# Population of Whole-body Statistical Adult Phantoms and Assessing the Uncertainty of Organ Doses in Hyperthyroid Treatment with $^{131}$I

Elie Hoseinian Azghadi, Hashem Miri Hakimabad*, and Laleh Rafat Motavalli

Physics Department, Faculty of Sciences, Ferdowsi University of Mashhad, Mashhad, Iran

*Corresponding author: mirihakim@ferdowsi.um.ac.ir

***Abstract*** - In this paper, a series of computational phantoms (males and females) were developed based on computed tomography (CT) images of a healthy Iranian population. The Monte Carlo calculation method was then used to estimate organ doses and their uncertainties to the hyperthyroid patient from administration of iodine-I31.

***Index Terms*** - statistical phantoms, dose uncertainty, hyperthyroidism

## I. INTRODUCTION

Computational phantoms can provide an essential tool to evaluate radiation dose in extensive areas such as radiation protection, radiation imaging, and radiation treatment. Many reference phantoms are currently being developed and widely used to estimate the radiation dose in either external or internal radiation exposures. However, different organs' shape, location and mass of individuals could affect significantly the resulting radiation dose.

A population of computational phantoms would taking into account the differences between the dosimetric data of different individuals. Recently, Segars *et al.* provided the first library of 4D computational phantoms for imaging research [1]. The uncertainties of dosimetry parameters quantified by Ebrahimi-Khankook *et al.* for external photon and neutron irradiation such as an in vivo neutron activation analysis (IVNAA) facility for individuals with only different lung sizes [2-4].

The whole-body statistical phantom series developed in this study was constructed based on anatomy of Iranian subjects. The series consists of 100 (50 males and 50 females) adult phantoms. Since an accurate manual segmentation was accomplished, these datasets could be applied as an atlas for developing auto segmentation codes, which in turn would be advantageous in image-guided surgeries.

In addition to various applications, the current database could be applied in internal dosimetry area, in which patient-specific phantoms were less utilized. $^{131}$I has been widely used in nuclear medicine to treat diseases of the thyroid (e.g. hyperthyroidism). The authors previously investigated the difference of organ dose estimates for ICRP voxel phantoms and stylized phantoms from administration of $^{131}$I [5-7]. The goal of $^{131}$I is to control hyperthyroidism by rendering the patient hypothyroid; this treatment is very effective, provided sufficient radiation is deposited in the thyroid [8].

The important questions that this study intends to answer are: what is the level of uncertainty in the organ doses when a reference model used for a group of people? And is there a systematic deviation between the results for Iranian statistical phantoms and ICRP voxel phantoms?

## II. METHODS

### *A. Phantom construction*

The body trunks of phantom series in this study were constructed from chest abdomen pelvis (CAP) CT images of a healthy population of Iranian patients collected from three Educational, Research, and Treatment Centers in Mashhad, and Tehran, Iran. CAP datasets were selected that exhibit normal anatomy of internal organs.

Selected organs were manually segmented from each dataset. The mesh models of the whole body according to trunks height, diameters and circumferences of the CAP models were created using MakeHuman software. The head and neck model was segmented from separated Image datasets and randomly added to the whole body models. The polygon models were imported into the *Rhinoceros*™ to adjust the location and orientation of models from different datasets.

### *B. Validation of statistical data*

The authors investigated the accuracy of whole-body phantoms from statistical viewpoint by gathering the information on segmental body composition analysis of 100 individuals from clinical impedance devices. The correlation between the trunk weight and total height for constructed phantoms was in good agreement with the distribution obtained for normal subjects.

### *C. Evaluation of uncertainty parameters*

The coefficient of variation (CV) was used to compare the amount of dose deviation from the mean value for the various situations.

## III. RESULTS

Estimations of organ doses exposed to the internally deposited radionuclide, were obtained for 7 level of thyroid uptake from 5% to 95%, using similar method described in our previous paper [9]. The calculations were performed for a unit of administered activity. However, hyperthyroidism control can be accomplished equally well by either administering a fixed activity or by calculating the activity based on the size of the thyroid and its ability to trap iodine. The first method is simple, and there is evidence that 10 mCi (370 MBq) results in hypothyroidism in 69% at 1 year. The second method requires three unknowns to be determined: the thyroid uptake, the size of the thyroid, and the quantity of radiation (μCi) to be deposited per gram of thyroid (e.g., activity (μCi) = gland weight (g) × 150 μCi/g × [1/24 hour uptake on %]) [8].

## IV. CONCLUSION

The series of anatomically variable phantoms developed in this work provide a valuable tool for evaluating radiation dose in various applications. In the present paper, authors try to evaluate organ dose uncertainty due to the anatomical changes of different patients undergoing hyperthyroidism treatment.

The thyroid dose and other important organ doses were calculated and the mean doses and their CV were obtained for each thyroid uptake. The results showed that the thyroid dose is strongly dependent on thyroid gland mass and uptake. In the case of constant administration activity of 10 mCi, the CV value of thyroid dose is significantly large (e.g. 37% for females) in comparison with the later method (2%). This issue was indicated in Figure 1. Therefore, obtained results imply that for effective treatment by deposit sufficient radiation in the thyroid, the later method should be recommended.

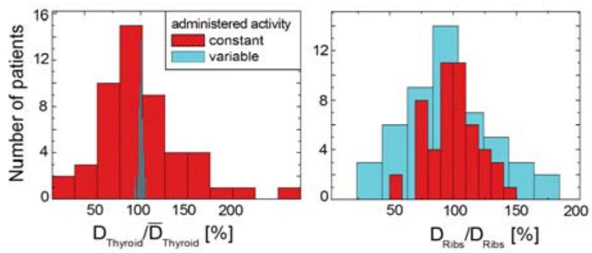


Figure 1. Histogram of thyroid, and active marrow dose in spongiosa bones of ribs per mean value for female phantoms. The mean doses are different for each thyroid uptake.

In the case of the second method of administrating activity the uncertainties in other important organ doses such as proportion of active marrow close to the thyroid, lung, and trachea were increased. Table 1 listed the CV values of dose to organs which have following properties: (1) dose dispersion larger than 20%, and (2) received considerable large dose. The later includes adjacent organs to thyroid gland, as well as major source organs in biokinetic model of radiopharmaceutical (e.g. stomach, bladder contents, and liver).

Table 1. Estimated uncertainty of thyroid dose using two method of administered activity

| Administered activity | CV [%] | |
|---|---|---|
| | Constant | Variable |
| Thyroid | 37 | 2 |
| Trachea | 49 | 51 |
| Esophagus | 74 | 67 |
| Lung | 24 | 44 |
| Active marrow (T-spine) | 50 | 86 |
| Active marrow (Ribs) | 20 | 44 |
| Stomach wall | 44 | 70 |
| Liver | 15 | 41 |

The principal contributor to the dose to nearby organs is the photons emitted by thyroid gland as thyroid uptake increases [7], which occurs in hyperthyroid patients. Therefore, larger CV values were obtained as a consequence of statistical variation of inter-organ distances between thyroid and foregoing organs in different phantoms. The highest marrow absorbed doses are delivered to the marrow in the thoracic spine, and ribs because of the short inter-organ distances between thyroid and these skeletal bones, and also their considerable fraction of total active marrow [6]. Since the administered activity is generally limited by the absorbed dose to the bone marrow, particularly in the treatment of thyroid carcinoma, assessing the level of uncertainty in this fatal tissue seems crucial.

The major contribution of the dose to the main source regions arose from self-irradiation of electrons [7]. By considering the fact that the mass of these organs are not essentially depend on thyroid gland mass, it could be concluded that various administered activities leads to a large statistical deviation from mean value.

It could be concluded that the evaluation of the uncertainty level using statistical phantoms is substantial, especially in the case of high-dose radiation fields. Also, special features of each race may have remarkable effects on resulting dose. For example, shorter necks of Iranian individuals yield to larger amount of dose delivered to lungs and other internal organs in comparison with ICRP reference adult phantoms.

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