Radiation Protection Dosimetry (2011), Vol. 144, No. 1–4, pp. 326–329
Advance Access publication 19 October 2010

doi:10.1093/rpd/ncq312

VARIABILITY OF RADIOIODINE MEASUREMENTS IN THE THYROID

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Monte Carlo simulations were carried out to study the response of a thyroid monitor for measuring intake activities of ^{125}I and ^{131}I. The aim of the study was 3-fold: to cross-validate the Monte Carlo simulation programs, to study the response of the detector using different phantoms and to study the effects of anatomical variations. Simulations were performed using the Swiss reference phantom and several voxelised phantoms. Determining the position of the thyroid is crucial for an accurate determination of radiological risks. The detector response using the Swiss reference phantom was in fairly good agreement with the response obtained using adult voxelised phantoms for ^{131}I, but should be revised for a better calibration for ^{125}I and for any measurements taken on paediatric patients.

INTRODUCTION

When radioactive iodine intake occurs, *in vivo* measurements of radioactivity in the thyroid are required to assess the committed effective dose. These thyroid measurements are performed with a spectrometer that has been accordingly calibrated using a standard neck phantom. However, measurements of the radioiodine activity may fluctuate drastically since the depth, size, shape and position of the thyroid gland varies widely from one individual to the other. The goal of the present study was to quantify the variability of measurements of radioiodine in the thyroid based on Monte Carlo simulations using both geometrical and voxelised phantoms. Separate evaluations were performed for the contributions of the size and the position of the thyroid, the size of the neck and the positioning of the detector.

MATERIALS AND METHODS

Instrumentation

The thyroid monitor used in the study was based on a 2 in.×2 in. NaI crystal detector mounted on a shielded lead/iron collimator. The crystal was placed at 9 cm from the edge of the collimator. The Swiss standard neck phantom used for the calibration was a 14-cm diameter cylinder with a height of 16 cm, made of polyethylene. The thyroid was simulated by two 20-ml vials placed inside the cylinder at 1 cm from the edge. This neck phantom is recommended by the Swiss national authorities and is hereby referred to as the GEDI phantom (Figure 1). Simulations were performed with the GEDI phantom and various voxelised phantoms: the Zubal VOXELMAN[1], MAX[2] and FAX[3], revised versions MAX-06 and FAX-06[4], male and female ICRP 110 adult reference computational phantoms[5] and the paediatric phantom of the UF-B series[6, 7]. Two iodine isotopes were considered in the study: ^{125}I [12.3, 45.6] keV and ^{131}I [311.6, 419.3] keV. The intervals correspond to the energy ranges that were used for identifying the isotope and determining intake activity.

Monte Carlo simulations

A cross-validation of the Monte Carlo simulation was first performed using the GEANT4 and MCNP5 codes with the GEDI phantom. The second step focused on studying the response of the detector in units of count per second (cps) per Becquerel of iodine and compared the respective response of the monitor using the GEDI and voxelised phantoms. The third step focused on studying the variability of the response as a function of anatomical parameters.

The volume containing the thyroid monitor was set as close as possible to the thyroid organ. Practically, it had to be inserted into the voxelised volume of the phantom by removing outer voxels. Schematic views are shown on Figures 2 and 3.

Anatomical variations were also simulated. The initial volume of the thyroid was then modified by substituting outer voxels associated with the thyroid glands by voxels of surrounding organs, or by changing surrounding voxels by thyroid voxels. Furthermore, in addition to the reference neck, two phantoms with 19 and 76 cm circumference (i.e. factors 0.5 and 2 from the reference) were generated by homothetic transformations of the three dimensions of each voxel. These extreme values are representative of the span of the size of regular necks. In a first approximation, one can assume that individuals of different build can be modelled by a simple homothetic transformation of the standard human body.

Figure 1. The GEDI phantom.

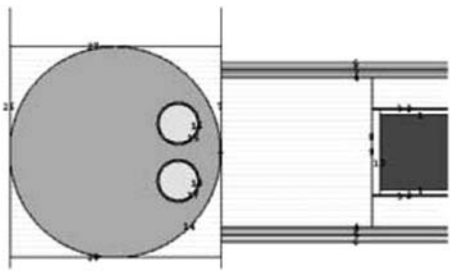

Figure 2. Schematic chart of the position of the thyroid monitor on the GEDI phantom.

Figure 3. Schematic chart of the position of the detector on the ICRP 100 male phantom. Thyroid glands appear in light colour.

This correction can be directly related to the neck circumference. A correction factor could thus be defined as a function of the size of the neck and normalised to a reference phantom. The average circumference of the neck of children aged from 0 to 3 months is 21 cm, and from 3 to 18 months is 23.5 cm[8].

Concerning horizontal (i.e. depth off-set) and vertical (i.e. up/downwards shifts) displacements, all voxels associated with the thyroid glands were extracted and repositioned along the corresponding axis, i.e. the corresponding voxels were displaced from the initial position by ± 2 and $\pm 2/\pm 4$ cm, respectively.

RESULTS

Comparison of Monte Carlo codes

The GEDI phantom was implemented in both GEANT4 and MCNP codes and the respective responses of the detector were determined. The responses are comparable for ^{131}I and ^{125}I (Table 1).

Comparison of phantoms

The size of the thyroid gland is similar in all adult voxelised phantoms, but twice as large in the GEDI phantom, i.e. 40.6 cm^3 to be compared with an average of 18 cm^3. Due to the different anatomical positions in the phantoms, the distance from the thyroid to the skin surface varied from 2 cm for adult ICRP 110 phantoms to 3.6 cm for MAX. The detector was placed as close as possible to the skin surface for each phantom. The distance from the thyroid to the crystal is not fixed, but close to 14 cm.

A rather large discrepancy was observed when comparing the response using different phantoms. Results are summarised in Figure 4. The difference was more apparent for low-energy gamma emitters, typically for ^{125}I. The response using the Voxelman phantom was 40 % lower than those obtained with the GEDI phantom for ^{131}I and even 65 % lower for ^{131}I. The same effect, although less accentuated, was observed with other voxel phantoms.

Study of the anatomical variability effects

Results are summarised in Table 2. The study of the effects of the anatomical variations was made using the MAX phantom exclusively.

Table 1. Response of the detector in units of cps per Becquerel using two Monte Carlo codes, MCNP results being the reference to calculate the ratio and compare the two codes.

Code	^{125}I		^{131}I	
	cps Bq^{-1}	Ratio (%)	cps Bq^{-1}	Ratio (%)
MCNP	0.00894	100	0.00322	100
GEANT	0.00901	101	0.00327	102

The maximum deviation from the response with the reference phantom was observed for the smallest thyroid (2.6 g, 2.4 cm^3, i.e. 1/8 of the reference size) and found to be 17 % for ^{125}I and 10 % for ^{131}I.

The size of the neck is a key parameter. Its variation has noticeable effects, in particular, for low-energy gamma emitters, i.e. ^{125}I. Homothetic transformations of a factor 2 changed the normalised response of the detector by 50 % for ^{131}I and by 70 % for ^{125}I.

The closer the thyroid was to the skin surface; the higher the response of the detector. This effect was most noticeable for ^{125}I. The detector response increased by 2 when the thyroid glands were moved 2 cm closer to the skin surface.

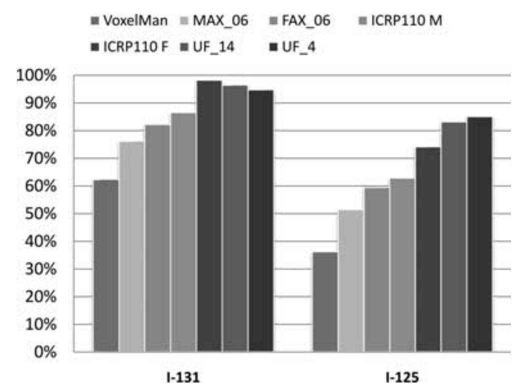

Figure 4. Relative detector response for ^{125}I and ^{131}I, using voxelised phantoms, compare with the response obtained with the GEDI phantom.

Table 2. Effects of the anatomic variations on the detector response normalised to the response obtained with the GEDI phantom.

Variation	Scale factor	Normalised response MAX/GEDI	
		^{125}I (%)	^{131}I (%)
MAX—reference	—	42	78
Thyroid volume	1/8	49	86
(fraction of MAX)	1/2	46	80
	×2	43	77
	×8	44	80
Neck diameter	1/2	92	117
(fraction of MAX)	×2	10	37
Horizontal displacement	−2	92	117
of the thyroid (cm)	+2	19	57
Vertical displacement of	−4	3	68
the thyroid (cm)	−2	27	72
	+2	47	76
	+4	42	75

The variation of the vertical position was relevant only for ^{125}I. The effect was not observed when the thyroid was displaced upwards, but was clearly observed when the organ was displaced downwards. A vertical shift of 2 cm reduced the estimated detector response by a factor 2.

The distance between the skin surface and the crystal is an important factor; the detector response was reduced by 10 % if the crystal was 1 cm further back and 40 % if displaced by 5 cm.

DISCUSSIONS

The slight difference between the two Monte Carlo codes can be explained by the fact that the MCNP code does not take into account the complete decay scheme of the radionuclide and does not take into account corrections for summation effects.

Measurements performed with ^{125}I, a low-energy gamma emitter, are generally more affected by geometrical changes, when compared with measurements of higher energy gamma from ^{131}I.

Geometrical effects explain the discrepancy observed in the response of the detector. Indeed, the vials in the GEDI phantom are close to the surface compared with voxel phantoms and have a shorter path length through matter. In Switzerland, thyroid monitors are calibrated using the GEDI phantom. The responses of the detector obtained with voxel phantoms were up to 60 % lower than those estimated with the geometrical GEDI phantom for ^{125}I, and 25 % lower for ^{131}I. In consequence, thyroid monitors that have been calibrated with the GEDI phantom clearly underestimate the intake activity and the calculated committed effective dose. This raises the question of the reliability of the monitors' calibration procedure and the possibility or need to introduce a correction factor for determining the intake activity measured with thyroid monitors calibrated using the GEDI phantom.

Better agreements (higher than 90 % for ^{131}I) were found when smaller necks were considered, i.e. women, teenagers and children. The difference is more apparent with low-energy gamma emitters like ^{125}I.

Varying the volume of the thyroid glands does not significantly alter the detector's response. Previous studies have shown similar results, even going further and showing that the shape of the glands does not have a strong effect[8]. Varying the horizontal position of the thyroid inside the phantom is also important. Indeed, in both cases, increasing the distance from the thyroid to the detector and the induced augmentation of the pathlength through tissues significantly reduces the detector's response. The effects of horizontal displacement of the thyroid gland are consistent with the exponential law of attenuation of the radiation in tissue with

$\mu = 0.3$ cm^{-1} corresponding to the energy range of ^{125}I, and $\mu = 0.1$ cm^{-1} for ^{131}I.

Without correcting for the size of the person's neck, the iodine activity in the thyroid may then been clearly overestimated in the order of 50 % (respectively, 100 %) in the case of ^{131}I (respectively, ^{125}I). For an adult, neck circumferences vary from 30 to 45 cm depending on body mass index and sex. Deviations span from −20 to +12 % in the case of ^{131}I, and from −40 to +20 % for ^{125}I. A correction factor based on the size of an individual's neck could be an effective and simple procedure to respond to a major accident situation. This correction factor would lead to a better estimation of the committed effective dose.

Uncertainties due to the position of the thyroid inside the neck could only be corrected after a clinical examination (i.e. ultrasound scan). This can be done for standard measurements or a small accidental intake but becomes a cumbersome procedure when used to respond to a major accident situation. Uncertainties due to the vertical position of the thyroid could be reduced by performing a scan to determine the position of the highest response, but this additional step in the overall procedure is time consuming.

Studying the variability of the detector response as a function of the displacement of the detector is beyond the scope of this paper and it was assumed that the centre of gravity of the thyroid glands and the detector is aligned.

The GEDI phantom could be slightly modified to get a closer response to ICRP 110 phantoms which are used to defined the new committed effective dose coefficients and therefore provide a better assessment of the radiological risk. For instance, the position of the vials could be adapted and placed further away from the surface. A more realistic thyroid shape could also be implemented in the GEDI phantom as a means for improvements.

CONCLUSION

Using a thyroid monitor that has been calibrated with the Swiss reference phantom leads to an underestimation of the activity, in particular for an adult male. This underestimation is estimated to be in the order of 20 % for ^{131}I and of 40–60 % for ^{125}I. The effect is less pronounced for individuals with a smaller neck, for female and paediatric patients, for example. Varying either the size or the mass of the thyroid gland has almost no effect on the measurement of the iodine activity(9). Determining the position of the thyroid is, however, the cornerstone for an accurate measurement, especially in the case of ^{125}I. A correction factor depending on the size of the neck of the patient could be introduced for a better estimate of the radiological risks in the case of large-scale accidental events. Further uncertainties due to the position of the thyroid inside the neck could only be corrected after a clinical examination (i.e. ultrasound scan) and could be done in standard measurements of radioactive iodine incorporation.

REFERENCES

1. Zubal, I. G. *et al. Computerized three-dimensional segmented human anatomy.* Med. Phys. **21**(2), 299–302 (1994).
2. Kramer, R. *et al. All about MAX: a male adult voxel phantom for Monte Carlo calculations in radiation protection dosimetry.* Phys. Med. Biol. **48,** 1239–1262 (2003).
3. Kramer, R. *et al. All about FAX: a female adult voXel phantom for Monte Carlo calculation in radiation protection dosimetry.* Phys. Med. Biol. **49,** 5203–5216 (2004).
4. Kramer, R. *et al. MAX06 and FAX06: update of two adult human phantoms for radiation protection dosimetry.* Phys. Med. Biol. **51,** 3331–3346 (2006).
5. International Commission on Radiological Protection. *Adult Reference Computational Phantoms ICRP* Publication 110. Ann. ICRP (2009).
6. Lee, C. *et al. The UF series of tomographic computational phantoms of paediatric patients.* Med. Phys. **32**(12), 3537–3548 (2005).
7. Lee, C. *et al. Whole-body voxel phantoms of paediatric patients—UF series B.* Phys. Med. Biol. **51,** 4649–4661 (2006).
8. *The handbook of the child measurements and capabilities.* Department of Trade and Industry, DTI/Pub/1732/2k/2.96 AR, URN 95/681, ISBN 0-9522 571-1-4 (1995).
9. Kramer, R. *et al. The assessment of the effect of thyroid size and shape on the activity estimate using Monte Carlo simulation*. Health Phys. **78**(6), 727–738 (2000).