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Exhalation of ^{131}I after radioiodine therapy: Dosimetric considerations based on measurements in exhaled air

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ABSTRACT

It is well known that a considerable amount of radioiodine is exhaled after radioiodine therapy (RIT) leading to unwanted radiation exposure through inhalation for non-involved persons. This study focuses on the amount of exhalation in the breath-out air of RIT-patients and the dosimetric consequences. Furthermore, the correlation between radioiodine uptake and exhalation was investigated.

The radioiodine species were collected in a filter system and quantified over time by measurements with a scintillation counter. The dosimetric implications were then studied for different exposure scenarios.

Of the activity administered to the patient, approximately 10^{-3}% (50–110 ppm) is exhaled. The radioiodine inhalation taking place following exhalation in the vicinity yields doses of up to 500 μSv (children, staying with the patient immediately after application and for the next 8 h). Three days after administration the doses are significantly reduced. This study lays emphasis on previous assumptions that exhalation depends on thyroid storage. Regardless of the type of thyroid disease, the predominant form exhaled is organic radioiodine. The amount of exhaled radioiodine is small but from the point of view of radiation protection, by no means negligible immediately after administration. Radiation doses received by incorporation of exhaled radioiodine can easily exceed 100 μSv soon after administration of radioiodine. Three days after RIT the radioactivity can still be measured in the exhaled air but even at maximum, the annual doses lie far below 10 μSv and are thus comparatively low.

1. Introduction

The use of radioiodine has been well established for over six decades for treatment of benign and malignant thyroid diseases. The exposure due to external radiation and possible contamination has been exhaustively studied by various authors (e.g. Sudbrock et al., 2009 and references therein) but the problem of incorporation of radioiodine by non-involved persons in the vicinity of patients treated with radioiodine has been investigated only sporadically (Barrington et al., 1996, 1999, 2000, 2008, Lassmann et al., 1998, Krzesniak et al., 1979, 1987, Schomäcker et al., 2001). Nevertheless, for more than thirty years it has been widely known that a variable amount of radioiodine is exhaled by patients after radioiodine therapy (Krzesniak et al., 1979, 1987, Nishizawa et al., 1980, Schomäcker et al., 2001). This may lead to unwanted radiation exposure in the vicinity of the patient through inhalation by personnel on the nuclear medicine ward and furthermore by relatives and members of the public after discharge of the patient. The issue of exhalation of radioactivity after nuclear medicine procedures is of major importance and has recently been considered in relation to developments such as the administration of ^{223}Ra.

Schomäcker et al. provided data on several aspects of radioiodine exhalation (Schomäcker et al., 2001, 2011). Previous investigations of our group demonstrated that the radioactivity in breath-out air from the patient amounted to between 0.008% (80 ppm) and 0.03% (300 ppm) (Schomäcker et al., 2001) and in a more recent report to between 0.008% (80 ppm) and 0.015% (150 ppm) (Schomäcker et al., 2011) of the activity administered. Furthermore, it was exhaled predominately in organically bound form (Schomäcker et al., 2001, 2011). Measurements in the room air illustrated that the amount of exhaled radioiodine differed significantly for the different thyroid diseases. The concentration of radioiodine in the room air of the care unit of patients receiving

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radioiodine therapy was confirmed to be proportional to the activity administered to the patient and revealed an exponential decrease over time. Surprisingly, the exhaled amount of radioiodine in the room air *increased* with increasing thyroid uptake. This result of our earlier investigations was unexpected and could only be explained by the assumption that the exhaled radioactivity was previously accumulated in the thyroid, in other words: the radioiodine must have passed the thyroid prior to exhalation. This assumption would also explain why the chemical form of the iodine is mainly an organic species (Schomäcker et al., 2011).

In this study we aimed to focus on two further aspects:

- the thyroid accumulation for all patients under consideration and the correlation to radioiodine exhalation
- the effective doses resulting from inhalation of previously exhaled radioiodine for various scenarios

With these findings we further investigated the correlation of radioiodine uptake and radioiodine exhalation. The aim was to obtain a predictive value for the exhalation by measurement of the thyroid metabolism. We further applied these findings for dosimetric scenarios. As the exhalation is time-dependent, our dosimetry demonstrates the effect of a typical in-patient stay of 3–4 days.

2. Materials and methods

2.1. Patients, sample analysis and determination of the thyroid uptake of the patients

A total of 47 patients were investigated (Table 1). The activity and the chemical form in the expiratory flow were measured for each patient, as described by Schomäcker et al. using a filter system (Schomäcker et al., 2011). The filter system is able to separate different chemical forms of iodine (elemental, organic, aerosol) (Wilhelm 1987). The thyroid uptake was also precisely determined in order to obtain a measured index for the organification of iodine that could be compared with the exhalation of radioiodine. The routinely measured thyroid uptake could be a useful variable for predicting the levels likely to be exhaled by a certain patient.

In order to test whether the amount of exhaled radioiodine depended on the thyroid uptake we established a precise time-activity curve for each patient and calculated the cumulated activity for thyroid. The whole-body activity and the thyroid activity were measured twice a day for each patient during their in-patient stay. All readings were taken using a calibrated scintillation counter. The so-called "cumulated activity" was determined from the time-activity curve derived from measurements of thyroid activity according to the following procedure:

The thyroid activity for each time-point was transferred to an Excel-sheet. In nearly all cases the curve shape was well described by a bi-exponential function, as shown in Eq. (1):

$$A(t) = A_0\left(e^{-\alpha_1 t} - e^{-\alpha_2 t}\right) \tag{1}$$

A_0, α_1 and α_2: general parameters of a bi-exponential function.

The measured data were fitted to a bi-exponential approximation of the time-activity function, thereby obtaining the parameters for the bi-exponential function A_0, α_1 and α_2. By integration of Eq. (1) the area under the time-activity curve was obtained which is the "cumulated activity". This quantity represents the total number of nuclear disintegrations taking place in the thyroid and is therefore proportional to the thyroid dose the patient received.

$$\int_0^\infty A(t)dt = A_0\int_0^\infty \left(e^{-\alpha_1 t} - e^{-\alpha_2 t}\right)dt = A_0\left(\frac{1}{\alpha_2} - \frac{1}{\alpha_1}\right) \tag{2}$$

A typical time-activity function for the thyroid uptake together with a bi-exponential fit is displayed in Fig. 1.

However, in our opinion, thyroid uptake is not an appropriate value in cases of carcinoma. Scintigraphy deonstrated that four patients treated for thyroid carcinoma had thyroid remnants while three had none. For both groups we therefore tested whether the amount of exhalation depended on the presence of thyroid tissue. The amount of exhalation measured for each patient was divided by the activity administered to account for the fact that exhalation is expected to increase with the activity administered.

2.2. Dosimetric calculations

Any person who stays in the same room (assumption $V = 30\ m^3$) with the patient may inhale radioiodine. For calculating the amount of radioactivity and the resulting effective dose, we assumed reasonable scenarios for iodine incorporation:

A time-activity curve (mean values of the corresponding patients) for the exhaled radioiodine activity $A_{exh.}(t)$ was established for each different form of disease (Fig. 2). The count rate for each sample derived by scintillation counting was converted into a radioactivity by using an iodine standard. Here, a filter with radioactivity measured in a dose calibrator beforehand served as standard.

A mono- or biexponential fit to the function $A_{exh.}(t)$ was derived

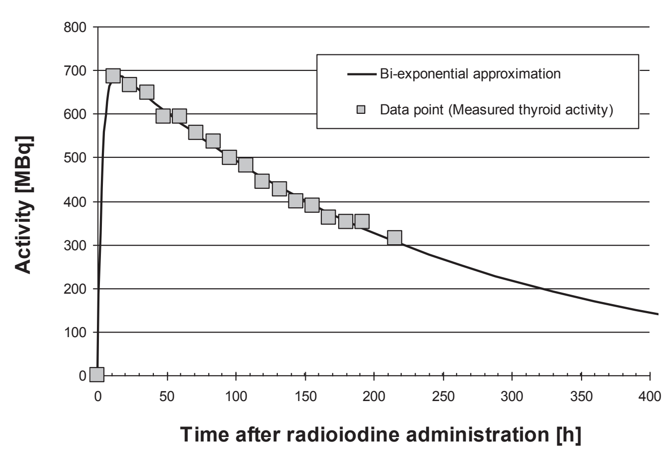

Fig. 1. Time-activity curve for the thyroid uptake of one patient. Error bars are not separately shown. The symbols are larger than the error of a single measurement.

Table 1
Overview: patient data.

Diagnosis	N	Female	Male	Activity [MBq]		Exhalation (mean value 100 h)	Half-life (mean)
				Mean	Span		
Adenoma	26	14	12	1380	1110–1480	120 kBq/m^3	8 h
Graves' disease	13	9	4	1050	370–1480	110 kBq/m^3	6 h
Carcinoma	8	5	3	3100	740–3700	540 kBq/m^3	12 h

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