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Original research paper

RADIATION EXPOSURE FROM PATIENTS AFTER RADIOIODINE THERAPY FOR THYROID CANCER

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Abstract. *Therapeutic treatment with radionuclides leads to radiation exposure. Exposure in the vicinity of patients undergoing radionuclide therapy for thyroid carcinoma needs to be discussed due to the high amount of radioactivity administered to the patient. This study presents the estimations of annual effective doses received by members of the public not directly involved in treatment procedures after patient discharge from our Department of Nuclear Medicine. After a few days of in-patient stay, the exposure is in general very low and a dedicated supervision of the patient after discharge is dispensable.*

Key words: *Radioiodine therapy, thyroid cancer, annual dose, dose rate, radiation exposure*

1. Introduction

The treatment of thyroid diseases with radioiodine exposes not only the patient but also medical personnel and members of the public coming into contact with the patient to radiation. During an inpatient stay, this presents no problem as long as none of the treatment procedures required involve close proximity to the patient. However, after discharge, the patient will inevitably come into contact with other people: this question has been occasionally discussed since decades [1] whether and in which cases the exposure of members of the public may be elevated and how this exposure could be monitored [1 - 8].

National legislation in Germany requires the annual effective dose for members of the public to be kept below an – H(1a) – of 1 mSv. This limit is unlikely to be reached when the whole-body activity for patients at the time of discharge is below 250 MBq and when a distance of at least 2 m away from the patient is kept. For outpatient treatments – routinely carried out in several countries – such estimations will yield higher annual doses, as the activity at discharge will be significantly higher.

For radioiodine treatment of thyroid carcinoma where high amounts of radioactivity – roughly in the range of 1 – 10 GBq ^{131}I – are applied, this radiation exposure may become a serious issue. Measurements have been carried out for persons in the vicinity of patients after discharge. Though no considerable transgression of exposure limits was seen, the number of cases evaluated was low.

The level of exposure in the vicinity of the patient can be estimated: dedicated dose rate measurements for patients after radioiodine therapy have been recorded by several authors [9, 10] that can be used to estimate the annual dose received through contact with the patient. Dose estimations for clinical staff during an inpatient stay have been carried out, but the situation after patient discharge remains unclear.

The aim of this study is to calculate annual doses in the vicinity of patients after radioiodine therapy for thyroid cancer on the basis of dose rate measurements, combined with measurements of whole-body activities at the time of discharge and the corresponding effective half-life taken from these repeated measurements.

2. Patients and Methods

2.1. Patients

Patients undergoing radioiodine therapy are routinely measured on our ward using a calibrated scintillation counter so that a consistent time-activity curve for the whole body is obtained for all patients. Time-activity curves for 170 patients treated with radioiodine for thyroid carcinoma between 2008 and 2009 were analyzed with regard to the following parameters:

- amount of radioactivity administered to the patient
- whole-body activity at the time of discharge from our ward
- effective half-life of the radionuclide in the patient

2.1. Scintillation counting

Before administration, each capsule was measured in an ionisation chamber type "Aktivimeter MED2000" (Nuklearmedizintechnik, Dresden, Germany), calibrated for several radionuclides, used routinely in nuclear medicine. This value was then entered into a database.

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Measurements for the time-activity curve for each patient were carried out repeatedly, the first reading being taken immediately after administration of the radioiodine capsule. These measurements were all obtained using a calibrated scintillation counter (5 cm * 5 cm NaI crystal, Nuklearmedizintechnik, Dresden, Germany). Two separate readings were taken at each time point: one for whole-body activity and another, immediately afterwards, for thyroid activity. These measurements were also transferred onto the database.

For measurements of very high activities, the fundamental problem of count-rate losses due to dead-time effects had to be taken into consideration. The onset of "saturation" due to count-rate losses begins at 150.000 cps and can be considered negligible even for the highest count rates detected that remained surely below 100.000 cps even immediately after therapy.

For whole-body activity measured at the time of discharge t_d, the respective dose rates at 0.5 m, 1 m and 2 m were determined using measured photon equivalent dose rates and ambient dose rates [9, 10]. Annual doses were calculated according to Eq. 1 for each distance using the effective half-life of thyroid measurements as a "conservative" guess function for the half-life after discharge, which in nearly all cases is equal to the measured half-life of the whole-body activity. The estimate of annual doses for each scenario assumed a constant distance to the patient.

$$H(1a) = \int_d^{1a} \dot{H}(t_d) \cdot e^{-\lambda_{eff} \cdot t}$$

$$\approx \int_0^{\infty} \dot{H}(t_d) \cdot e^{-\lambda_{eff} \cdot t} = \frac{\dot{H}(t_d)}{\lambda_{eff.}} \qquad (1)$$

3. Results

The summary of the data of the therapies for 170 patients treated with radioiodine for thyroid carcinoma are shown in Table 1.

Table 1. Statistical data of the therapies.
Activity admin. denotes the activity administered to the patient. Activity dis. denotes the whole-body activity at the time of discharge

Parameter	In-patient stay [d]	Activity admin. [MBq]	Activity dis. [MBq]	Effective half-life [d]
Mean	4.02	4753	77	1.10
Maximum	8	9825	700	6.50
Minimum	3	1923	5	0.40
Median	4	3849	48	0.9
1. Quartile	4	3728	28	0.7
3. Quartile	4	5670	88	1.2

At the time of discharge, the activity rose to 700 MBq in one individual case but the arithmetic mean of 77 MBq and median of 47 MBq show clearly that the activity was very low at discharge. This finding is accentuated by the 1st quartile (28 MBq) and the 3rd quartile (88 MBq) values. Just 36 of 170 patients were discharged with more than 100 MBq and only 13 with more than 200 MBq.

Taking further into account the typically low effective half-life for treatments of thyroid carcinoma with ^{131}I, it is evident that the limit of 1 mSv for non-involved members of the public will not be reached at a distance of 2 m (Table 2). Maintaining a distance of 2 m from the patient is the strategy commonly employed for radiation protection purposes but coming into closer contact needs to be considered as well [2].

An annual dose of 1 mSv at 2 m distance might be expected in two very rare cases, where the patients each had an extraordinarily long effective half-life (~6 d). In both cases, whole-body scintigraphy unambiguously confirmed thyroid remnants of considerable volume. As the dosimetry for these two cases is excluded from Table 2, the mean and maximum values do not take the patients with a substantial thyroid mass into account.

The mean annual dose for a distance of 2 m was found to be 37 µSv (median: 22 µSv), only a very few doses lying beyond 100 µSv (N=14) or 200 µSv (N=4). The first quartile for the 170 single doses is hence very low at 11 µSv, while that for the third quartile is ~40 µSv. The range is apparently small, 50% of the calculated annual doses falling within the region of 11 – 42 µSv, which may be considered low exposure.

Table 2. Exposure scenarios and corresponding doses.
Column H_x: Doses based on measurements of the photon equivalent dose rate [9]
Column H*(10): Doses based on measurements of the ambient dose rate [10]

	Annual dose @ 0.5 m [µSv]		Annual dose @ 1 m [µSv]		Annual dose @ 2 m [µSv]	
	H_x	H*(10)	H_x	H*(10)	H_x	H*(10)
Dose rate per GBq	147	124	43	44	13.3	13.0
Mean	414	349	121	124	37	37
Maximum	8743	7375	2558	2617	791	773
Minimum	12	10	4	4	1	1
Median	250	210	73	74	22	22
1. Quartile	121	103	36	36	11	11
3. Quartile	454	383	133	136	41	40

Table 2 also shows that the situation is similar for a distance of 1 m (mean annual dose: ~ 120 µSv, median: ~ 70 µSv). Even for a very close contact of 0.5 m, the limit of 1 mSv is seldom reached (N=14). The mean annual dose at 0.5 m is ~ 400 µSv (median: ~ 200 - 250 µSv).

The difference between the arithmetic mean and median – the former always being significantly higher – is another proof for the low annual doses in most cases. Interestingly, the values for H*(10) are slightly smaller than for H_x as the corresponding ambient dose rates that were measured beforehand are lower. The dose rate constants are in contrast higher for H*(10). The observed differences are within the error of the corresponding dose rate measurements [10].

4. Discussion

Even for treatment of thyroid carcinoma with high amounts of radioactivity, exposure of the public and caregivers to radiation after patient discharge *certainly* remains low. This assumption only holds if the duration of the inpatient stay is long enough (3–4 days). The legislation governing radioiodine therapy is known to vary between countries. Some authors consider outpatient treatment to be safe enough but clear restrictions after discharge are suggested for this procedure [11, 12]. We would argue that this is an issue requiring further debate.

Our dosimetric data were derived from radiation measurements taken repeatedly during in-patient stays, combined with dose rates for patients treated with radioiodine [9, 10] – an approach that should be feasible in routine clinical practice. For adequate radiation protection, an inpatient treatment of at least three or better four days is recommended together with repeated measurements of whole-body activity (or, alternatively, ambient dose rate) in order to establish whole-body activity curves and the effective half-life. If it is then clear that the effective half-life has remained below 1 d, discharge after three days may be considered safe from a radiation protection point of view. If, on the other hand, the effective half-life considerably exceeds 2 d, we would recommend a longer inpatient stay. Other authors have reached a similar conclusion [13] with regard to discharge planning, based on comparable data.

For the radiation protection scenarios under consideration in this study, the annual doses may only theoretically exceed 1 mSv at a distance of 2 m when the effective half-life is very long (>> 2 d) and, coincidentally, the patient is discharged early (sooner than 5 or 6 days after administration). These cases are – as described above – extremely rare. The same assumption of low annual doses holds even for a distance of 1 m and practically also for 0.5 m.

Even though the exposure is in general very low, exceeding the annual dose of 1 mSv is still a possible but very exceptional scenario, which nevertheless demands close monitoring of radiation in the vicinity of patients *before* discharge or, alternatively, of carers after patient discharge, which is far more challenging [11]. In our opinion, the data of this study justify the conclusion that monitoring during the in-patient stay will be sufficient.

Marriot et al. showed as well that doses to which carers are exposed at 1 m, measured via EPD, depend decisively on the time elapsed since administration [13]. Furthermore, Barrington et al. [5, 6] demonstrated that after treatment of hyperthyroidism, maximum doses received by family members may significantly exceed 1 mSv even if the median dose is very low. This finding suggests that the issue of radiation protection after discharge demands further investigation, even though, as pointed out by Williams et al., regulations may already be too strict [12].

Though we certainly agree that in the majority of cases where exposure is definitely very low and regulations could be eased, a simple approximation suffices to demonstrate that for every day the patient is discharged earlier the annual dose in Table 2 has to be multiplied by roughly a factor of 2 – according to Table 1, the mean half-life is about 1 d – leading to a "worst-case"-scenario that for the outpatient treatment scenario a factor of 16 has to be applied. With a patient who also has sizeable thyroid remnants, annual doses may then exceed 10 mSv at maximum for a person constantly in contact with the patient at a distance of 2 m. For close contact, we could even expect 50 mSv to be reached. But we must admit that a) this is an extremely rare case and b) the scenario commonly used for annual dose estimations is itself a coarse approximation that – in our opinion – tends to overestimate annual doses.

On the other hand, the topic has been discussed by several authors [see Ref. 11 and citations therein] and valuable *direct* measurements of doses in the vicinity of the patient have been provided by Willegaignon et al. and Jeong et al. [11, 14], demonstrating that 1 mSv is seldom reached or exceeded after outpatient treatments. Though this constitutes important verification that exposure regularly remains low, such a finding could be counteracted, in our opinion, by the so-called "Hawthorne-Effect". By this effect, well documented in organizational sociology, people aware of being under observation habitually behave in a way that is more compliant with (organizational) rules they have been told to obey. Furthermore, the small study groups are unlikely to have contained the rare outliers discussed above. It is simpler and less complicated to estimate the exposure on the basis of dose rate measurements.

According to Culver et al. [2], for radiation protection purposes, the distance of 0.5 m has to be taken into account for so-called "personal distances" between family members and our results justify the assumption that in most cases the annual doses remain below 1 mSv even for this distance. Our recommendation therefore, in line with that of Culver et al. [2], would be to avoid intimate contact (< 0.5 m) for at least seven days or to greatly restrict the amount of time spent in very close proximity. In this way, noncompliance with annual dose limits of 1 mSv would become even more improbable as it is without this recommendation. On the other hand, the personal distances discussed by Culver et al. show that the assumption that a distance of 2 m can be maintained for a long time might be unrealistic - an argument that we would agree with.

Furthermore, a possible dose contribution by inhalation of ^{131}I has to be considered. Schomäcker et al. demonstrated that the amount of radioiodine in the patient's exhaled air might also be a significant factor [15], not to mention the risk of extensive cutaneous contaminations. After an inpatient stay of three days which is comparable to the typical duration of 4 days in this study (Table 1), the dose attributable to inhalation reaches a maximum of about 10 μSv. From the authors' point of view, this shows once again that an inpatient stay of four days, allowing sufficient measurements of the radioiodine retention, is at any rate highly recommendable.

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