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MEASUREMENT AND ANALYSIS OF PATIENT ATTENUATION CORRECTION FACTOR DURING RADIOIODINE THERAPY

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The calculated dose rate from the radioiodine therapy patient should normally include a factor accounting for the attenuation and scatter of patient body tissues. The attenuation factor is currently neglected, and not applied in operational radiation protection. Realistic estimation of radiation dose rate levels from radioiodine therapy patients when properly performed will reduce operational cost and optimise institutional radiation protection practice. In this work, the existence of a patient body tissue attenuation factor is verified by comparing the dose rates measured from the radioiodine capsules immediately before administration with those measured from the patient immediately after administration. The correlation between the factors suspected to influence the patient body tissue attenuation and the measured dose rates from the patient normalised per unit activity is statistically analysed. The calculated attenuation correction factor based on authors' measurements was (0.55 ± 0.17). The measured dose rate per unit of radioactivity from the patient showed a negative correlation with their body mass index.

INTRODUCTION

For more than 50 years, radioiodine has been used in the treatment of different benign and malignant thyroid diseases. Radioiodine therapy (RIT) is the most practised type of radionuclide therapy in our institution. We treat annually around 100 patients; these patients are admitted in two treatment rooms specially designed for inpatient treatment of radioiodine.

The difference between theoretical expected dose rate value from the patient and the measured one is mainly attributed to the patient body tissue attenuation. The correlation between the measured exposure rate from the patients and their body mass index (BMI) and body weight was studied and the results are presented. Calculated statistical parameters, namely Pearson coefficient of correlation (r), coefficient of determination (r^2) and the level of significance known as the (p) value were used to assess the degree of significance of the relationship between the measured exposure rates and some of the patient physical characteristics suspected to influence the attenuation factor.

It has been reported by Siegel *et al.*[1] that it is more realistic to use the line source approximation than the point source when reporting theoretical dose rates to exposed hospital staff from the radioactive patient as an alternative to actual dose rate measurements. The measured dose rate at 1 m per unit of administered activity predictably decreased with increasing patient size expressed as BMI because of increasing photon attenuation[2].

Correction factors to be applied to the dose rate measurements to account for attenuation and scatter in the exposed individual have been proposed. In the case of Iodine-131, the measured dose rate at 1 m, which reflects only the surface entrance dose rate to the exposed individual, should be multiplied by 0.62 to correctly reflect the total-body dose rate as proposed by Sparks *et al.*[3].

Yi *et al.*[4] proposed a self-shielding factor for the point source model to be 0.6 ± 0.16. In another study, Willegaignon *et al.*[5] modelled the correction factor to be equal to 0.638 when dose rates are measured at 1 m from the patient.

The calculated dose rate from the patient should normally be estimated as the gamma exposure rate constant multiplied by a factor accounting for patient body tissue attenuation. The aim of this work was to measure the patient attenuation correction factor (ACF) using direct dose rate measurements routinely performed during patient hospitalisation in the institution.

MATERIALS AND METHODS

The dose rates were measured from the patients immediately after administration of the radioiodine capsules at 1 m anterior to the patient body surface facing the abdominal region. The measured dose rates were compared with the dose rate measured from the unshielded radioiodine capsules measured immediately before administration in order to avoid correcting for radioactive decay.

The dose rate meter type used to measure the dose rates in this study was Ionisation chamber (Thermo, Smart Ion, Type: 2120G). The activity of the capsules was measured using clinical dose calibrator (Capintec, CRC-15R).

The dose rate at 1 m from the unshielded ^{131}I capsules measured in μSv h^{-1} was divided by the activity measured in GBq to obtain the normalised dose rate per unit activity. All patients in the study were

surveyed using the same calibrated dose rate meter; the meter has a valid calibration certificate from a nationally accredited secondary standard laboratory (SSDL) and classified by the IAEA.

In order to minimise the subjective error while performing dose rate measurements at 1 m from the capsules or the patients, the measurements were done by the same staff member from the medical physics department.

The dose rate from a patient containing radioactive material can be estimated using a point source model and given by

$$\dot{D} = \Gamma A_{0/r^2} \quad (1)$$

where r is the distance from the source to the measurement point usually located at 1 m; Γ is the gamma exposure rate constant reported to be 59.5 μGy h^{-1} m^{-2} MBq^{-1} and A_0 is the administered activity in MBq[6].

The ratio of the measured dose rate to the calculated dose rate from the unshielded capsules was (1.04) for the instrument used in the survey; the instrument response was within 4 % from the expected value.

The following can be assumed: the ratio of the dose rate measured from the patient ($\dot{D}_P$) to the one measured from the unshielded capsules ($\dot{D}_{cap}$) equals the patient attenuation correction factor (ACF).

$$\dot{D}_P = \dot{D}_{cap} \times ACF \quad (2)$$

The existence of a relationship between the (ACF) and the patient's body thickness is hypothesised; the radioiodine photons will be attenuated by absorption and scatter while passing through the body tissues.

The patient body mass index (BMI) in kg m^{-2} is defined by

$$\mathrm{BMI} = W/H^2 \quad (3)$$

where W is the weight in kilograms (kg) and H is the height in meters (m).

RESULTS

Patient attenuation correction factor

The average in air dose rate per unit activity from the capsules was found to be 69 μSv h^{-1} GBq^{-1}, with a standard deviation of 7 and a coefficient of variation of 10.8.

The ACF was calculated as the ratio of dose rate with attenuation (from the patient) to the dose rate without attenuation (dose rate in air). The average ACF was found to be 0.55 ± 0.17. Figure 1 shows the relationship between the measured dose rate from the patients and the measured dose rate from the unshielded capsules.

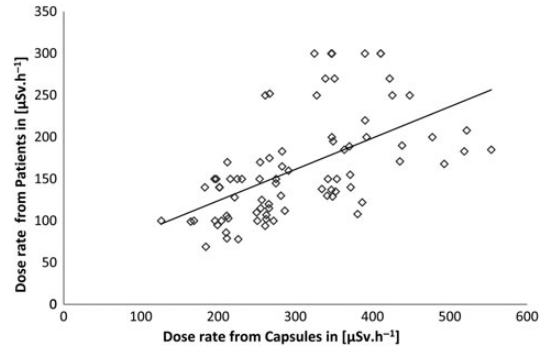

Figure 1. The measured dose rate from the patients as a function of the dose rate measured from the unshielded capsules.

The uncertainty level is due to the positioning distance and the dose rate values errors. The uncertainty levels are in the same order of magnitude as other published studies[7].

The measured average whole-body dose rate at 1 m from the surveyed patients and normalised per unit of administered activity was 38.4 ± 11.8 μSv h^{-1} GBq^{-1}.

Statistical analysis

The correlation between the different variables in the data was assessed using linear regression by calculating the Pearson correlation coefficient (r) and the coefficient of determination (r^2) and the significance level (p) value, which are all presented in Table 1.

The measured dose rate per unit activity from the patient showed a negative and non-significant correlation with their BMI (Figure 2). There was also a non-significant correlation between the patient weight in kilograms and the dose rate per unit activity.

DISCUSSION

The measured average whole-body dose rate at 1 m from the surveyed patients and normalised per unit of administered activity was 38.4 μSv h^{-1} GBq^{-1}. These results are in agreement with the results reported by Barquero *et al.*[8] who reported an average normalised dose of 52.8 $\pm$11.4 μSv h^{-1} GBq^{-1}. O'Doherty *et al.*[7] reported an average normalised dose of 60 μSv h^{-1} GBq^{-1} with a range of 50–80 μSv h^{-1} GBq^{-1} and also reported a patient population size of 60 with the average age, weight and height was 59.6 y, 62.2 kg and 162.7 cm, respectively. Table 2 shows patients demographics.

Table 1. Results of Pearson correlation coefficient (r), coefficient of determination (r^2) the level of significance at 0.01 two-tailed probability (p) value; the number of patients in this study is 80.

Variable 1	Variable 2	r value	r^2 value	P value
Dose from capsules (unshielded)	Dose from patients (shielded)	0.560	0.314	<0.001
BMI (kg m^{-2})	Measured normalised dose rate (μSv h^{-1} GBq^{-1})	−0.1771	0.0313	0.116
Mass (kg)	Measured normalised dose rate (μSv h^{-1} GBq^{-1})	−0.2146	0.0461	0.056

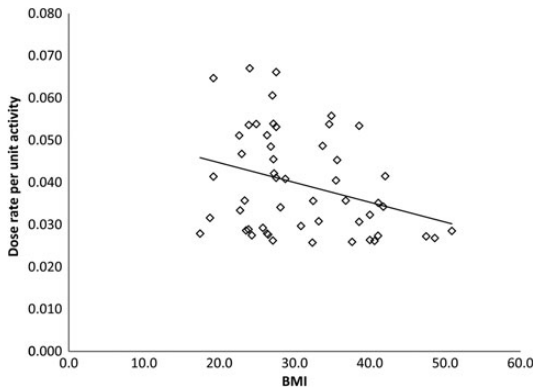

Figure 2. The measured dose rate per unit activity from the patients in μSv h^{-1} MBq^{-1} as a function of the BMI in kg m^{-2}.

Table 2. Patient demographics.

Data element	Average value	Data range
Number of patients included in the study	80	
Age	48	13–91
Mass (kg)	78	43–135
Height (cm)	158	130–195
BMI (kg m^{-2})	31.3	17.4–50.9
Administered activity (MBq)	4357	1805–7910
Measured normalised dose rate (μSv h^{-1} GBq^{-1})	38.4	19.9–67.0
Attenuation factor	0.55	0.28–0.96

Measurements of patients' dose rate at a fixed distance have been used as a discharge criterion in some countries. External exposure rate method has been frequently used for monitoring of ^{131}I patients' body burden[9].

A strict application of regulation of radioactive materials used in medical facilities in some countries has created a large waiting list for patients diagnosed with differentiated thyroid cancer (DTC) and referred for radioiodine therapy (RIT) post-thyroidectomy. Hospital admission is mandatory in Japan for RIT in patients with DTC, because the use of more than 500 MBq of ^{131}I on an outpatient basis is prohibited. It has been reported by *Higashi et al.* [10] that a delay in the treatment delivery for non-medical reasons has resulted in a negative survival outcome for the group of patients with DTC in Japan. It is clear from this example that application of restrictive regulations when it is not necessary could be harmful. There is a need to investigate and probably apply more realistic radiation protection regulations based on practical evidence and on the results of multiple risk assessment exercises published in the scientific literature over the past years[11–15]; these studies have demonstrated the safe nature of radioiodine therapy as an outpatient treatment modality.

Lee and Park[16] reported that if the total admission time in the hospital can be shortened while maintaining safety regulations, more patients who need high dose radioiodine therapy can be treated. Some patients complain about the inconvenience of isolation and the anxiety that they experience from solitude.

The dose calculations based on the measured dose rate at 1 m and patient-specific factors will significantly overestimate the actual dose to others from patients released after ^{131}I therapy[3]. The primary reason for this is that the patient dose rate is a measurement of surface entrance dose rate with no correction for attenuation by the body of the exposed individual[2]. It can be seen from the previous statement that body attenuation can be applied to both the source of radiation (i.e. the patient) and the target (i.e. the exposed individuals).

The current patient release criterion based on the total effective dose equivalent evaluated at 1 m from the patient is safe, since there is an overestimation of the estimated dose rate from the patient because scatter and attenuation by body tissues are not taken into consideration. The instructions given to the patient post-release regarding radiation safety precautions are sufficiently conservative. The application of a more accurate estimation of the predicted radiation dose rate from the patient will allow the patient to be released earlier from hospital confinement, therefore reducing hospitalisation cost and benefiting the patients and their families personally and psychologically.

Radiation shielding materials are often incorporated in the walls of the treatment rooms to protect adjacent

areas. Patient body attenuation is not considered in the shielding design calculations. More practical and economical assumptions can be proposed when patient's ACF is taken into account in the shielding design calculations. Significant cost reduction can be achieved.

The normalised dose rate per unit activity measured from the patient can be used to formulate more reasonable written safety instructions given to the patients upon release from the hospital. Such a dose rate is directly measured from the patients which includes body attenuation.

In this work, a simple method for measuring the patient attenuation factor based on dose rate measurements in $\mu Sv\ h^{-1}$ as a function of the ^{131}I capsule activity in MBq and the routinely measured dose rates from the patient post-administration has been presented. The measured attenuation factor can be currently used to predict the dose rates from the patients in situation where direct dose rate measurements are not possible, like in accidental dose reconstruction scenario[17], where dose estimations are required, it can also be used in radiation risk assessment performed by radiation protection personnel.

CONCLUSION

A more accurate theoretical estimation of radiation dose to individuals exposed to radioactive patients based on the administered activity and taking into account the ACF is possible when direct dose rate measurements are not possible.

Radiation safety specialist performing risk assessments, shielding design and developing safety instructions to the released patient after radioiodine therapy could benefit from the measured ACF.

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