 0.0001$) in group 2, and 68.6 (41.53–112.36) h and 54.7 (36–80.6) h ($p < 0.0001$) in combined group, respectively. Importantly, the pre- and post-therapy median effective half-life serially dropped after each successive cycles of iodine-131.

Conclusions There was a significant difference in pre-therapy and post-therapy effective half-life in all types of lesions. These results may have implications in calculating the correct therapeutic dose in children and in young adults.

Keywords Effective half-life · Thyroid cancer · Pediatric · Radioiodine therapy · Pre-therapy · Post-therapy

Introduction

Determination of absorbed doses is a mandatory requirement before the administration of any radiopharmaceutical for therapeutic purpose to administer maximal dose to target lesions and permissible dose to the healthy organs. In case of treatment with iodine-131, radiation doses from radioiodine delivered to extrathyroidal tissues may induce acute side effects such as

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nausea and vomiting, sialadenitis and xerostomia, loss of taste, bone marrow suppression, and late occurrence of second primary malignancy [1]. Thus, treatment should be aimed at optimizing the radiation dose delivered to neoplastic thyroid tissues and minimizing the radiation dose delivered to normal extrathyroidal tissues/organs.

The parameters needed to determine the absorbed dose of I-131 are effective half-life (T_e), size/mass of the lesions, and cumulative activity in the lesion. The accurate determination of T_e is important when performing dosimetry; more so in children and adolescents undergoing I-131 therapy because of increased sensitivity to radiation in this age group. Keeping all of the parameters constant higher the value of T_e, higher would be the radiation absorbed dose and hence lower would be the predicted administered activity for therapy dose and vice-versa. Snyder et al. advocated a generalized value of 120 h (5 days) for remnant in adults with DTC for calculating absorbed dose [2]. However, taking a fixed value of T_e in all patients is convenient but not advisable as it has been shown by many authors that T_e varies from 2 to 8 days in thyroid remnant and metastatic lesions [3–7].

Many authors have studied T_e in hyperthyroidism [8, 9] and thyroid cancer patients [3–7] in adults**.** However, little data is available on estimation of T_e in the pediatric thyroid cancer patients and exclusively with lesion-wise T_e distribution. The primary objective of this study was to determine pre-therapy (diagnostic) and post-therapy T_e of different lesions, i.e., remnant, node or lung, and secondary objective was to see changes in T_e with subsequent therapies in the same lesion in pediatric and young adults.

Methods

Patients

One hundred fifteen consecutive patients ($M = 34$; $F = 81$) with age ≤ 21 years (mean ± SD = 17.91 ± 2.95 years; range = 6–21 years) and histologically proven differentiated thyroid cancer (DTC) were prospectively included in this study over a period of 4 years. Ethical clearance was obtained from the institute ethics committee and the patients recruited were those already scheduled for a diagnostic I-131 whole-body scan (WBS). Informed consent was obtained either from patients or from parents of patients (< 18 years) who volunteered for this study.

After the I-131 WBS, 31 patients were excluded. Twenty-nine were excluded because of no evidence of residual disease/thyroid tissue seen in thyroid bed or extrathyroidal sites on WBS. Two patients were excluded due to technical reason, one had vomited immediately after the therapeutic activity was administered, and the other had diffuse lung metastasis superimposed with breast uptake as this patient had recently stopped breastfeeding. Out of the remaining 84 patients (mean ± SD = 17.94 ± 3.11 years; range = 9–21 years; M:F = 24:60), 27 patients (M:F = 11:16) were below 18 years (mean ± SD = 14.62 ± 2.23 years; range = 9–17 years) (group 1) and 57 patients (M:F = 13:44) were ≥ 18 years (mean ± SD = 19.67 ± 1.17 years; range = 18–21 years) (group 2). Of 84 patients, 75 were undergoing the I-131 WBS for the first time and 9 had already undergone RAI therapy in the past before being recruited in this study (Fig. 1). The TNM staging according to 7th Edition AJCC, 71/84 (84.5%) patients were having clinical stage I and 13/84 (15.5%) patients were in clinical stage II at the time of enrolment in this study.

A total of 114 studies were conducted in 84 patients and 253 lesions were detected. The distribution of the lesions was as follows: intact lobe = 10, remnant = 51, nodes = 118, and lungs = 74 (diffuse = 72 and focal = 2). T_e was determined in each of these 253 lesions (124 lesions in < 18-year-old patients and 129 lesions in 18–21-year-old patients) after administering 2 mCi diagnostic activity of I-131 and 1.11–5.55 GBq (30–150 mCi) therapeutic activity depending on the extent of disease (Fig. 1). Table 1 depicts the demographic profile of all 84 patients. None of the patients had bone metastasis. Lung metastases were diffuse (micro-nodular) in all except one case that had macro-nodular lung metastases. In the case of diffuse lung metastases, each lung was considered as a single lesion and ROI was drawn separately over both the right and left lung.

Acquisition Protocol

All patients were off thyroxine for 4 weeks post-thyroidectomy—before administration of diagnostic dose of I-131, and their TSH (thyroid stimulating hormone) values were > 30 μIU/L except in patients who had hemithyroidectomy. The mean ± SD of TSH value in patients who had undergone hemithyroidectomy was 9.4 ± 7.6 μIU/ml and in the rest of the patients was 114 ± 42 μIU/ml. None of the patients was given recombinant TSH (rhTSH) injection. The diagnostic activity of 74 MBq (2 mCi) I-131 was administered orally in the liquid form followed by WBS. As per our institutional protocol therapeutic activity of 1.11 GBq (30 mCi) I-131 was administered to patients for thyroid remnant ablation, 1.48 GBq (40 mCi) for lobar ablation, 1.85–3.7 GBq (50–100 mCi) for nodal metastasis, and 3.7–5.55 GBq (100–150 mCi) for lung metastases. Therapeutic activity was administered immediately after acquiring 72 h or 96 h diagnostic WBS.

Serial WBSs were done at different time points under a single head gamma camera (Siemens, E. Cam) to acquire anterior and posterior views. Medium energy collimator was set as close to the patient as possible. Scan speed was set at 15 cm/min. WBS was done at 24, 48, 72 h [10], and sometimes at 96 h in few cases where patient agreed to stay longer. Patients were asked to void before all scans. All the patients were scanned ≥ 6 times (three times pre-therapy and three times post-therapy) for the determination of T_e in lesion. For better accuracy, images were acquired

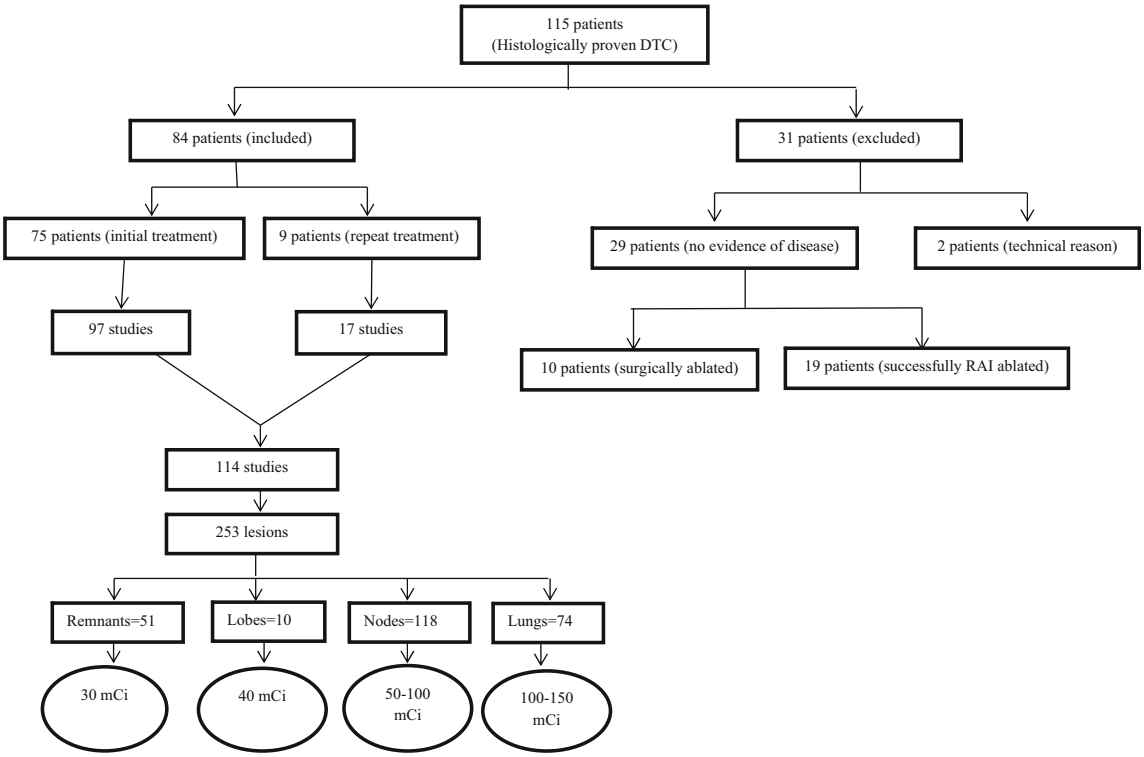

Fig. 1 Flowchart showing number of patients/studies included in the study

even after 72 h wherever possible. Acquisition was delayed until 24 h of activity administration to maximize the uptake of I-131 in the lesion and washout of background activity from the body. On therapeutic dose administration, it is assumed that there could be count loss if images are acquired immediately. Hence, by delaying the acquisition for 24 h, there is negligible possibility of significant count loss as most of the activity would have washed out.

Determination of T_e

Activity determinations in lesions were done using region of interest (ROI) technique. Individual ROIs were drawn on 24-h images for each lesion on both anterior and posterior projections and stored for subsequent use in serial images of the same patient. Geometric mean of anterior and posterior counts ($\sqrt{\text{anterior} \times \text{posterior}}$) was calculated to know the attenuation corrected counts in each lesion. Background correction of lesion counts was done as mentioned below by subtracting counts/pixel in background ROI drawn close to the lesions as shown in Fig. 2 so that it captures a typical number of counts per pixel that represents background and scattered radiation within the lesion. Care was also taken to avoid drawing background ROI in the pathway of any star effect [11].

$$\text{Net Counts}_{\text{lesion}} = \text{Counts}_{\text{lesion ROI}} - \left(\text{Counts/pixel}_{\text{background ROI}} \times \text{No.of pixels}_{\text{lesion ROI}}\right)$$

The counts in the lesion were measured in all the subsequent scans in the same way using the stored ROIs. Then a graph of time versus counts was plotted and mono-exponentially fitted to determine the T_e. The same process was repeated after administering the therapeutic activity of I-131.

Statistical Analysis

The descriptive statistics namely mean 95% CI (confidence interval) were determined in case of normally distributed data whereas median and interquartile range (IQR) in case of skewed data. Comparison of T_e pre- and post-therapy was done by determining p value using Wilcoxon signed ranks test. p value < 0.05 were considered as significant.

Results

Is T_e same or variable in different lesions?

Table 2 shows the median and IQR of T_e pre-therapy and post-therapy in all types of lesions as well as the overall, i.e., considering all types of lesions together in all three age categories except thyroid remnant of group 1 that was expressed in mean and 95% CI which was normally distributed. The statistical analysis of intact lobe in group 1 was not possible due to small sample size, i.e., only two patients. T_e post-therapy was found

Table 1 Patient characteristics

Parameters	Number of patients	Percentage (%)
Total patients studied	84	
Total studies performed	114/84	
Sex		
Male	24/84	28.57
Female	60/84	71.43
Age category		
< 18 years	27/84	32.14
≥ 18 years	57/84	67.86
Histopathology		
Papillary	77/84	91.67
Follicular	7/84	8.33
Surgery		
Hemi-thyroidectomy	10/84	11.90
Total/near total/sub-total thyroidectomy	74/84	88.10
WBS findings		
Intact lobe	10/84	11.90
Only remnant	24/84	28.57
Only nodes	26/84	30.95
Remnant + nodes	11/84	13.10
Only lung	1/84	1.19
Remnant + lung	1/84	1.19
Nodes + lung	7/84	8.33
Remnant + node + lung	4/84	4.76
RAI therapy cycles		
Once	68/84	80.96
Twice	6/84	7.14
Thrice	6/84	7.14
4 times	4/84	4.76

to be lesser than pre-therapy in all types of lesions and all age categories. The median/mean T_e was found to be maximum in intact thyroid lobe, minimum in lung lesions, and intermediate in remnants and nodes. The differences in pre- and post-therapy T_e was found to be statistically significant (p value < 0.05) in the node and lung, and when all lesions were clubbed together in all three groups (groups 1, 2, and combined) whereas intact thyroid lobe and remnant was statistically insignificant (Table 2). The data were normally distributed in the case of thyroid remnant of group 1, whereas skewed in the rest. The median/mean T_e in the intact lobe, thyroid remnant, and lung was higher in group 1, whereas in lymph node and in the combined assessment of all lesions together, it was higher in group 2 but the difference was not significant (Table 2).

What happens to the T_e if patient undergoes repeated cycles of RAI therapy?

Table 3 shows the T_e of lesions in 11 patients who underwent more than one cycle of RAI therapy after inclusion in this study. It was observed that the median/mean T_e decreased on subsequent therapies in remnants, nodes, and the lungs in both pre- and post-therapy. In the combined assessment of all lesions, the difference between pre- and post-therapy T_e was statistically significant ($p < 0.05$). Moreover, the difference in T_e between the cycles of RAI therapy was also statistically significant except between post-therapy of the 1st and 2nd cycle ($p = 0.182$) when all lesions were assessed together.

How many data points were optimum for T_e calculation?

Table 4 shows the comparison of pre-therapy T_e when three and four time points acquisition was taken into consideration in 26 different lesions among 12 patients. The fourth time point scan was done at 96 h in these patients. The difference in median T_e between three and four time points of acquisition was not found to be significant ($p = 0.164$) in the combined assessment of all 26 lesions. However, in the individual assessment, the difference in mean T_e of nodal lesion ($p = 0.011$)

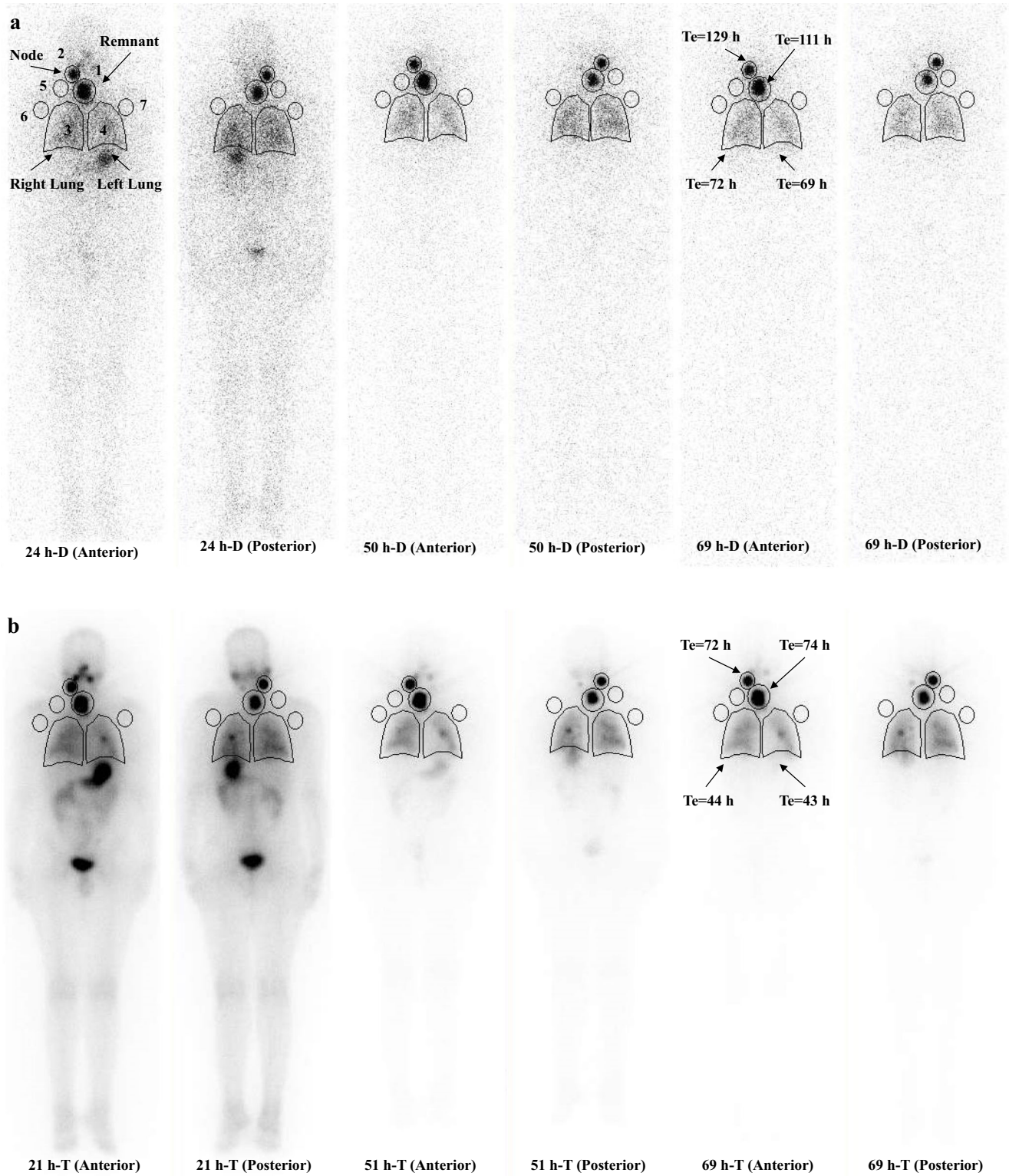

Fig. 2 Sequential acquisition of a 15-year-old male patient with histologically proven papillary thyroid cancer having remnant, node, and bilateral diffuse lung metastasis showing T_e both **a** pre-therapy and **b** post-therapy. Acquisitions (anterior and posterior views) were performed on days 1, 2, and 3 in both pre-therapy and post-therapy. ROIs (1, 2, 3, and 4) are drawn around lesions and for background correction, ROIs (5, 6, 7) were drawn near lesion. ROI number 5 was used for background correction of both remnant and node. T_e pre-therapy and post-therapy are denoted over the image. Diagnostic dose of 74 MBq (2 mCi) and therapy dose of 3.7 GBq (100 mCi) I-131 was given to the patient. (D = diagnostic image, T = therapeutic image)

Table 2 Comparison of pre- and post-therapy T_e in different types of lesion

		< 18 years; $n = 27$ (group 1)					18–21 years; $n = 57$ (group 2)					≤21 years; $n = 84$ (combined group 1 + 2)				
		No. of lesions	Median (hours)	IQR (hours)	*p* values	Difference in median (%)	No. of lesions	Median (hours)	IQR (hours)	*p* values	Difference in median (%)	No. of lesions	Median (hours)	IQR (hours)	*p* values	Difference in median (%)
Intact Lobe	Pre-therapy	2*					8	192	186.7–192	0.0938	23.96	10	192	181.1–192	0.1563	18.23
	Post-therapy							146	131–178.5				157	132–192		
Thyroid remnant	Pre-therapy	18#	100.23	75.9–124.4	0.7474	3.32	33	85.5	56.7–115.9	0.4476	0.01	51	87.17	58.75–121.6	0.3039	5.80
	Post-therapy		96.9	69.7–124.07				80.49	56.2–122.7				82.11	55.1–127.7		
Lymph nodes	Pre-therapy	62	59.84	30.05–115.9	< 0.0001	17.28	56	71.26	48.46–105	< 0.0001	18.75	118	68.5	44.3–113.9	< 0.0001	19.42
	Post-therapy		49.5	35.86–69.09				57.9	38.3–77.69				55.2	37.3–75.2		
Lungs	Pre-therapy	42	44.5	30.3–66	0.0031	10.74	32	37.62	29.6–72	0.0047	20.15	74	43.5	29.6–69.5	< 0.0001	15.17
	Post-therapy		39.72	29.8–51.9				30.04	23.5–54.9				36.9	26.8–52.2		
Overall	Pre-therapy	124	59.8	37–112	< 0.0001	18.73	129	73.9	46.2–112.7	< 0.0001	18.81	253	68.6	41.53–112.36	< 0.0001	20.26
	Post-therapy		48.6	35.2–70.8				60	57.4–85.9				54.7	36–80.6		

*Values could not be derived due to small sample size

Values were normally distributed and expressed in mean and 95% CI

was statistically significant but in the remnant and lung was insignificant. The value of pre-therapy T_e of nodal lesion was normally distributed and are expressed in mean and 95% CI, whereas the rest were skewed and expressed in median and IQR.

Outcome at the Time of Last Follow-up

Out of 82 patients followed-up so far, 65 patients (79.27%) (lobe = 10; remnant = 23; node = 27; lung = 5) showed complete remission, 15/82 (18.29%) had stable disease (node = 3; lung = 9), 1/82 (1.22%) was lost to follow-up, and 1/82 (1.22%) with lung metastasis progressed and expired. Seventy-five patients who were treated at our center for the first time with radioiodine; 58 (77.33%) patients (lobes = 10; remnant = 22; nodes = 24; lungs = 2) achieved complete remission after a single dose of RAI therapy, whereas 7/9 (77.78%) patients who underwent retreatment had complete remission at the time of last follow-up and the median number of RAI therapies among them were 4 and in the range of 2–5.

Discussion

A dosimetric approach in RAI therapy of adult thyroid cancer was first introduced by Benua et al. [12] in the early 1960s and is still being used in the management of DTC patients at few centers across the world. Determination of T_e is an important parameter in dose calculation, because it may differ, with a range from 1.6 to 7.5 days, in giving a possible difference in the formula by a factor of 4.6. This contributes to a greater error in the formula than that expected from other factors, i.e., thyroid volume determination, which is estimated to be a factor of about 1.5 and is also considered a significant source of error [13]. A long pre-therapy T_e could result in over-treatment and vice-versa if it is not considered in the absorbed dose calculation.

Variable methodologies are used for the determination of T_e. Two important methods of measurements are either by uptake probe or by scintigraphy. In case of hyperthyroidism, counting for T_e determination can be done by using uptake probe because the target position is known, i.e., in the neck, but in case of thyroid cancer where the position of metastatic lesion is not known, scintigraphy gains importance. Number of days of counting is another important factor in the determination of T_e. T_e is expected to be more accurate for a longer period of counting, i.e., up to one half-life. In the case of hyperthyroid patients given RAI therapy, the counting can be continued for several days, but in case of thyroid cancer patients where a given diagnostic dose has to be followed by a therapy dose, counting or acquisition cannot be delayed for long because it may cause a stunning effect in the lesions [14–16]. Watanabe et al. [8] and Pant et al. [9] have reported

Table 3 Trend of T_e in lesions of patients who had undergone multiple cycles of RAI therapy ($n = 11$)

Lesion Type	No. of lesions		First cycle			Second cycle			Third cycle		
			Pre-therapy	Post-therapy	*p* value	Pre-therapy	Post-therapy	*p* value	Pre-therapy	Post-therapy	*p* value
Remnant	4	Median (hours)	168.38	104.04	<0.0001	101.4	65.8	0.8750	57.6	40.05	0.1250
		IQR (hours)	121.15–192	96.52–109.48		74–118	97–123		37–69.2	31.7–45.1	
Node	16	Median (hours)	92.7	67.6	0.0004	63.4	47.2	0.0182	43.4	36	0.1099
		IQR (hours)	71.9–181.4	49.6–94.7		41.9–83.2	33.9–71.8		28.9–60.3	29.5–46.03	
Lung	16	Median (hours)	*57.2*	*38.5*	*0.0004*	41.7	34.3	0.5186	*36.6*	*33.5*	*0.2017*
		IQR (hours)	*40.8–73.3*	*27.1–49.9*		29–58.4	31.2–43.8		*27.08–46*	*26.4–40.6*	
Overall	36	Median (hours)	83.3	53.7	<0.0001	52.4	42.3	0.0194	39.8	36.3	0.0055
		IQR (hours)	52.2–144.1	36.6–90.27		37.4–74.5	32.6–66.6		30.9–54.2	29.3–40.2	

Values in italics (1st and 3rd cycle of lung) are normally distributed and are expressed as mean and 95% CI

T_e calculation using either one or two time points respectively as a convenient method. However, their results were confined to Graves' disease patients. In routine practice diagnostic, WBS is done at either 24 or 48 h post-administration. But to administer accurate calculated dose to the patient, a minimum of three time point scanning of the lesion is necessary [10] to determine the accurate T_e which varies from patient to patient as was observed in our study (Table 2). Therefore, in our study, pre-therapy acquisition was restricted to 72 h.

Interestingly, additional lesions (node and lung metastasis) were observed in two patients at 48-h diagnostic scan and in three patients (all nodes) on post-therapy scan. Bekerman et al. have stated that 35% of metastatic lesions in thyroid cancer patients might be missed if only a 24-h scan is employed thus concluding that 48- or 72-h WBSs should be performed in patients suspected of having recurrent or metastatic thyroid cancer [17]. Keeping this in mind, we scanned patients up to 72 h pre- and post-therapy and found it useful in 2/84 patients, albeit, in small percentage, not as high as 35% claimed by Bekerman et al.

Barrington et al. observed bi-exponential clearance of radioiodine for patients to ablate the thyroid after surgery and mono-exponential clearance for those receiving subsequent treatments for residual or recurrent disease [18]. In our study, 494/506 (pre- and post-therapy of 253 lesions) curves of lesions drawn showed mono-exponential fitting with correlation coefficient (r^2) of 0.97 ± 0.04. In the remaining 12 curves (2.4%), the r^2 values ranged from 0.67 to 0.89. The lower values of "r^2" were because the counts in these lesions either increased or remained constant between two time points of acquisition. This small fraction (2.4%) of the curves could be bi-exponential or more, however, this would not affect overall results.

For the remnant tissue, the median pre-therapy and post-therapy T_e were 87.17 h (3.63 days) and 82.11 h (3.42 days), respectively. Various authors determined T_e of remnant tissue in adult DTC (2–4) and the most recent one reported by Hanscheid et al. who found 48 ± 53 h T_e in such patients [7]. Interestingly, we observed for the first time different T_e in different nodes of the same patient. Chatzopoulos et al. also showed that the clearance of I-131 is faster in subsequent therapies in patients with metastatic DTC [19]. Lassmann et al. showed 51% reduced pre-therapy T_e after the second tracer dose administration and further reduced to a mean of 30% during ablation therapy of thyroid remnants [20]. However, in our study, the corresponding values were 37% and 19%, respectively. Moreover, this value further reduced to 6% during the third cycle of RAI therapy (Table 3).

We confirmed in pediatric and young adult DTC patients that the pre-therapy T_e was found to be longer than post-therapy. We are in agreement with the results of Verburg et al.

Table 4 Comparison of pre-therapy T_e when three or four time points of acquisition were taken into consideration in 13 studies among 12 patients

Lesion type	Number of lesions	Scan time points	Median (hours)	IQR (hours)	Difference in median (hours)	Difference in median (%)	*p* value
Remnant	5	3 4	120.31 110.5	102–141 74–134	9.81	8.15	0.0625
Node	*17*	*3* *4*	*99.2* *86.7*	*81.8–116.5* *74.2–99.1*	*12.5*	*12.60*	*0.0110*
Lung	4	3 4	58.6 70.2	53.1–65.4 65.7–72.2	−11.6	−16.52	0.1250
Overall	26	3 4	90 77.3	74.9–110.7 72.7–87.5	12.7	14.11	0.164

Values in italics (node) are normally distributed and expressed as mean and 95% CI

[21]. Hadjieva observed that about one-third of patients had an actual absorbed dose that was somewhat less than the projected dose due to shortened T_e of I-131 after therapy in thyroid remnants [22]. Yeung et al. showed that the percentage uptake of the therapeutic dose is on average only one-half of that predicted from the dosimetric uptake in thyroid remnants after surgery, even at a median dose of 40 MBq only [23].

The median T_e in lungs post-therapy in this study was 44.5 h (group 1) that was comparable to the findings of Samuel et al., i.e., 46.8 ± 7.2 h in children below 18 years of age with pulmonary metastases. They also showed a consistent decrease in radiation-absorbed dose to the lungs in subsequent therapies [24]. This could be explained by a decrease in T_e in subsequent therapies. In fact, we have also observed a similar decrease in T_e in subsequent therapies (Table 3). In the lungs, the T_e post-therapy in three cycles of RAI therapy in eight patients was found to be 38.5 h, 34.3 h, and 36.6 h.

On some occasions, T_e was found to be 192 h (8 days), i.e., same as physical half-life of I-131 in 28/506 (5.53%) lesions (lobe = 6, remnant = 6, node = 12, and lung = 4) pre-therapy and nine lesions (lobe = 4, remnant = 4 and lung = 1) post-therapy. The reason for long T_e could be because the clearance of I-131 in these lesions was slower. In these lesions, delayed acquisition may be useful in determining the more accurate T_e.

As in our study, we found that T_e was higher in pre-therapy than post-therapy scans for most lesions indicating that using pre-therapy dosimetry values may lead to underestimation of therapeutic activity to be administered. In the centers where dosimetrically determined therapeutic activity is administered, there the lesions will receive lesser absorbed dose than predicted. Hence, to achieve the absorbed dose as intended, i.e., 300 Gy to ablate thyroid remnants, 80 Gy to ablate nodal metastases, and 27.25 Gy to ablate lung metastases [25, 26], there is a need for correction factor. Thus, the findings of this study points towards consideration of applying a correction factor to the obtained pre-therapy dosimetry results. However, the possible explanation for the above findings could be the possibility of stunning of thyroid/cancer cells.

Conclusion

In pediatric and young adults with DTC given RAI therapy, we found a difference between pre-therapy and post-therapy T_e when analyzed for all lesions together as well as individually. T_e was found to be maximum in lobes, intermediate in remnants and nodes, and minimum in the lungs. T_e was found to be higher in pre-therapy, i.e. for the diagnostic dose and decreased in post-therapy. The decrease was also observed in subsequent cycles of RAI therapy. These results have potential implications in calculating the absorbed dose (Gy) to lesions and hence in the administration of correct therapeutic dose as intended in pediatric and young adult patients with DTC.

Compliance with Ethical Standards

Conflict of Interest Praveen Kumar, Chandrasekhar Bal, Nishikant Avinash Damle, Sanjana Ballal, S.N. Dwivedi, and Sandeep Agarwala declare that they have no conflict of interest.

Ethical Approval All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants or from parents of participants (< 18 years) in this study.

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