行政院國家科學委員會專題研究計畫　成果報告

使用γ-攝影機的醫學影像對甲狀腺癌患者各器官之有效半衰期及體內劑量評估

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使用 γ-攝影機的醫學影像對甲狀腺癌患者各器官之有效半衰期及體內劑量評估

Effective Half-Life and Internal dose of Some Organs in Thyroidectomy Patient using Medical Imagings of γ-Camera

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主持人：陳健懿
執行機構及單位名稱：中山醫學大學 醫學影像技術學系
Email: ccy@csmu.edu.tw

摘要

本研究探討藉 γ-攝影機進行放射性碘(碘-131)所形成的醫學影像來重新估算全身及甲狀腺有效半衰期(T_{eff})，五位女性(41.0±4.4 歲)及一位男性(35 歲)甲狀腺癌患者經全部或近乎全切除手術後，攝入 1.1GBq 碘-131(^{131}I-NaI)的第 2 天至 7 天進行全身掃描(whole-body scans WBS)。醫學影像行成的膀胱、唾液腺、胃、睪丸、大腿內側及甲狀腺之像素可由每一週中擷取，有效半衰期(T_{eff})並以加權平均法重新估算。結果顯示上列器官的 T_{eff} 為由 0.99 至 9.90 天。此值與文獻上全切除患者相符合但與國際放射防護委員會(ICRP)30 號報告的正常成人極大不同，並使用 Medical Internal Radiation Dose 3 (MIRDOSE 3)軟體，分別估算 ^{131}I-NaI 造成的劑量，結果發現最大吸收劑量的是膀胱，其次是大腸壁，並與其他文獻比較。

關鍵字: 有效半衰期，甲狀腺切除患者，醫學影像，體內吸收劑量, MIRDOSE3

ABSTRACT

Effective half-life (T_{eff}) of ^{131}I of whole-body and some organs were evaluated via in-vivo scintigraphic medical imagings of γ-camera herein. Five female (age 41.0±4.4) and one male (age 35) patients underwent near-total thyroidectomy were selected to re-estimate T_{eff} and calculate internal dose. Post-treatment whole-body scans (WBS) were subsequently performed for day 2 to day 7 after administration of 1.1 GBq of ^{131}I-NaI. Pixels of scintigraphic images had been obtained from bladder, salivary, stomach, testes, thigh, thyroid, and whole-body during 7 days intervals. T_{eff} of organs mentioned above was evaluated by weighting factor intensification methodology and the derived effective half-life (T_{eff}). T_{eff} ranged was deviated from 0.99 to 9.90 days among whole-body in this study. These results indicated that T_{eff} of whole-body of thyriodetomy patient was in good agreement with those of complete ablation but quite different from normal adult recommended by ICRP 30. The Internal dosimetric were evaluated using MIRDOSE 3 software. The highest absorbed dose was in the testes; the second highest was in the larger intestine (LLI) wall.

Keywords: thyroidectomy patient, ^{131}I , absorbed dose, MIRDOSE 3

1. Introduction

Thyroid cancer is estimated to be responsible for 1% of all clinical cancers, and well differentiated cancer of follicular cell origin accounts for 80% to 90% of all thyroids during the past fifty years. Total or near-total thyroidectomy followed by radioiodine (^{131}I) ablation therapy is beneficial in decreasing the recurrence rates. The standard treatment of thyroid carcinoma includes surgery with either a total or near-total thyroidectomy. ^{131}I-NaI is often utilized as ablative or adjuvant therapy following surgery. However, the corrected researches concerning effective half-life (T_{eff}) of ^{131}I in whole-body, thyroid and other organs are not well established using in-vivo scan in order to get clear scintigraphic imagines yet. The estimated radiation dose actually delivered to a thyroid remnant by ^{131}I is usually unknown.

1.1 T_{eff} of ICRP 30 and MIRDOSE 3

The effective half-life of ^{131}I in a patient without normal thyroid glands is quite different compared to normal person.[1] Either the 12 d biological half-life (T_{bio}) of short-terms or 120 d of long-terms recommended by the ICRP 30 report has appeared in many literatures.[1] But not all those recommended values for T_{eff} simply do apply to the special group of patients who haven't normal functioning thyroids.

Earlier studies using NaI(Tl), ion chamber or calculation model to perform whole-body scan (WBS) as well uptake of neck have been reported.[2] However, no precise activities of whole-body and some organs were cleanly analyzed in order to re-evaluate T_{eff} of whole body.

Medical internal dosimetry is calculated from measurements of radioactivity in the patient who is near-total thyroidectomy. The MIRDOSE 3 software is employed to evaluate the internal dosimetry per-unit-administered activity from user-entered residence times (τ_h) in source organs for a given radionuclide and phantom. The radiation dose is an effective quantity for the reasons of treatment planning, predicting radiation effects, correcting biological effects with further dose and maintaining complete records of radiation dose estimates.

1.2 The remainder-body activity

The MIRDOSE 3 software requires accounting of all activity throughout the patient over time for a complete evaluation. All ^{131}I-NaI activity in remainder-body tissue, not included among the major source organs, is termed remainder-body activity. The remainder-body tissue is the whole body minus any source organs which have been calculated. The τ_h of a remainder-body is calculated as the same as source organs. Dosimetric evaluations have relied on whole-body and lesion retention of ^{131}I estimated from diagnostic therapy studies. Furthermore, Fisher showed that dosimetric evaluations are not a precise science; rather, evaluations are based on rough estimations.[1]

2. Experimental

Five female (age 41±4.4, weight =

54.6±5.4 kg) and one male (age 35, weight = 84 kg) were found to have a hard, thyroid nodule on a routine physical examination. Table 1 lists six patient's characteristic. Well differentiated carcinoma of the thyroid was managed with surgery followed by ^{131}I therapy by the Department of Nuclear Medicine of Chung-Shan Medical University Hospital (CSMUH). Patients underwent near-total thyroidectomy. WBSs via γ-camera were performed approximately after the 2nd week of operation in this study.

case no.	Gender	age	weight(kg)	syndrome	status of remnant
1	Female	46	57	palillary thyroid cancer	complete ablation
2	Female	37	58	palillary thyroid cancer	minimal residual
3	Female	37	55	palillary thyroid cancer	complete ablation
4	Female	38	41	palillary thyroid cancer	minimal residual
5	female	47	62	Palillary thyroid cancer	complete ablation
6	Male	35	84	Palillary thyroid cancer	complete ablation

2.1 Image acquisitions

Six patients were treated with 1.1 GBq (29.5 mCi) ^{131}I in 6 weeks after thyroidectomy surgery. During this time, thyroid medication had been discontinued for 6 weeks. Care was taken that no iodine containing drugs that the patient had ingested and no radiographic contrast agents had been administered for 1 week before WBS. Patients were asked to return for in-vivo WBS at 2-7 day during the first week. On the first day (d 1), the patient was allowed a light breakfast. Before WBS, patient was asked to release urine. Post-treatment WBS was subsequently conducted from d2 to d7 after adminstration of 1.1 GBq of ^{131}I-NaI. WBSs were performed with Siemens E-CAM coincidence γ-camera, equipped with a high-energy, parallel-hole collimator.

Two day (d2) after the administration of ^{131}I, images were collected from the bladder, salivary, stomach, testes, thigh, and whole-body, respectively.

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2.2 In-vivo WBS via E-CAM γ-camera

In-vivo WBS was using Canberra 7350-PE collimator connected to 19 inch height × 13 inch width and 5/8 inch thickness NaI(Tl) crystal of Siemens E-CAM γ-camera which positioned at a fixed distance of 5 cm from the patient's body. The thigh was chosen for the background correction. Quality assurance and regular quality controls were

conducted, energy peak calibration of the NaI(Tl) detector was performed before each day and energy resolution tests were calibrated daily by CSMUH.

2.3 Effective and Biological half-life (T_{eff}, T_{bio})

The decay of ^{131}I of thyroidetetomy is due to both the physical decay and the biologic elimination of ^{131}I activity. The T_{bio} was evaluated with the formula:

$$\frac{1}{T_{eff}} = \frac{1}{T_{bio}} + \frac{1}{T_{phy}} \quad (1)$$

T_{bio} is the biological half-life and the physical half-life (T_{phy}) of ^{131}I that is 8.04 day.

To re-estimate the T_{eff}, its activity (A_i) is measured from different time intervals (T_i). Figure 2 and plotted a normalized straight line of T_{eff} on semi logarithmic scale among whole body and some organs of interesting.

$$Ai = A_0 \, e^{-\frac{\ln 2}{T_{eff}} Ti} \quad (2)$$

2.4 The percentages of the administration activity

The percentages of the administration activity of individual organs (%AA) were calculated with the following equation and published elsewhere:

$$\%AA = \frac{A_i}{A_0} \times 100 \quad (3)$$

Furthermore, the administration activity of thyroid remnants is defined as radioiodine uptake. The WBSs were performed for up to 1 week after an ^{131}I-NaI capsule was administered. Time-activity curves were generated from d1 to d7 for 20 min by fitting the organ-specific scintigraphic images, obtained from ROIs to decay durations.

2.5 Data Analyzing

In contract, however, ingested radioiodine is completely absorbed from the stomach into blood and does not pass through the other compartments of the gastrointestinal tract.[11] Since the first scan was obtained 2 hr after treatment, data regression were normalized to 100% at day 2 following administration of ^{131}I. A_0 is activity of individual organ of d2, while the activity (A_i), can be determined from various in-vivo scanned pixels under the assumed conditions and the weighted mean (A_w) of A_i is given by:

$$A_w = \frac{\sum W_i A_i}{\sum W_i} \quad (4)$$

Where the weighting factor (W_i) is derived from its percent standard deviation (% σ_i) and standard error (σ_i) as

$$\sigma_i = \sqrt{A_i} \quad (5)$$

$$\% \, \sigma_i = 100 / \sqrt{A_i} \quad (6)$$

$$W_i = \sigma_i^{-2} \quad (7)$$

And the weighted standard error ($\sigma(A_w)$) is given by

$$\sigma(A_w) = \left(\sum W_i \right)^{-1/2} \quad (8)$$

These T_{eff} of whole-body and some organs were re-estimated from the slop of the fitted of the normalized residual activity.

2.6 Internal dosimetric calculations

Internal dosimetric calculations from radioiodine therapy depend upon biodistributions of the ^{131}I-NaI in the individual organs, remainder-body and thyroid remnants,

as well as characterizations of the rate of uptake and clearance from each organ. Time-activity curves were generated for the anterior positions

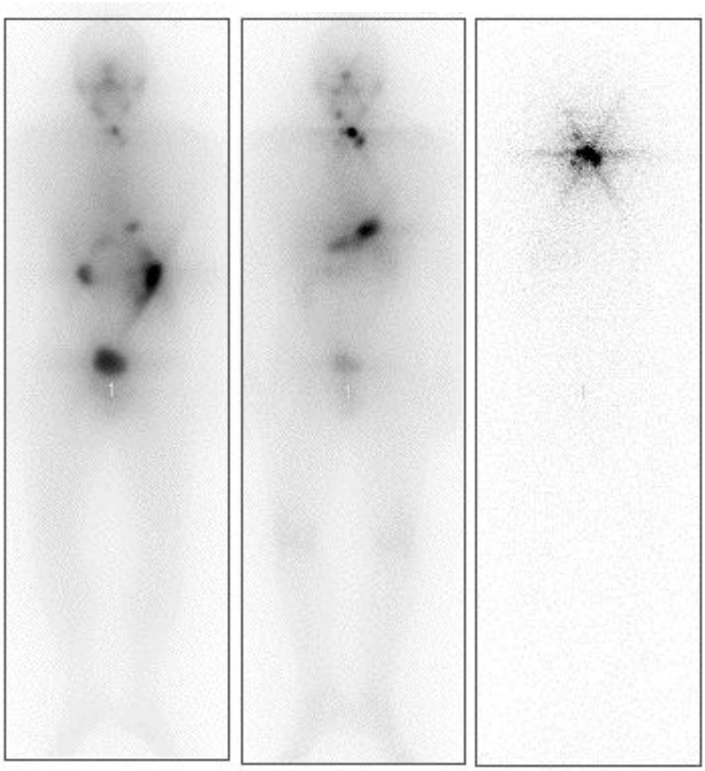

Fig.1. Whole-Body scan (a)2 d, (b)3.3 d, (c)8 d, after 1.1GBq ^{131}I administration showing intensely scintigraphic images.

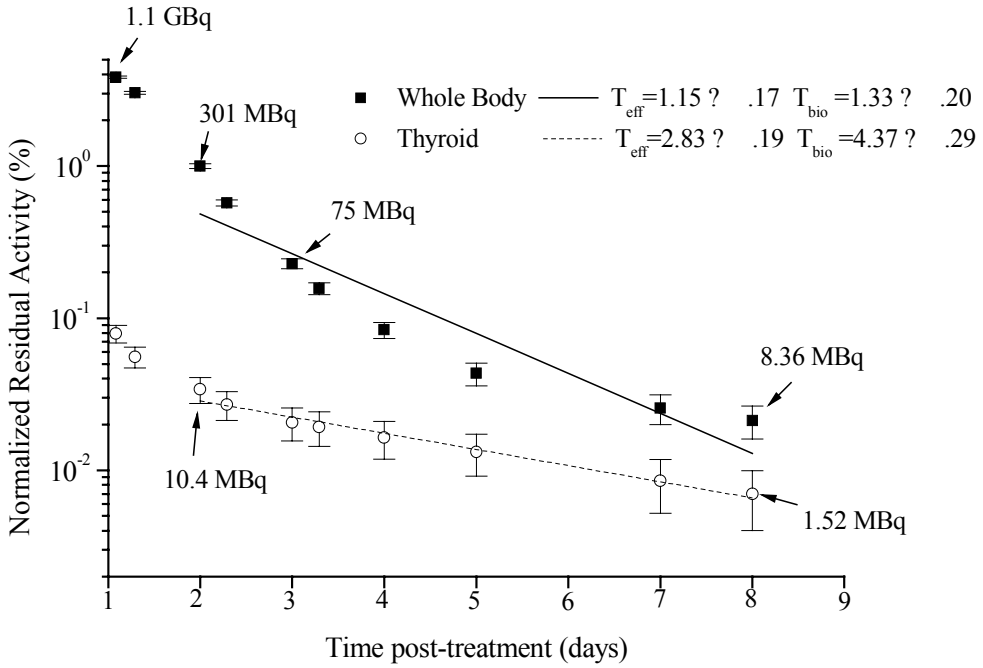

Fig 2. Normalized residual activity of ^{131}I of thyroid and whole-body for thyroid

of the bladder, brain, heart, intestine, liver, lungs, salivary glands, stomach, testes, and thyroid remnants, as well as for the posterior position of kidney.[2] Background activity of thyroid remnants was subtracted with thigh. The reference phantom selected from MIRDOSE was an adult phantom of 70 kg. The τ_h of source organs were determined by applying a linear-fit method to the pixels of Simens E-CAM γ-camera of CSMUH.[1] An estimate of the long-term retention of the time-activity curve was calculated by T_{eff}.

The τ_h of each source organ was calculated from the pixels under the fitted curves of $f(t_i)$ versus time intervals. Using the trapezoidal rule expressed as[1]

$$\tau_h = \frac{1}{2}\int_i^n f(t_i)dt + \int_n^{n+1} f(t_i)e^{-\lambda_{eff}t_i}dt \qquad (9)$$

where $f(t_i)$ = % AA/100 is the cumulated activity (A_i) for any source organ divided by the total activity A_0 administrated to the patient at time t. Theτ_h of individual organs, thyroid remnants and remainder activity were input directly into the MIRDOSE 3 software.

3. Results and discussion

An important step in the evaluation of dose for thyroidectomy patient is the exact T_{eff} of some organs of interesting. This means fraction of ingested iodine that has been absorbed by the thyroid as well as T_{eff} of whole body, and thyroid. Uptake in the brain was low. Table 2 and Fig. 3 presents τ_h and T_{eff}, during various intervals after administration of ^{131}I-NaI to time-activity curves for the bladder, brain, heart, intestine, liver, lungs, salivary glands, stomach, testes, and thyroid remnants for the male patient. The administrated activity measured at the thyroid remnant at 2 h, 24 h and 168 h was 1.98±0.26%, 0.91±0.18% and 0.19±0.08%, respectively (Fig. 2). Table 3 presents the evaluation of internal dosimetry (mGy/MBq s) and S-value from patient's time-activity curves using MIRDOSE 3 for the male patient 35 year-old.

3.1 T_{eff} of WB and Thyroid

An NRC guidance document assumes a T_{eff} of 0.32 d for the extrathyroidal component is 95% of the total. Limited information is available describing the T_{eff} of ^{131}I in the thyroid. Determining the T_{eff} is an important factor in dose calculation, in that the T_{eff} may differ. The mean T_{bio} is 16 days for Graves' disease and 30 days for toxic nodular goiter, range 2.0 to 120 days. Table 3 lists T_{eff} ranging from 1.6 to 7.5 days, giving a possible difference by a factor of 4.6 reported by Berg et al.

3.2 Dosimetry

The highest absorbed radiation dose was in the testes (1.27 mGy/MBq); the second highest dose was in the LLI wall (1.05 mGy/MBq). The patient's estimated EDE was 0.508 mGy/MBq. The MIRDOSE 3 software can calculate effective dose as defined in the ICRP 23 publication. Based on the effective dose of 0.508 mGy/MBq calculated in this study, patient can be easily estimated with 1.1GBq ^{131}I-NaI, combined with imaging obtained from Siemens E-CAM coincidence

γ-camera in CSMUH. The EDE of near-thyroidectomy patient was 0.560 Sv for the treatment of 1.1GBq ^{131}I. These τ_h calculated from the linear-fits for the individual organs were highest in the intestine (2.44 hr), and second highest in the lung (2.10 hr) (Table 3).

Table 2. Residence time (h) for ^{131}I-NaI for individual source organs

Organ	Residence time (h)	Effective Half-life (h)
Bladder	0.927	22.84±3.52
Brain	0.400	23.83±2.34
Heart	0.513	25.15±3.19
LLI	2.441	22.71±2.66
Kidney	0.617	21.43±2.36
Liver	1.22	23.04±2.73
Lung	2.090	31.20±5.00
Remainder	8.33	28.87±6.03
Salivary	0.646	38.88±5.06
Stomach	1.985	23.83±2.94
Testes	0.413	24.42±4.14
Thy(net)	1.051	67.90±4.52

Table 3. Evaluation of Internal dosimetry (mGy/MBq) and primary, secondary contributors for using MIRDOSE 3 software for thyroidectomy patient for ^{131}I-NaI

Target organ	Total Dose (mGy/MBq)	Primary Contributor (%)		Secondary Contributor (%)	
Adrenal	0.472	Rem. B	50.1	Stomach	11.8
Brain	0.451	Brain	91.4	Rem. B	7.8
Breasts	0.029	Rem. B	68.2	Lungs	17.5
Gallbladder Wall	0.495	Gall W.	92.1	Rem. B	3.4
LLI Wall	1.050	LLI	97.9	Rem. B	1.8
Small Intestine	0.052	Rem. B	50.1	LLI	32.6
Stomach	0.523	Stomach	94.7	Rem. B	3.2
ULI Wall	0.045	Rem. B	56.2	LLI	16.6
Heart Wall	0.110	Heart	69.9	Rem. B	14.2
Kidneys	0.281	Kidneys	92.0	Rem. B	3.0
Liver	0.113	Liver	82.4	Rem. B	5.6

Lungs	0.268	Lungs	94.2	Rem. B	2.8
Muscle	0.032	Rem. B	68.7	LLI	9.4
Ovaries	0.060	LLI	51.0	Rem. B	44.0
Pancreas	0.065	Rem. B	38.4	Stomach	36.3
Red Marrow	0.037	Rem. B	63.3	LLI	14.5
Bone Surfaces	0.035	Rem. B	72.8	LLI	7.7
Skin	0.024	Rem. B	80.5	LLI	4.2
Spleen	0.050	Rem. B	47.8	Stomach	29.8
Testes	1.270	Testes	99.0	Rem. B	0.60
Thymus	0.035	Rem. B	64.4	Lungs	16.9
Thyroid	0.026	Rem. B	88.2	Lungs	7.2
Urine Bladder Wall	0.040	Rem. B	64.7	LLI	28.4
Uterus	0.042	Rem. B	64.4	LLI	29.2
Eff Dose Equiv.	0.508	Gonads	62.5	Rem. B	29.1

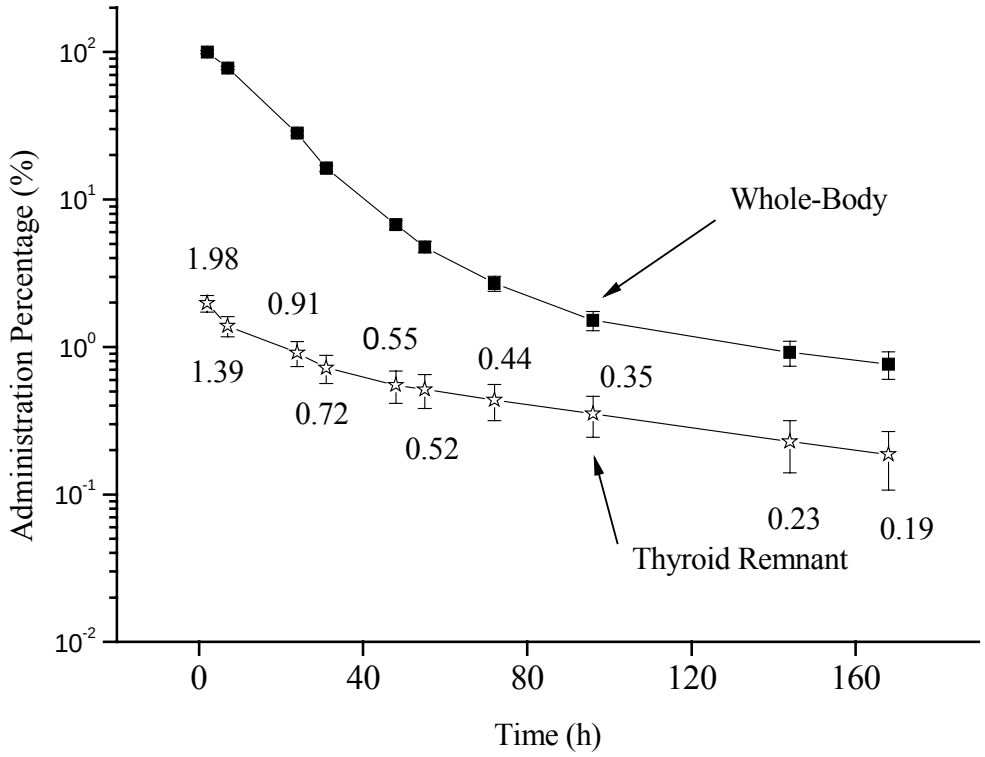

Figure 3 Administration percentage of ^{131}I in thyroid at various times after administration of ^{131}I-NaI.

Conclusion This is the first study using in-vivo

E-CAM γ-camera to measure the activity of whole-body and some organs of interesting in total or near-total thyroidetomy for six patients. Up to five organs and whole-body's T_{eff} had been evaluated. The results showed T_{eff} of whole-body is 9.7±4.6, 3.9±1.9, 1.31±0.45, 1.12±0.28 days and thyroid were found 9.5±4.0, 6.2±2.1, 2.01±0.31, 2.67±0.30 days. T_{eff} of bladder, salivary, stomach and testes were 0.95±0.14, 1.62±0.21, 0.99±0.11, and 1.01±0.17, respectively for the male patient. T_{eff} of salivary showed significantly different from those organs. T_{eff} is much shorter than ICRP 30 which T_{bio} of short-terms is 12 d and long-terms is 120 d though this unique patient. The MIRDOSE 3 software effectively calculates medical internal doses. Only calculate τ_h and T_{eff} of individual organs, thyroid remnant and remainder were calculated and the entered into MIRDOSE 3 to obtain radiation dose estimates. The effective dose of 0.508 mGy/MBq obtained in this study for the near-thyroidectomy male patient was easily calculated with 1.1 GBq ^{131}I-NaI following E-CAM tomography imaging. These data were in good agreement with published reports for patients who underwent complete ablation. The administrated activities measured at thyroid remnant at 2 h, 24 h and 168 h were 1.98±0.26%, 0.91±0.18% and 0.19±0.08%, respectively.

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