Use of dual-head gamma camera in radionuclide internal contamination monitoring on radiation workers from a nuclear medicine department

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Abstract. As a part of an internal dosimetry program that is performed at the Mexican National Institute of Cancerology-Nuclear Medicine Department, in the present work we suggest a procedure for the routinely monitoring of internal contamination on radiation workers and nuclear medicine staff. The procedure is based on the identification and quantification of contaminating radionuclides in human body by using a dual-head whole-body gamma camera. The results have shown that the procedures described in this study can be used to implement a method to quantify minimal accumulated activity in the main human organs to evaluate internal contamination with radionuclides. The high sensitivity of the uncollimated gamma camera is advantageous for the routinely detection and identification of small activities of internal contamination. But, the null spatial resolution makes impossible the definition of contaminated region of interest. Then, the use of collimators is necessary to the quantification of incorporated radionuclides activities in the main human organs and for the internal doses assessment.

1. Introduction

Intake of radionuclides may occur by several routes (ingestion, skin absorption, etc.) [1]. In the case of occupational exposure in a nuclear medicine service the main route of intake is by inhalation. Implementation of a monitoring program to detect and measure radionuclide contamination and to evaluate doses from intake of radioactive material is essential to verify compliance with regulations and to provide assurance that the operational radiation protection is working. The aim of such a program is to guarantee and document that workers, under the risk of internal contamination in addition to external exposure, are adequately protected against a risk associated with normal practices, accidental situations or malicious acts. The program also provides information in order to optimize radiation protection [2]. To perform a monitoring program requires appropriate bioassay measurement methods with adequate detection capability. Conventionally, *in vivo* measurements of internal contamination requires probe monitoring (whole-body or organs specific counting) which have prohibitive costs for most of the installations that work with unsealed radioactive sources. However, in the case of a nuclear medicine department, the use of planar imaging systems to perform a routine monitoring program is feasible. These systems, particularly dual-head whole body scanners, provide both cost- and time-effective methods for acquiring data for personnel dosimetry studies [3]. The aim of this work is to present a method for detection, identification and quantification of internal contamination by means of a dual-head gamma camera in nuclear medicine department radiation workers.

2. Materials and Methods

2.1 Gamma camera

The gamma camera used in this work was an e.cam® Siemens dual-head 180° fixed-angle gamma camera, equipped with two 59.1 x 44.5 x 0.95 cm^3 NaI(Tl) crystals and an hexagonal array of 59 photomultiplier tubes for each crystal. This design provides a convenient means for simultaneous acquisition of anterior-posterior conjugated images. This equipment was evaluated as a screening tool for the direct *in vivo* detection, identification and quantification of small traces of common radionuclides used in nuclear medicine.

2.2 Anthropomorphic phantom

A REMCAL whole body anthropomorphic calibration phantom for radionuclides [4], containing major organ volumes, was used to calculate gamma camera sensitivity factors (cpm/μCi) and Minimum Detectable Activities (MDA). The phantom consists of an articulated anthropomorphic plastic shell of vacuum-formed Tenite II polymer 2 to 3 mm thick, containing major organ volumes (lungs, thyroid, heart, kidneys, spleen, pancreas, stomach, bladder and simplified lower intestinal tract). Selected organs can be filled either with water or a mixture of water and the radionuclide of interest. The phantom has a height of 175 cm and a mass of 73.5 kg (FIG.1).

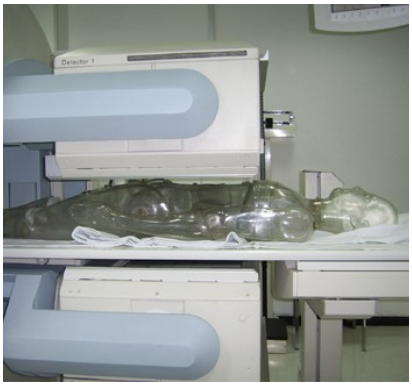

FIG.1. Water filled anthropomorphic phantom being scanned with the dual-head gamma camera.

2.3 Sensitivity factors

Anterior and posterior static images, 10 and 20 cm from the phantom, respectively, were acquired during 5 minutes. Sensitivity factors (cpm/μCi) for thyroid, kidneys, and bladder were obtained by injecting small activities of ^{131}I from 3.0 ± 0.2 μCi (0.111 MBq) to 10.0 ± 0.2 μCi (0.370 MBq) and using the uncollimated camera or Medium Energy (ME) and High Energy (HE) collimators.

Organs and background counting rates were obtained from the images (FIG. 2). Using ImageJ® software, a region of interest (ROI) was draw around the organs. The sum of the counts in the defined ROI was divided by the acquisition time to obtain the counting rate (cpm). Images were acquired using a symmetric energy window of 15% around the photoelectric peak, and stored in a 256x256 pixel matrix. The sensitivity factors were calculated as the quotient of ROI´s counting rate and activity.

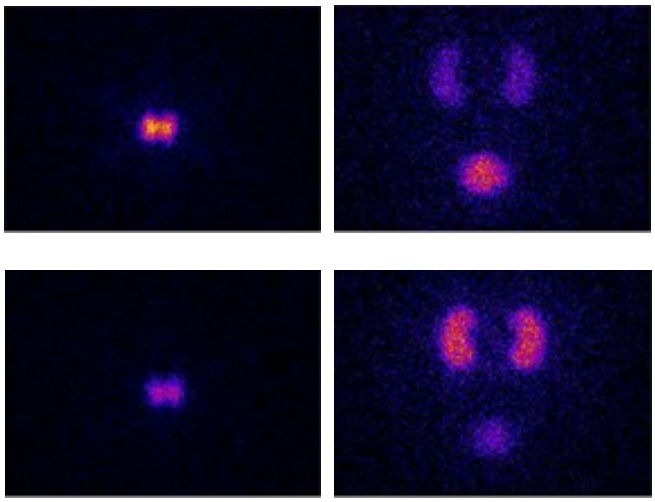

FIG.2. Thyroid (left) and kidney-bladder (right) phantom images in the anterior (top) and posterior (bottom) positions (^{131}I, HE collimator).

2.4 Minimum Detectable Activity (MDA)

In order to evaluate the capability of the gamma camera to detect low activities, the MDA was calculated using the following equation [5]:

$$MDA(Bq) = 3.7x10^4 \cdot \frac{4.65\sqrt{B \cdot t} + 3.0}{f \cdot t}, \quad (1)$$

where

B is the background counting rate (cpm);
f is the sensitivity factor (cpm/μCi) for particular radionuclide, organ and collimation condition;
t is the counting time (min).

A radionuclide MDA, for a particular counting time, is the activity that increases the counts recorded by an amount that is statistically significant in comparison to random variations in background counts that would be recorded during the same measuring time [6].

2.5 Radionuclide identification capability and energy resolution

The gamma camera multichannel analyzer display of pulse-height spectrum was used to evaluate the uncollimated camera capability for the identification of low activities of radionuclides. Spectra were acquired using low activity point sources of ^{99m}Tc, ^{67}Ga, and ^{131}I, with activities from 2.0 ± 0.2 μCi (0.074 MBq) to 4.0 ± 0.2 μCi (0.148 MBq). The sources were placed in air at 20 cm from the detectors surface.

The energy resolution (width of the main photopeaks measured across of half-maximum amplitude, referred to as the full width at half maximum FWHM) was evaluated by means of the spectrum displays.

3. Results and Discussion

Sensitivity factors for thyroid, bladder, kidneys, using ^{131}I, are shown in FIG.3. Calculated MDA by means of equation (1) are shown in Table 1.

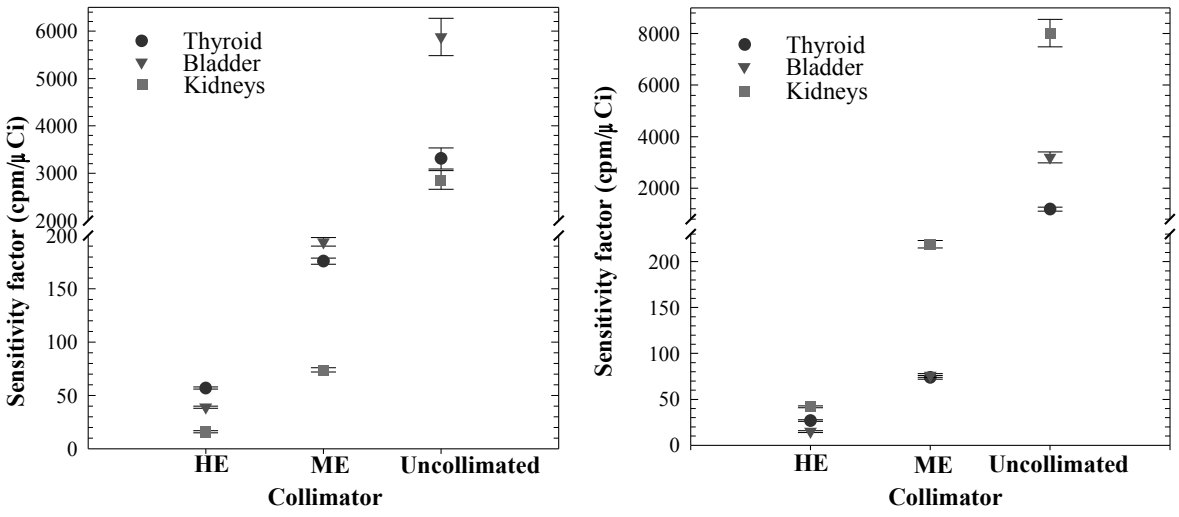

FIG.3. *Sensitivity factor using ^{131}I, for anterior (left) and posterior (right) views.*

Table 1. MDA (Bq) using a counting time of 5 min for anterior / posterior images.

Organ	Collimator		
	HE	ME	UC
Thyroid	5, 948 / 11, 298	2, 139 / 4, 945	175 / 499
Bladder	11, 586 / 27, 407	2, 603 / 6, 450	133 / 251
Kidneys	27, 793 / 9, 867	6, 763 / 2, 240	265 / 100

According to FIG.3 and Table 1, the uncollimated camera presents the maximal sensitivity. However, the null spatial resolution makes impossible the definition of a contaminated region of interest (see the FIG. 4). Therefore, the use of collimators is necessary for the quantification of incorporated radionuclides activities in the main human organs, and for the internal doses assessment.

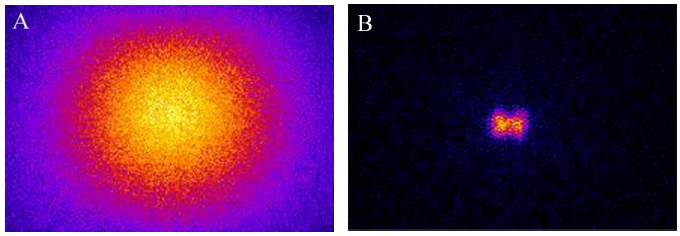

FIG.4. Anterior ^{131}I [3.0 ± 0.2 μCi (0.111 MBq)] images of thyroid phantom using uncollimated camera (A) and HE collimator (B).

FIG.5 shows an example of a ^{67}Ga spectrum. This spectrum makes possible the identification of common radionuclides used in nuclear medicine. The obtained spatial resolution as the FWHM for each one of the radionuclides is shown in Table 2.

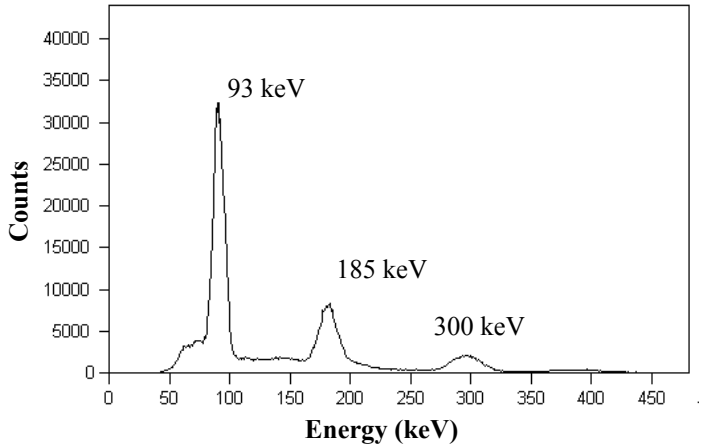

FIG.5. ^{67}Ga spectra obtained with gamma camera multichannel analyzer display. Radionuclide identity can be known by means of 93, 185 and 300 keV photopeaks showing in the spectra.

Table 2. Energy resolution (FWHM) for common radionuclides used in nuclear medicine.

Radionuclide	Photopeak (keV)	FWHM (keV)	Energy resolution (*) (%)
^{67}Ga	99.3	11.1	11.9
	184.6	18.9	10.2
	300.2	28.9	9.6
^{99m}Tc	140.5	14.4	10.3
^{131}I	364.5	35.5	9.7

(*) Energy resolution was calculated as the FWHM divided by the energy at the maximum of the peak, and multiplied by 100.

According with these results, here we propose a trace-stage general strategy which takes in account practical considerations. First stage has two goals: to determine the occurrence of internal contamination and identify the radionuclides. To achieve this, it is necessary to increase the system sensitivity, and we propose the use of the uncollimated gamma camera. This first screening measurement consists in the periodical acquisition of two static images of head-chest and abdominal region, and the acquisition of an energy spectrum using the gamma camera multichannel analyzer display. The second stage, only for workers who present internal contamination, evaluates the incorporated activity, using the appropriated collimator to optimise the resolution-sensitivity tradeoffs required to obtain useful images for the quantification of organs activities by means of a previously obtained sensitivity factor. Finally, the third stage has the purpose of assess the committed effective dose by means of an appropriate dosimetric model.

4. Conclusions

The evaluation of a gamma camera performance in terms of sensitivity, energy resolution and detection capability, shows the feasibility of the proposed procedure for the identification and quantification of low levels of internal contamination. The wide availability of gamma cameras in nuclear medicine departments makes possible the implementation of the proposed strategy.

Our next goal is to determine calibration factor for different organs and radionuclides, and to use these data to perform internal dose estimations based on ICRP or MIRD schema.

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