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Technical Notes

A new method to evaluate the residual activity in patients undergoing ^{131}I thyroid therapy

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ABSTRACT

The radioiodine administration is a standard therapeutic approach to both benign thyroid diseases, such as hyperthyroidism, and carcinomas. The high administered ^{131}I activities are of radiation protection concern, due to relevant patient residual contamination. The aim of this work was to develop a new procedure based on external radiometric surveys and on a mathematical model in order to estimate the ^{131}I activity in patients undergoing hyperthyroidism radioiodine therapy.

In the first stage of this study, a suitable detector was chosen and its response vs. activity was characterized. The experimental verification was performed measuring the ambient dose equivalent rate from patients receiving radioiodine administration. The results confirm the reliability of the proposed method, as shown by the slight differences between the administered activities and the ones calculated from external measurements. Furthermore, the same procedure was applied to detect the percentage residual activity in patients at two preset time intervals: 4 hours and 4 days after the radioiodine administration. The obtained results clearly highlight that the method can ensure a level of reliability compatible with the radiation protection purposes.

Introduction

From the radiation protection point of view, the ^{131}I clinical use is one of the most critical nuclear medicine practices. This consideration is based primarily on the specific physical characteristics of this radioisotope:

1. long half-life (8.04 days [1]), when compared to other radioisotopes for medical use, such as ^{99m}Tc (6.01 hours [1]),
2. 364.48 keV (81.6%) photon energy peak [1],
3. slow radiopharmaceutical clearance, due to the thyroid uptake.

^{131}I-iodide therapy is currently the most common treatment for hyperthyroidisms and thyroid carcinomas [2–4]. In these cases, relevant radioiodine activities are administered to patients, causing significant residual internal contamination during the post treatment period. This is of critical concern in the radiation protection field, especially in considering the external radiation exposure to the families of patients treated with ^{131}I [5–7] and the health protection of public [8–11]. For this reason, radionuclide therapy practice requires verification of compliance with safety standards, concerning both the hospitalization and the discharge of patients undergoing such treatments [12–17].

This study regards hyperthyroidism customized treatment procedures, based on pre-therapeutic dosimetry, in which the administered activity is assessed on thyroid functionality and volume evaluation [18–23].

The actual guidelines recommend the determination of the patient residual activity at the hospital discharge by means of dose rate or residual activity determination, combined with patient based considerations [14,15]. For practical reason, a single measurement of the ambient dose equivalent rate, $\dot{H}^*(10)$ [24], at 1 m (<0.030 mSv/h corresponding to a 600 MBq administered activity) is suggested [15].

To reduce the experimental and inherent uncertainties related to this method, a systematic approach based on external measurements of $\dot{H}^*(10)$ at two different distances (1 and 3 m) and at prefixed intervals of time post-dose administration (after administration, before the discharge and 4 days later) was developed. These results were compared with the ones obtained by the currently adopted single external measurement at 1 m and before patient discharge.

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Methods and materials

The methodological approach

As the patient residual activity estimation based on radio toxicological analysis were left out for several reasons (i.e. complexity, needed resources and required time), in this study the attention was focused on a method based on activity, A, direct measurements.

From a theoretical point of view and keeping out systematic uncertainties analysis, this process is affected by an experimental error, $\Delta A/A$, which is mathematically described by:

$$\frac{\Delta A}{A}=\sqrt{\left(\frac{\Delta N}{N}\right)^2+\left(\frac{\Delta FWHM}{FWHM}\right)^2+\left(\frac{\Delta B}{B}\right)^2+\left(\frac{\Delta \eta}{\eta}\right)^2} \quad (1)$$

where N and B are the total and background count rates, η is the counting efficiency and the symbol Δ represents the experimental error associated to each variable.

In general, the contributions due to the energy resolution *FWHM* (if a large acquisition window is set on the measuring instrument) and B (which can be regularly acquired with an adequate counting statistics and subtracted from each measurement) can be neglected.

The contributions due to both the statistics, $\Delta N/N$, and the count efficiency, $\Delta\eta/\eta$, must be analyzed. The clinical γ emissions are normally of sufficient intensity to result in a good statistical measurement and to minimize the relative error, while attention was paid to detection efficiency.

The main factors affecting $\Delta\eta/\eta$ are the geometrical setup of the measurements, the count rate linearity, the patient anatomy and the body distribution of the iodine. The main effort was focused to quantify the effect of the radioiodine distribution in the patient body on experimental efficiency.

The proposed methodological approach has to provide:

1. the choice of the suitable instrumentation and the characterization of its response, according to the specific technical requirements [25] and through a calibration performed by an ACCREDIA calibration center (LAT 077);
2. the development of a mathematical model describing the cause-effect relationship between the patient residual activity and the external photon measurement;
3. an overall validation criterion, under controlled experimental conditions;
4. a practical method suitable for clinical use.

A mathematical model was implemented in order to evaluate the radioiodine activity, A, starting from $\dot{H}^*(10)$ measurements and using the $0.0672\pm0.0055\ \mu Sv\ m^2\ h^{-1}\ MBq^{-1}\ \Gamma$ constant.

Given the variability of this value in the available scientific literature [26–29], the Γ constant was calculated on the basis of about 40 experimental measurements of point sources of known activities (from 100 to 700 MBq) at different source-detector distances (from 1 to 4 m). To avoid that the detector response could affect the Γ constant value, ^{137}Cs point sources activities (3% uncertainty) were calculated by the same instrument used in this study, adopting the Γ constant value proposed in literature [26,27]. The differences between the experimental results and the sources certificated values were in the 5% range. The ^{131}point sources were prepared following the standard method adopted for radiopharmaceutical nuclear medicine practice: the radioiodine solution was previously introduced in a small test tube and the activities were measured by a well counter (CAPINTEC CRC - 25R, 2.1 percentage deviation).

In the case of a point source, the basic relationship between A and $H^*(10)$ rate can be expressed by the following mathematical formula:

$$A=\frac{\dot{H}^*(10)r^2}{\Gamma} \quad (2)$$

where r is the source-detector distance.

In clinical applications, the distance between the detector and the patient external surface is not the effective distance, d_{eff}, of the point source representing the volumetric radioisotope distribution within the human body.

To quantify the effective distance, two $H^*(10)$ rate values were measured at known prefixed distances d_1 and d_2, where $d_1<d_2$, from the patient jugular surface in the upright position.

The effective distances d_{1eff} and d_{2eff} are obtained by adding Δd to d_1 and d_2, where Δd is a virtual distance accounting for both the radiation source geometry and the body tissues attenuation.

Applying the distance inverse square law and extrapolating the experimental data, the following mathematical relationship can be adopted:

$$\dot{H}_1^*(10)d_{1eff}^2=\dot{H}_2^*(10)d_{2eff}^2 \quad (3)$$

If the new parameter C is introduced:

$$C=\sqrt{\frac{\dot{H}_2^*(10)}{\dot{H}_1^*(10)}} \quad (4)$$

Eq. (3) becomes $d_{1eff}=Cd_{2eff}$, corresponding to:

$$d_1+\Delta d=C(d_2+\Delta d) \quad (5)$$

It follows that the additive virtual distance is:

$$\Delta d=\frac{Cd_2-d_1}{1-C} \quad (6)$$

For a given patient-detector distance d, the geometrical and patient attenuation correction factor is then given by:

$$F=\frac{d_{eff}}{d}=\frac{d+\Delta d}{d} \quad (7)$$

The mathematical relationship for the patient residual activity estimation now becomes:

$$A=F^2\frac{\dot{H}^*(10)d^2}{\Gamma} \quad (8)$$

The experimental approach

The ATOMTEX AT1123 plastic scintillator detector was chosen as experimental device, on the basis of its intrinsic characteristics and performances, according to international requirements [25]. The survey meter was periodically calibrated. Before the clinical trial start-up, it was characterized in terms of response linearity versus radiation field intensity: $H^*(10)$ rate measurements were performed by means of ^{131}I point sources of different intensities (from 150 to 1000 MBq) and in different geometrical conditions, varying the distance from 1 to 5 meters. Another advantage was related to the statistical error percentage of each reading which amounted to 8%, corresponding to two standard deviations.

Furthermore, to verify the reliability of this method, an experimental check was performed by measurements carried out on patients under treatment.