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RESEARCH

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Estimation of effective doses to whole-bodies and hands of facilitating staff from radioiodine-131 ablation therapy patients

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Abstract

Background Workers in the field of radiation therapy are exposed to radiation hazards, and it is necessary to take precautions to limit the radiation dose to nursing staff and physicists.

Objective To evaluate the external dose rate (EDR), effective whole-body dose (EHD) and hand equivalent dose (HED) for facilitating staff from radioiodine-131 (RAI-131) ablation therapy patients.

Methods One hundred and eighty patients were selected from two radiotherapy centers in Cairo, Egypt in this study and divided into three groups, Group-A, Group-B and Group-C according to administered activities of (RAI-131) of 3700 MBq, 4440 MBq and 5550 MBq for ablation therapy patients respectively. The EDR, EHD and HED were measured using electronic dosimeters.

Results The average EDR were 79.1 ± 12.1, 22.7 ± 8.5, 7.0 ± 4.0, 2.9 ± 1.3 and 1.9 ± .9.0 μSv h^{-1} for group-A, and about 87.8 ± 14.0, 25.6 ± 9.0, 8.1 ± 5.0, 3.4 ± 2.0 and 2.4 ± 1.0 μSv h^{-1} for group-B and were 93.5 ± 17.0, 31.6 ± 11.0, 10.1 ± 7.0, 4.7 ± 3.0 and 3.4 ± 1.5 μSv h^{-1} for group-C at 2 h, second, third, fourth and fifth days, respectively after administration of RAI-131. The average annual effective doses were 2.76 ± 0.09 and 1.55 ± 0.05 mSv at center 1, and were about 2.96 ± 0.09 and 1.71 ± 0.06 mSv at center 2 for physicists and nurses, respectively.

Conclusion The EDR as well as the EHD and the HED received by radiation therapy workers up to the fifth day of administered activity RAI-131 were within the limits of values recommended by the International Commission on Radiation Protection (ICRP).

Keywords Radiotherapy, RAI-131, External dose rate, Patients, Annual effective dose

Background

Radiation hazards in radiotherapy centers arise from the use of RAI-131. Therapeutic doses of RAI-131 typically range from 150 to 7400 MBq for patients with thyroid cancer. Workers in radiotherapy centers are advised to take the necessary precautions to reduce the radiation risk from the use of radioactive iodine and to reduce the annual radiation dose to less than 5 mSv per year [1, 2].

The International Commission on Radiation Protection (ICRP) has set its recommendations for the annual dose that the member of the public should be allowed to receive within the limits of less than 1 mSv y^{-1} [3]. The

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United States Nuclear Regulatory Commission (NRC 1997) has established recommendations that a patient receiving radiation therapy may be released so that the total effective dose equivalent to any other individual does not exceed 5 mSv [4]. According to the IAEA, the rate of radiation dose must be less than 70 μSv h^{-1} at a distance of 1 m from the patients to release them [5]. Also, European Union (EU) regulations stipulate that the external dose rate for patients receiving RAI-131 must be reduced to less than 20 μSv h^{-1} at 1 m to release them [6]. Obviously, using the NRC methodology in the U.S, patients with administered activity higher than 7.4 GBq can be discharged from the hospital (based on the dose limit of 5 mSv) provided they are given specific written instructions before discharge to reduce the dose to others [7].

A number of radiotherapy centers in Egypt, Cairo, provide therapeutic doses of RAI-131 to treat thyroid cancer to approximately 150–200 patients annually. These centers are considered regional centers for a number of patients from Middle Eastern countries, and patients are kept in designated isolation rooms until dose rates from the patients come within safe radiation limit as per NRC, PNRA Egyptian National Atomic Energy Authority guidelines.

The aim of this study was to the estimation of effective doses to whole bodies and hands of facilitating staff from RAI-131 ablation therapy patients.

Methods

The study was carried out in two different radiation therapy centers in Cairo, Egypt. One hundred and eighty patients were recruited. The patients were divided into three groups (Group-A, Group-B and Group-C) according to the value of administration activity of RAI-131. The first group (Group-A) which consisted of 60 patients, received the administered activity 3700 MBq for each patient. The second group (Group-B) consisted of 60 patients, who received the administered activity 4440 MBq for each patient. The third group (Group-C) consisted of 60 patients, who received the administered activity 5550 MBq for each patient.

Measurement EDR and EHD

The external dose rate was measured for the patients administered RAI-131 using a digital radiation dosimeter model Ranger Radiation Alert. The range of the digital dosimeter is from 0.01 μSv h^{-1} to 1 mSv h^{-1}. A digital dosimeter was calibrated annually at the Egyptian National Atomic Energy Authority. The initial measurement was performed 2 h after RAI-131 administration, when no urinary excretion had yet occurred, and at 1, 2, 3, 4 and 5 days. The external dose rate was measured from the patients in a private room, and the radiation background was taken into account. Three measurements were taken for each time, and the average was taken for each measurement. The radiation dose rate, time spent at a distance of 1 m from the patient and a cumulative dose were calculated for each radiation treatment procedure, and then the average value of each parameter was calculated for all cases.

The effective whole-body dose [$H_p(10)$] was measured using a pocket dosimeter (DMC 3000), ranging from 1 μSv to 10 Sv. The radiation doses received by each operator were recorded at the end of each procedure. The time spent on each procedure was recorded. This study was conducted over a full year from August 2022 to August 2023.

The wrist hand dose [$H_p(0.07)$] was also measured using a wrist hand dosimeter (PM1603A) ranging from 1 μSv to 10 Sv. The hand dosimeter was placed on the left wrist. The hand dose was calculated and corrected for environmental background. Total hand doses were measured for each individual for a full year. The dosimeter was worn only during procedures and was kept in a protected box after each measurement.

Results

All patients' data including age, sex, etc. were recorded and the average was plotted in Table 1. All patients had previously been treated with complete or near-total thyroidectomy.

The radiation dose rates for patients who received 3700, 4440 and 5550 MBq of radioactive iodine RAI-131 were presented in Tables 2, 3, and 4, respectively. External dose rates were obtained at a distance of 1 m in front of the middle of the chest of patients for 5 days after RAI-131 administration. External dose rate measurement showed an exponential curve for all three Groups-A, B and C after administration of 3700, 4440 and 5550 MBq of radioiodine (Fig. 1).

Table 1 Characteristics of patient populations used in dose measurements

Examination	Group (1)	Group (2)	Group (3)
Activity (MBq)	3700	4440	5550
(mCi)	(100)	(120)	(150)
No. of patients	60	60	60
Age, years	49.7 ± 17.0	51.2 ± 14.7	56.5 ± 9.1
Height, cm	165.4 ± 22.3	163.9 ± 7.9	170.2 ± 13.1
Weight, Kg	79.4 ± 14.0	83.6 ± 18.2	77.2 ± 13.9
Body mass index (BMI)	29.4 ± 2.7	32.1 ± 3.0	26.7 ± 0.9
Body surface area (BSA), m^2	2.0 ± 0.3	2.0 ± 0.2	2.0 ± 0.4

Table 2 Radiation dose rate, elapsed time, and cumulative dose due to staff exposure to thyroid cancer patients treated with RAI-131 for the Group-A

Phase	Range, Average Dose rate (μSv/h)	Elapsed time, (min)	Average accumulative dose, (μSv)	Dose reduction factor (F_R)	Γ,(μSv m^2/MBq h)
2 h	(67.0–91.1) 79.1 ± 12.1	1.3 ± 0.2	1.70 ± 0.57	0.999	0.021 ± 0.004
Second day	(14.6–31.0) 22.7 ± 8.5	1.5 ± 0.3	0.70 ± 0.23	0.998	0.006 ± 0.002
Third day	(5.0–9.2) 7.0 ± 4.0	2.0 ± 0.1	0.20 ± 0.12	0.997	0.002 ± 0.001
Fourth day	(1.6–4.2) 2.9 ± 1.3	2.2 ± 0.5	0.10 ± 0.10	0.995	0.001 ± 0.001
Fifth day	(1.0–2.8) 1.9 ± 0.9	2.5 ± 0.9	0.08 ± 0.08	0.993	0.00 ± 0.001

Table 3 Radiation dose rate, elapsed time, and cumulative dose due to staff exposure to thyroid cancer patients treated with RAI-131 for the Group-B

Phase	Range, average dose rate (μSv/h)	Elapsed time, (min)	Average accumulative dose, (μSv)	Dose reduction factor (F_R)	Γ,(μSv m^2/MBq h)
2 h	(73.7–101.9) 87.8 ± 14.0	1.3 ± 0.2	1.9 ± 0.6	0.999	0.019 ± 0.004
Second day	(16.5–34.7) 25.6 ± 9.0	1.5 ± 0.3	0.6 ± 0.4	0.998	0.006 ± 0.002
Third day	(11.3–4.9) 8.1 ± 5.0	2.0 ± 0.1	0.3 ± 0.1	0.997	0.002 ± 0.001
Fourth day	(1.5–5.3) 3.4 ± 2.0	2.2 ± 0.5	0.1 ± 0.1	0.995	0.001 ± 0.001
Fifth day	(3.6–1.2) 2.4 ± 1.0	2.5 ± 0.9	0.1 ± 0.1	0.993	0.001 ± 0.001

Table 4 Radiation dose rate, elapsed time, and cumulative dose due to staff exposure to thyroid cancer patients treated with RAI-131 for the Group-C

Phase	Range, average dose rate (μSv/h)	Elapsed time, (min)	Average accumulative dose, (μSv)	Dose reduction factor (F_R)	Γ, (μSv m^2/MBq h)
2 h	(76.7–110.9) 93.5 ± 17.0	1.3 ± 0.2	2.03 ± 0.74	0.999	0.017 ± 0.003
Second day	(20.5–42.7) 31.6 ± 11.0	1.5 ± 0.3	0.79 ± 0.49	0.998	0.006 ± 0.002
Third day	(14.3–5.9) 10.1 ± 7.0	2.0 ± 0.1	0.34 ± 0.16	0.997	0.002 ± 0.001
Fourth day	(2.5–6.9) 4.7 ± 3.0	2.2 ± 0.5	0.17 ± 0.14	0.995	0.001 ± 0.001
Fifth day	(1.9–4.9) 3.4 ± 1.5	2.5 ± 0.9	0.14 ± 0.13	0.993	0.001 ± 0.001

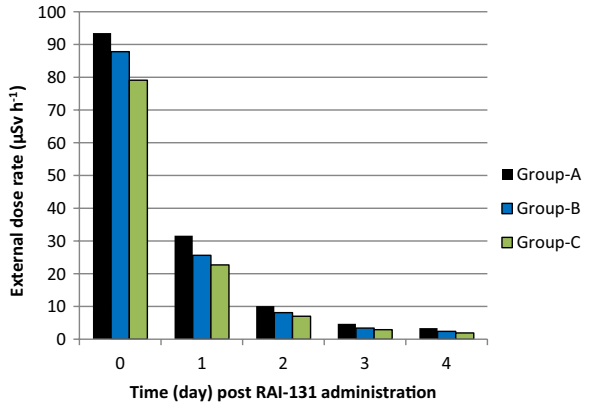

Fig. 1 External dose rate (EDR) as a function of time (day) post RAI-131 administration

The average accumulative dose for Groups-A, B and C was also calculated and plotted in the Tables 2, 3 and 4.

Over a 1-year period, a total of 180 investigations of RAI-131 therapy were included. The administered activities for each patient were 3700, 4440 and 5550 MPB. The average time taken and effective dose for each study are presented in Table 5. Each physicist or nurse performs 192 cases per year, which is shown in the table.

Hand radiation doses were measured for physicists and the results are presented in Table 6. The measurement was performed for physicists at a rate of 192 procedures per year.

Discussion

The radiation doses received by staff, members of the public and families of patients receiving radioactive iodine treatment will be affected by the activity maintained by the patients and the duration of contact with these individuals and their proximity. The dose administered to patients will vary depending on the amount of thyroid tissue present and the rate of renal and intestinal excretion [6, 7].

EDR

The average radiation dose rates for the three groups at a distance of 1 m were 79.1 ± 12.1, 22.7 ± 8.5, 7.0 ± 4.0, 2.9 ± 1.3 and 1.9 ± 0.9.0 μSv h^{-1} for Group-A, and about 87.8 ± 14.0, 25.6 ± 9.0, 8.1 ± 5.0, 3.4 ± 2.0 and 2.4 ± 1.0 μSv h^{-1} for Group-B and were 93.5 ± 17.0, 31.6 ± 11.0, 10.1 ± 7.0, 4.7 ± 3.0 and 3.4 ± 1.5 μSv h^{-1} for Group-C at at 2 h, second, third, fourth and fifth days, respectively after administration of RAI-131.

The results showed that the group administrated of 5550 MBq of radioactive iodine had a higher radiation dose rate than the administration of 3700 and 4440 MBq. The value of the EDR at 2 h after RAI-131 administration was chosen to be 100%. The mean external dose rate EDR was set in a monoexponentially curve for the three groups according to the following equations and shown in Fig. 1:

$$D_A = 161.4e^{-0.9516t} \quad (1)$$

$$D_B = 172.2e^{-0.9216t} \quad (2)$$

$$D_C = 177.1e^{-0.8535t} \quad (3)$$

where D_A, D_B and D_C are the external dose rate for Groups-A, B and C, respectively, and t is the time after the initial dose rate.

It can be seen from the results, that the mean dose rates for Group-A at 1 m distance were lower than the

Table 5 Average effective whole-body dose to staffs while performing duties with Therapeutic RAI-131 procedures for the prospective annual dose at center (1 and 2)

Work group		No. of workers	No. of procedures	Total effective dose (μSv)	Prospective annual dose (mSv)	Average effective dose per procedures(μSv)
Center 1	Physicist	1	192	2762 ± 90	2.76 ± 0.09	14.39 ± 0.46
	Nurse	1	192	1546 ± 55	1.55 ± 0.06	8.05 ± 0.28
Center 2	Physicist	1	192	2956 ± 95	2.96 ± 0.10	15.39 ± 0.49
	Nurse	1	192	1706 ± 63	1.71 ± 0.06	8.88 ± 0.32

Table 6 The hand equivalent dose for physicists in centers (1 and 2)

Work group	No. of workers	No. of procedures	Total effective dose (μSv)	Prospective annual dose (mSv)	Average effective dose per procedures(μSv)
Center 1	1	192	1901 ± 95	1.901 ± 0.10	98.98 ± 0.49
Center 2	1	192	2215 ± 11	2.215 ± 0.01	115.36 ± 0.57

corresponding value for Group-B followed by Group-C due to the lower administration activity for Group-A compared with Groups-B and C.

From Tables 1, 2 and 3 the calculated accumulative dose for Group-A, at times 2, 24, 48, 72 and 96 h were 1.70 ± 0.57, 0.70 ± 0.23, 0.20 ± 0.12, 0.1 ± 0.09 and 0.08 ± 0.08 μSv, respectively. For Group-B the values were 1.90 ± 0.64, 0.60 ± 0.44, 0.30 ± 0.10, 0.12 ± 0.11 and 0.10 ± 0.10 μSv, respectively. The corresponding values for Group-C were 2.03 ± 0.74, 0.79 ± 0.49, 0.34 ± 0.16, 0.17 ± 0.14 and 0.14 ± 0.13 μSv, respectively.

The average EDR per MBq was also calculated for the three groups post-administration, and the values were 0.021 ± 0.001, 0.019 ± 0.001 and 0.017 ± 0.001 for Groups-A, B and C, respectively.

There are several studies in the literature on measuring the EDR from the patient after administrated of radioactive iodine and the results were not always identical [8–12]. The difference in the measurement method, the device used, the accuracy of the device, and the patient's physiological factors affect the measurement results. In this study, three measurements were made each time and the average was taken. Moreover, it was observed from the results that radioactive iodine is excreted in urine droplets quickly during the first 2 days. However, the patients are kept in an isolated room until EDR decreases to less than 18 μSv h^{-1} to protect the people around them from the radiation emission of their body.

By comparing the results of this study with other studies in the literature. Barrington et al. [13] and North et al. [14] found that external dose rates were 0.046 and 0.019 μSv MBq^{-1} at 1 m for 0 day and 1 day, respectively. As for Cheryl and Dworkin [15], found that the average external dose was about 0.068 μSv MBq^{-1} at 1 m. These results are higher than the results of the present study. Al-Hag et al. [16] measured the external dose rate for patients at 1 m and found the EDR was 0.028 ± 0.008 μSv h^{-1} MBq^{-1} which is close to the results of our study. Damir et al. [17] found that the radiation dose rate at 0 days after one hour of activity administration was 158 μSvh^{-1} for 3700 MBq, 224 μSvh^{-1} for 5550 MBq and 302 μSvh^{-1} for 7400 MBq, this result is higher than our study for the administered activity of 3700 and 5550 MBq.

Effective whole-body dose [$H_p(10)$]

From Table 5, we note that the average effective whole-body doses received by the physicist and nurse are 2.76 ± 0.09 and 1.55 ± 0.06 mSv at center 1, respectively, while was about 2.96 ± 0.10 and 1.71 ± 0.06 mSv at center 2. The effective whole-body dose for physicists was higher than for other staff due to the time spent preparing RAI-131 for the patient.

The average whole-body dose for each procedure was about 14.39 ± 0.46 and 8.05 ± 0.28 for the physicist and nurse in center 1, respectively, while it was 15.39 ± 0.49 and 8.88 ± 0.32 at center 2, respectively.

By comparing these doses between the two centers, we notice a difference in the effective doses between the two centers due to the variation in case factors in each individual facility, such as the physiological characteristics of the patient, procedures, staff performance, and protective devices. For example, the workers in the first center are more experienced and educational level than the workers in the second center. In addition to, the equipment used in the first center is more radiation shielding than the equipment used in the second center (The thickness of the glass is higher). Also, the results were compared with the results of previous medical literature; The annual effective dose per study was reported to be approximately 8.9 μSv by Zeff et al. [18] while 6.5 μSv by Benitar et al. [19], and 7.2 μSv by Biran et al. [20].

Hand doses [Hp(0.7)]

The average hand doses for each study were 19.01 ± 0.10 and 22.15 ± 0.01 mSv, at centers 1 and 2, respectively. The average hand dose for each procedure was about 98.98 ± 49 μSv at center 1, while it was 115.36 ± 5.70 μSv at center 2. The high hand radiation doses received by the physicist were due to the high amount of radioactivity being handled and from interaction with vials containing radioactive iodine. However, the physicist's experience in handling radioactive materials and syringes plays a major role in reducing the time for each step of the procedure.

In comparison with the report of the International Commission on Radiation Protection (ICRP), which has about 20 mSv per year for the whole body and 500 mSv per year for the hand, it was found that the whole body and hand doses are within the permissible limits.

Limitations

The retained body activity in the patient by measuring the activity concentrations of RAI-131 in the urine has not been studied due to the possibility of contamination of the device used to calibrate and measure the radioactive intensity of radioactive iodine RAI-131.

Conclusions

The radiation dose rate EDR at 1 m from patients treated with RAI-131 decreases exponentially. It was also clear from the study that the radiation dose depends on the administered activity, and the discharge of patients should be two days after the administered activity, as the average dose rate at 1 m was less than 20 μSv h^{-1}.

The annual effective whole-body dose received by the physicists and nurses in the study centers was within

the limits of values permitted by the International Commission on Radiation Protection (ICRP). The study also indicated that physicists receive higher radiation doses than nurses. Also, the measured annual effective dose for physicists' hands was within the permissible limits of 500 mSv per year.

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Author contributions
Conceptualization, EE and SH; methodology, EE and SH; validation, TM; formal analysis, EE and AM; investigation, AM and EE; resources, SH, AM; data curation, EE and AMI; writing—original draft preparation, AM; writing—review and editing, EE, AMI, TM; visualization, SH, TM; supervision, EE, SH, TM. A MI; project administration, EE and AM. All authors have read and agreed to the published version of the manuscript.

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