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Assessing effective half-life of I-131 in 39 thyroid cancer patients at Dong Nai General Hospital

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Abstract: Radioiodine therapy to kill the residual cells after surgery in thyroid cancer patients is a widespread treatment method nowadays. Despite the therapeutic benefits, the amount of I-131 that remains in the patient's body also causes radiation risks to caregivers and persons in close contact. This study assesses the effective half-life (T_e) of I-131 in 39 patients who underwent thyroid cancer treatment at Dong Nai General Hospital. Radioactive activity on the patient's body was measured by survey meter GAL20-C (ELSE SOLUTIONS), placed 1.0 meters away from the patient, at 0.5; 2.0; 4.0; 6.0; 24.0 hours; and 7 days after administration. The measurement data was fitted by a mono-exponential function respecting time by the least squares method to figure out the effective half-life. The result function has a good coefficient of determination, $R^2 \approx 1$, T_e were $7.89 \pm 1.55\ h$ (high-activity group), and $5.83 \pm 1.76\ h$ (low-activity group). The effective half-life was proved to be different between these two groups of patients.

Keywords: *Biokinetic model, effective half-life, internal radiotherapy, nuclear medicine, radioiodine.*

I. INTRODUCTION

Radioiodine therapy to kill the residual cells after surgery in thyroid cancer patients is a widespread treatment method nowadays. Beta radiations of maximum energy of 608 keV emitted from the decay of I-131 will destroy any residual thyroid cells, and help to prevent the risk of recurrence and metastasis. The advantage of this method is completely removing thyroid tissue. In addition, gamma rays of 364 keV from I-131 are also used for imaging to evaluate the effectiveness of treatment and detect metastatic tumors. However, the amount of I-131 that remains in the patient's body also causes a radiation safety risk to people who are caregivers or live nearby. The average lifetime of I-131 in a patient body can be up to 100 hours [1]. Therefore, after administration, patients must be isolated until the radioactivity in their body decreases to below the safety threshold of 1100 MBq before being discharged [2]. The model of the metabolism of iodine in human body, which is called the biokinetic model, not only helps to estimate the isolation time interval but also is the basis of patient and occupational dosimetry.

The biokinetic model of iodine is a set of mathematical functions that describes the amount of iodine in human organs or entire body over time after administration. This model was studied for the first time by Brownell in 1951, and Riggs in 1952 [3]. A multi-

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compartmental model that described the the metabolism of iodine between organs by first-order differentiated equations was introduced in publications 53, 80, and 106 of the International Commission on Radiological Protection (ICRP) for radiopharmaceutical dosimetry. A simpler model with three compartments (named blood, thyroid, and rest of body) was optimized for age-dependent dosimetry in ICRP publication 56. Since the ICRP publications 128 (2017), a new model developed by Rich Leggett (2010) was used for assessing radiopharmaceutical dose to adults, and occupational intake. This model was extended to infants, adolescents, and children [4].

Biokinetic models was mainly applied to estimate the dose caused by radiotracer in nuclear medicine. Andersson, et al. [5] calculated effective doses per administrated activity of 358 radiopharmaceuticals for adults. They used a reference computational adult phantoms (given by ICRP 110) for voxel and geometry, the biokinetic model (given in ICRP 53, 80, 100,106) for estimating the cumulated activity, and the new tissue weighting factors (given in ICRP 60, 103). Foreman and Dewji [6] calculated the external dose rate irradiated to hotel housekeepers from the bed linens that were potentially radiation-contaminated by patients after radioiodine therapy. They used a modified biokinetic model of Leggett (2010) to estimate the total activity of I-131 that could be excreted via urine and sweat up to 5 days after administration. Monte Carlo N-Particle simulation was performed on these contaminated linens, with a computational phantom that presents a housekeeper.

Measurement time-activity curve of iodine is a main task to investigate the biokinetic model. Radioactivity over time can be measured by whole-body or organ-of-interest scan using a gamma camera; whole-body measurement using a radiation survey meter or spectrometer; and in-vitro assessment on human specimens. Gamma camera scan, as well as in-vitro assessment, gives accurate counting based on organ-focusing capability. However, these methods are high-cost, time-consuming, and not available for high activity due to the camera dead time. Patients administered a treatment dose should wait at least 24 hours for the decrease of radioactivity before gamma camera scanning. Measurement by survey meter is a quite simple method. A handle survey meter is positioned 1 – 2 meters away from the patient. Radiation emitting on the entire body is detected and recorded at many preset times. This kind of assessment can be performed very quickly, low cost, and less disturbing to patients and the treatment process. This method can only be used to assess the time-activity curve of a whole-body, not for a specific organ. However, such data are also helpful for patient discharge forecasting, or occupational dosimetry.

In this research, the effective half-life of I-131 was assessed on 39 patients who had been treated for thyroid cancer at Dong Nai General Hospital. The results of this study will contribute to clarifying the Vietnamese-specific values and provide data for occupational dosimetry as well.

II. THE MAIN PART OF REPORT

A. Research subjects and methodology

There were 39 patients (5 males and 34 females) with thyroid cancer who took part in this study. All of them had undergone a whole-thyroid gland thyroidectomy. After surgery, they were additionally treated with radioiodine (I-131) therapy at Dong Nai General Hospital. Patients were orally administered radioiodine in capsulate. 13 patients took 100.52 – 149.30

mCi (103.28 mCi of average, called high-activity group), and 26 patients took 28.20 – 31.20 mCi (29.85 mCi of average, called low-activity group). Patients in the low-activity group had been treated more than 2 times. After administration, patients were quarantined for 6 hours (low-activity group), and 24 hours (hight-activity group). 7 days later, all of the patients were required to back to the hospital for a whole-body scan on a gamma camera to evaluate treatment efficiency and assess metastasis.

Survey meter GAL20-C, ELSE SOLUTIONS (Italy) was used to assess whole-body time-activity curves in this study. It was equipped with a gas-filled detector and a touch-screen for operating stand-alone or connecting to SmartEye software via ethernet connection. The radiometer was mounted on a wall, 1.0 meters away from a patient who stood upright on a platform. The count rate was demonstrated on the software screen in the $\mu Sv/h$ unit.

For each patient, the count rate was measured at time points: 0.5 – 1.0 – 2.0 – 4.0 – 6.0 – and 168 h (7 days later). Particularly, patients of the high-activity group had an additional measurement at 24 hours after administration. The biokinetic model of I-131 follows the mono-exponential rule [7],

$$\mathrm{A}(t) = A_0 \times \alpha \times e^{-\beta t}, \quad (1)$$

Where $\mathrm{A}(t)$ is count rate at time point t, α, and β are two characteristic parameters of the model, A_0 is the administration activity. β relates to physical half-time (T_p), biological half-time (T_b) by equation [7]

$$\beta = \frac{ln2}{T_e} = \frac{(T_p+T_b)\times \ln(2)}{T_p \times T_b}, \quad (2)$$

Where T_e is the effective half-life. Biokinetic models in some documents can be given in the form of T_e, or average lifetime (τ),

$$\tau = \frac{T_e}{ln2} = \frac{1}{\beta} \quad (3)$$

The measured data of each patient was fitted to function (1) by the least squares method, using MATLAB's Curve Fitting tool. Only α and β were derived directly from the empirical data of patients by fitted functions while τ and $T_e$were calculated from β. Their standard deviations were estimated by the error propagation formula. Additionally, the fitting tool provided a coefficient of determination (R^2) that can be used for evaluating the agreement between empirical data and the model. Chi-squared test was used to decide whether the parameters were similar or different. The significance level for statistical testing was 0.05.

Table I. Mean, standard deviation (SD), and relative standard deviation (RSD) of parameters

	Low-activity group				**High-activity group**			
	$\alpha\left(\frac{\mu Sv/\mathrm{h}}{mCi}\right)$	$\beta\ (h^{-1})$	$\tau\ (h)$	$T_e\ (h)$	$\alpha\left(\frac{\mu Sv/\mathrm{h}}{mCi}\right)$	$\beta\ (h^{-1})$	$\tau\ (h)$	$T_e\ (h)$
Mean	1.90	0.12	8.41	5.83	1.71	0.09	11.39	7.89
SD	0.26	0.04	2.54	1.76	0.21	0.02	2.24	1.55
RSD	13.69%	30.23%			12.02%	19.66%		

Results

Table I shows the mean, standard deviation, and relative standard deviation of α, β, τ, and T_e in these two groups of patients. Fig.1 shows the coefficient of determination of the fitted functions of 39 patients. Fig.2 shows the α and β values found in the low-activity and hight-activity groups.

B. Discussion

Fig.1 shows the coefficient of determination (R^2) of 39 patients. The Mean of R^2 was 0.98 (range 0.94 – 1.00) showing a good agreement between the empirical measuring data and the biokinetic model defined by the mono-exponetial function. Many papers used bi-exponential (two terms of exponential) functions for time-activity curve fitting [8, 9]. The bi-exponential model is more accurate since it reflects the recycling of iodine through the thyroid. However, the retention time in the thyroid gland is too short to enable the resolution of bi-exponential [10]. So, mono-exponential may be acceptable in case just several time points were measured.

In Table I, the mean (±SD) of α and β were $1.90 \pm 0.26 \left(\frac{\mu Sv/\mathrm{h}}{mCi}\right)$ and $0.12 \pm 0.04\ (h^{-1})$ for the low-activity group; as well as $1.71 \pm 0.21 \left(\frac{\mu Sv/\mathrm{h}}{mCi}\right)$ and $0.09 \pm 0.02\ (h^{-1})$ for the high-activity group. There was a significant difference in values of α and β between these groups (p-values were 0.017 and 0.001 for α and β testing). As a consequence, τ and T_e were significantly different between the two groups. This result was consistent with study of Kumar, et al. [11]. They showed a significant difference in T_e between pre and post-therapy, as well as between patients who were treated for the first time and patients who repeated the treatment. T_e was observed to decrease on subsequent therapies. In our study, T_e also decreased from $7.89 \pm 1.55\ h$ (high-activity group) to $5.83 \pm 1.76\ h$ (low-activity group). Patients taking low activity had been treated many times while the high-activity patients just initialized the treatment.

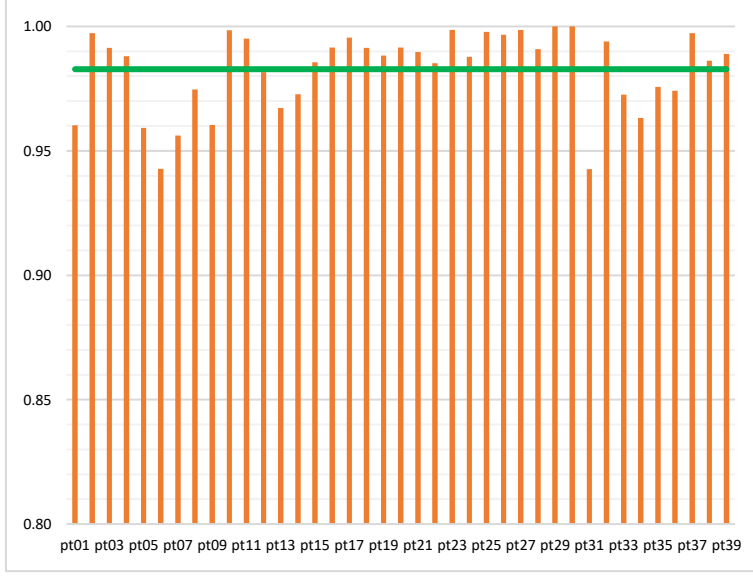

Fig.1. Coefficient of determination (R^2) of curve fitting

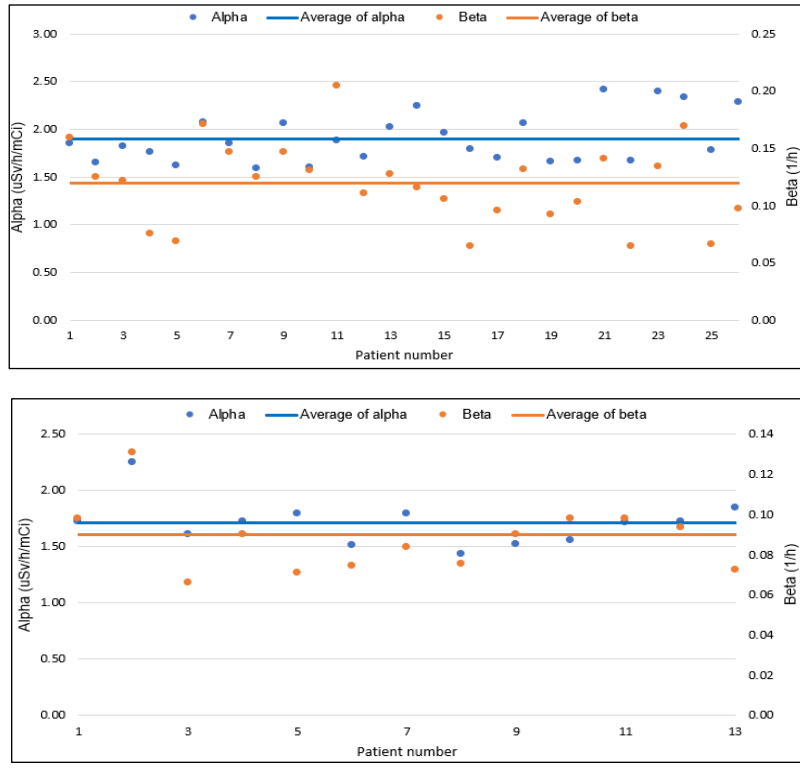

Fig. 2. Fitting parameters (α, β) of the model. The higher figure is the one of the low-activity group, the lower is of the high-activity group.

Tabei, et al. [9] assessed clearance of I-131 in four groups of patients, who administered 100, 150, 200, and 250 mCi. They also use a radiation survey meter to measure the external dose rate at a fixed distance of 1.0 meters away from patients. Time-dose rate data was fitted to bi-exponential functions. The first exponential term indicated the fast phase of clearance while the other term referred to the longer phase. The mean T_e of the fast phase was in range of 6.00 to 11.76 h. This range agreed with our result of T_e. In our study, the assessments were only perform upto 24 hours, so the T_e should be comply with the fast phase. Tabei's study was also consistent with us in that T_e decreased when administration activity (A_0) increase.

The mean τ $(\pm SD)$ of the high-activity group was $11.39 \pm 2.24\ h$, significantly similar to the value published in ICRP publication 53, for patients with thyroid iodine uptake 0% [12] ($p = 0.644$). The uptake 0% could be explained by the fact that all patients underwent thyroidectomy before radioiodine therapy. On the other hand, τ $(\pm SD)$ of the low-activity group was $8.41 \pm 2.54\ h$. It did not agree with any value in ICRP 53 ($p < 0.001$). The reason may be that low radioactivity causes a higher statistical error. In addition, the clearance process of iodine in the human body depends on the individual atopic, age, and health status of each.

III. CONCLUSIONS

This study investigated the effective half-life of I-131 in 39 patients treated with I-

131 for thyroid cancer after thyroidectomy at Dong Nai General Hospital. The half-life was drawn from the observation data by cure fitting on a mono-exponential function. The results showed that there was a significant difference in iodine clearance between the low-activity and the high-activity group. The effective half-life was within range and agreed with several studies. Our study was also the first research that studied the effective half-life of Vietnamese patients.

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