Theoretical comparison of absorbed dose estimation using dose commitment formula and medical internal radiation dose in radioactive iodine-131 therapy

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ABSTRACT

Background: Radioactive iodine-131 (RAI-131) is used for the treatment and diagnosis of thyroid disorder. It is commonly used for internal radionuclide therapy of hyperthyroidism and differentiated thyroid cancer. The estimation of absorbed dose to thyroid remnants/tumors is the concern of nuclear physicians in RAI-131 therapy of carcinoma thyroid patients. The purpose of this study is to compare theoretically the estimated absorbed dose to thyroid remnants/tumors by dose commitment formula and medical internal radiation dose (MIRD) in RAI-131 therapy. The study is significant to recognize the limitations and advantages of the two techniques compared.

Methods: The absorbed doses to 21 different masses of thyroid remnants/tumors were estimated from MIRD and dose commitment formula; however, the residence time (τ), percentage uptake ($\%U$), and initial administered activities (A_0) were kept fixed. The previously published S-values of different masses of thyroid remnants/tumors were used in the study. The mean percentage difference and variation factor of absorbed doses between the two techniques were also measured.

Results: It was observed that the mean percentage difference between the two methods was 18.24% with a standard deviation of 19.25. However, the mean variation factor between the two methods was found to be 1.0687 (min: 0.766712 and max: 2.784375) with a standard deviation of 0.422885.

Conclusion: It is concluded that the methods are well matched only for some masses of thyroid remnants/tumors [3/21] but not for other masses [18/21]. It is also concluded that dose commitment formula can be used as an alternative to estimate the absorbed dose to single thyroid remnant/tumor as it is more useful than MIRD, because of some limitation of S-values in MIRD.

Keywords: Absorbed dose, RAI-131 therapy, MIRD, dose commitment.

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Introduction

Radioiodine-131 is used most commonly for the treatment of thyrotoxicosis [1,2] and differentiated thyroid carcinoma (DTC) due to its suitable half-life and adequate energies of emitting beta particles [1]. Patients with DTC after surgical procedure are treated with RAI-131 for ablation of remnants and recurrence such as local or distant metastasis. The therapeutic activity of RAI-131 is administered to the patients according to clinical conditions and decided by nuclear physicians [3]. The radiation absorbed doses to thyroid remnants/tumors and different organs can be calculated by Monte Carlo codes, such as MCNP, EGS, GEANT4, and MABDOSE. The internal doses can also be calculated by many images, based on computational codes, such as SIMDOS, RTDS, RMDP, and 3D-1D [1]. There has also been an important improvement in the dosimetry field over the previous periods. Some societies use a dosimetry technique based on the blood and urine sample measurements, but the others use the images based on whole-body dose determinations, medical internal radiation dose (MIRD), patient-specific Monte Carlo simulations, and dose-point kernel convolution dosimetry [4]. The result of these techniques may be different from each other depending on various factors. The exact estimation of absorbed doses to thyroid remnants/tumors is the concern of nuclear physicians in RAI-131 therapy of carcinoma thyroid patients. The correct assessment of these absorbed doses has accepted significance in the recent past. The purpose of the study is to compare theoretically the estimated absorbed doses to thyroid remnants/tumors in RAI-131 therapy of carcinoma thyroid patients using MIRD technique and dose commitment formula for the first time. It is also important to know the limitations and advantages of the techniques used in this study.

Materials and Methods

The radiation absorbed doses to 21 different masses of thyroid remnants/tumors in RAI-131 therapy were measured mathematically according to MIRD and dose commitment

technique as shown in the following equations (1) and (2), respectively. All these measurements were done carefully through Excel software.

$$D_1 = \%U * A_0 * \tau * S \quad (1)$$

$$D_2 = \frac{A_0 * E * \%U}{m * 100} * \frac{(1 - e^{-\lambda E * t})}{\lambda_E} \quad (2)$$

In Equation (1), A_0 is the initial activity of I-131 to be administered to a patient, τ is residence time, %U is 24-hour percentage uptake, and S is S-value. S is S-value (mean absorbed dose to the target per unit nuclear disintegration of radionuclide in the source) [5] and is calculated either manually having information of particles and radiations emitted from I-131, mean number of emissions (n) along with mean energies ($\bar{E}$) [6], or Monte Carlo radiation transport code using computational models of the human anatomy (mentioned in phantoms). The masses were considered as unit density spheres. The previously published S-values by Michael G. Stabin were taken for the calculation of absorbed doses in MIRD [7].

In Equation (2), m is mass of thyroid remnant/tumor (kg), E is average energy released by RAI-131 per transformation (MeV/t), $\%U$ is 24-hour percentage uptake of thyroid/tumor, λ_E is effective decay constant, and A_0 is the initial activity of RAI-131.

In both methods, the same factors, e.g., τ, $\%U$, and A_0 were considered. The results of both the methods were compared by percentage difference, which was calculated from the following Equation (3).

$$\%\ Difference = \frac{|D_1 - D_2|}{(D_1 + D_2)/2} * 100\% \quad (3)$$

The variation factor (V.F) between absorbed doses by MIRD and dose commitment formula was also measured for all masses using the following Equation (4).

$$V.F = \frac{D_1}{D_2} \quad (4)$$

Results and Discussion

Radiation absorbed doses, variation factor, and percentage differences between the two techniques for 21 different masses of thyroid remnants/tumors are shown in Table 1.

To compare both the techniques, the graph was drawn for absorbed doses versus a number of readings (representing the different masses of thyroid remnants/tumors), as shown in Figure 1.

The above graph and table demonstrate that the absorbed doses by MIRD were less than the dose commitment method only for 0.5–40 g masses of thyroid remnants/tumors. The absorbed dose by former technique was 26.4% less for 0.5 g, and gradually, the percentage difference was decreased up to 13.7% for 40 g mass of thyroid remnant/tumor. The absorbed doses by two techniques were well matched for 400–1,000 g masses of thyroid

Table 1. Absorbed doses by MIRD and dose commitment methods for different masses of thyroid remnants/tumors, their percentage difference, and variation factors (V.F).

M (G)	τ (H)	$\%U$	A_0 (MCI)	D_1 (GY)	D_2 (GY)	%DIFFERENCE	V.F
0.5	90	3%	150	3074.922	4010.531	26.4093	0.793614
1	90	3%	150	1591.407	2005.265	23.0134	0.807065
2	90	3%	150	809.19	1002.633	21.3534	0.82213
4	90	3%	150	412.1474	501.3164	19.5233	0.832891
6	90	3%	150	278.3614	334.2109	18.2344	0.837195
8	90	3%	150	209.8499	250.6582	17.7231	0.837195
10	90	3%	150	168.851	200.5265	17.1507	0.842038
20	90	3%	150	85.23468	100.2633	16.2035	0.85010
40	90	3%	150	43.69626	50.13164	13.7174	0.87163
80	90	3%	150	29.94003	25.06582	17.72251	1.194456
100	90	3%	150	22.981	20.05265	13.60958	1.146033
300	90	3%	150	18.61137	6.684218	94.30223	2.784375
400	90	3%	150	4.979216	5.013164	0.67949	0.993228
500	90	3%	150	4.040555	4.010531	0.745846	1.007486
600	90	3%	150	3.398598	3.342109	1.676058	1.016902
1,000	90	3%	150	2.103894	2.005265	4.800463	1.049185
2,000	90	3%	150	1.105893	1.002633	9.794501	1.102989
3,000	90	3%	150	0.760639	0.668422	12.90589	1.137962
4,000	90	3%	150	0.588011	0.501316	15.91728	1.172935
5,000	90	3%	150	0.47958	0.401053	17.83421	1.195802
6,000	90	3%	150	0.407292	0.334211	19.71164	1.218667

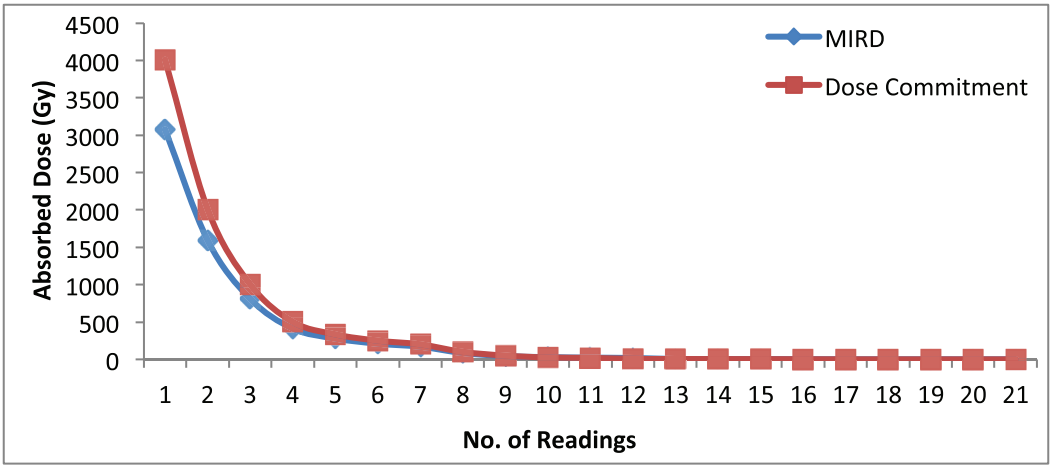

Figure 1. *Comparison of absorbed doses by MIRD and dose commitment methods for the same %U, τ, m, and A_0.*

remnants/tumors. The absorbed doses by MIRD were greater than the dose commitment formula for the leftover masses. The mean percentage difference between the two methods was 18.24% with a standard deviation (SD) of 19.25. However, the minimum and maximum percentage difference between the two methods was 0.68% and 94%, respectively.

The results indicate that the absorbed doses by MIRD and dose commitment vary from each other by an average factor of 1.0687 (min: 0.766712 and max: 2.784375) with a standard deviation of 0.422885. The mean value of the variable factor is well harmonized with that of the Peter J. Mount-ford [8], who stated in their editorial that the absorbed doses of the organs by MIRD schema concur with the definite patients' doses within a factor of 3. The reason for this difference in the accuracy of the absorbed doses by MIRD schema is the uncertainties in S-factor and cumulated activities in the source organ [8–10]. It is also worthy to mention that, in all S-values used in this study, Michael G. Stabin neglected transitions that did not provide more than 0.1% to the total energy per transition [7]. The reason for uncertainty in S-values is that S-value calculation needs a uniform distribution of RAI-131 activity in the thyroid remnants/tumors and is defined for standard anthropomorphic phantoms. However, uncertainty in cumulated activity is due to different %U, τ, A_o, and m of target. In this study, the reason of this error is definitely due to S-factor only as the two methods were compared with each other for the same τ, %U, A_o, and m (so the same cumulated activities).

Conclusion

It is concluded that MIRD and dose commitment techniques are well matched only for some masses of thyroid remnants/tumors [3/21], but not for other masses [18/21], and has different percentage differences. The reason for this percentage differences is uncertainties in S-value calculation. It is also concluded that the dose commitment formula can be used as an alternative to estimate the absorbed dose to single thyroid remnant or tumor. The reason for this preference is that there are some limitations on S-values in the MIRD technique.

Limitation of the Study

This theoretical study is applicable only for a single thyroid remnant/tumor that is considered both as a source and target in RAI-131 therapy.

List of Abbreviations

DTC	Differentiated thyroid carcinoma
MIRD	Medical internal radiation dose
RAI-131	Radio-iodine-131
SD	Standard deviation

Conflict of interest

The authors declare that there is no conflict of interest regarding publication of this article.

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Consent for publication

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Ethical approval

Not applicable.

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