INTERNAL DOSIMETRY FOR RADIONUCLIDE DIAGNOSTIC IN NUCLEAR MEDICINE BONE SCAN PROCEDURES

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Abstract. This study aims to estimate the absorbed doses and biological parameters in the critical organs of patients during bone scan scintigraphy, using SPECT data based on technetium 99m-methyl diphosphonate (^{99m}Tc-MDP) in nuclear medicine (NM) procedures. Tc uptake of different critical organs (ROIs) such as kidneys and bladder were calculated at different times (0.2 h, 1 h, 1.45 h, and 3 h) after the administration of mean activity A_0 equal to 11.53 mCi. The absorbed dose, biological half-life ($T_{1/2}$), and residence time (τ) were computed using Medical Internal Radiation Dosimetry (MIRD) Report 13 of biokinetic model. The data were analyzed using a computational toolkit called (IntDosCalc) developed under Matlab code. The results of the present study showed that the value of the absorbed dose for critical organs such as the kidney and bladder were 0.007 and 0.393 mGy per unit of administrated activity, respectively. The cumulated activity, residence time, effective half-life and biological half-life were discussed in detail.

Key words: Absorbed dose, nuclear medicine, medical internal radiation dose, technetium-99m.

INTRODUCTION

The application of scintigraphy studies in nuclear medicine was developed in the last years with the use of many techniques and a variety of radioisotopes. However, one of the most used radionuclides in nuclear medicine routine is the technetium-99m (^{99m}Tc) [12], representing nearly 80 % of the data diagnostics of the different organs such as liver, kidneys, heart, bone, spleen, lung, and thyroid gland [6]. The estimation of the absorbed dose levels for each specific critical organ during the scan irradiation is needed to be optimized in order to diminish the biological effects and the risk of radiation exposure [3]. However, the calculation of the internal dose evaluation is considered important in various alternative treatments or

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diagnostic techniques in nuclear medicine. In most cases, the absorbed doses by the intestines and kidneys are higher because they adsorb the highest amounts of radiopharmaceutical products [2, 5]. The main object of this paper is to estimate the absorbed dose in these critical organs, especially in bone scintigraphy studies. To calculate the absorbed doses, a computer program called IntDosCalc, which means an abbreviation of the internal dose calculator, has been developed based on MATLAB code (Matrix Laboratory) to study the physical dosimetry in bone scan procedures.

MATERIALS AND METHODS

In this study, we have developed a platform-independent software named (IntDosCalc) using the Matlab (Matrix Laboratory) environment which provides tools used for internal dose calculation according to MIRD formulation [9, 11]. One of very important things in the field of internal dosimetry is the collection of time and activity from patient data. In order to obtain the physical parameters of our model, SPECT Image Processing DICOM files of patients were acquired at various time points after the radiopharmaceutical injection. To determine the radioactive quantity, we draw manually the region of interest (ROI) at different times in each organ (anterior and posterior). This process will give several counts given a cumulated activity on each time frame.

CALCULATION OF THE CONJUGATE ACTIVITY

To determine the value of radiation activity in target organs, the conjugate view method was applied to each SPECT data image. Using our software, ROIs were drawn on anterior and posterior data images for each organ activity [7]. Finally, the obtained counts were converted to activity, A_i (mCi), using formula [8]:

$$A_i = \sqrt{\frac{I_{\mathrm{A}} \cdot I_{\mathrm{P}}}{\mathrm{e}^{-\mu x}}} \cdot \frac{f_i}{C} \tag{1}$$

where: I_{A} and I_{P} represents the counts per unit of time for the anterior and posterior SPECT images, respectively, measured in counts/s; μ represent the attenuation coefficient of the source organ (cm^{-1}); f_i is the correction factor for the source organ; C is the system calibration of the imaging system, given by count rate per unit activity; x is the organ thickness (cm).

ABSORBED DOSES CALCULATIONS

The absorbed doses per unit of administered activity in organs were calculated using SPECT data files. The radiation absorbed dose of organs in body was calculated by the sum of all the product of residence time (τ) for different source organs and the S-values for the source-target organ, $S_{r_k \leftarrow r_h}$, which yielded the absorbed dose, D_{ri} (Gy), to a target organ (r_k) per unit administered activity (A_0), according to the MIRD formulation [10]:

$$D_{r_k \leftarrow r_h} = \sum_h \tilde{A}_h \times S_{r_k \leftarrow r_h} \tag{2}$$

where $\tilde{A}_h$ is the cumulated activity (mCi·h) in the source organ (r_h), given by the equation (4), $S_{r_k \leftarrow r_h}$ represents the specific absorbed fraction in the target organ per unit of mass [3]:

$$S_{r_k \leftarrow r_h} = \sum_i \Delta_i \frac{\Phi i_{r_k \leftarrow r_h}}{m} \tag{3}$$

where Δ_i represents the mean energy of radiation *i* per nuclear transition, $\Phi i_{r_k \leftarrow r_h}$ is the absorbed fraction of absorbed radiation in target *k* per emission of radiation *i*, *m* is the masse of the target organ (kg).

$$\tilde{A}_h(t) = A\int_0^{\infty} \mathrm{e}^{-\lambda_{\mathrm{eff}} t}\mathrm{dt} \tag{4}$$

where *A* represents the initial activity of the radiopharmaceutical, in mCi.

In this respect, the area of the time activity curve for each organ was calculated as described in the study of Mohsen Cheki [4] where the effective decay constant, λ_{eff} is given by the sum of the physical and the biological decay constants ($\lambda_{\mathrm{Phy}}+\lambda_{\mathrm{Bio}}$). It is necessary to consider both the biological, λ_{Bio} and physical, λ_{Phy} characteristic to the radiopharmaceutical molecules [1]. The effective decay time, T_{eff} can be defined as:

$$T_{\mathrm{eff}} = \ln 2/ \lambda_{\mathrm{eff}} = \tau_{\mathrm{eff}} \times \ln 2 \tag{5}$$

RESULTS

The results from such study represent an important level in the evaluation of internal absorbed doses and biological effects. In addition, several studies have demonstrated the usefulness of SPECT data images as a method for absorbed dose estimations in humans. However, our software was focused on the accuracy of residence time calculation and organ dose calculation by estimating absorbed doses to target organs using a planar nuclear medicine bone scan procedure, at different times after the Tc injection in the patients using nuclear medicine devices. The selected source organs were kidneys, liver, bladder, and the total body. After a ROI was drawn on an anterior image, this ROI was copied to a posterior image and copied to a series image at a different time using IntDosCalc presented in Figure 1.

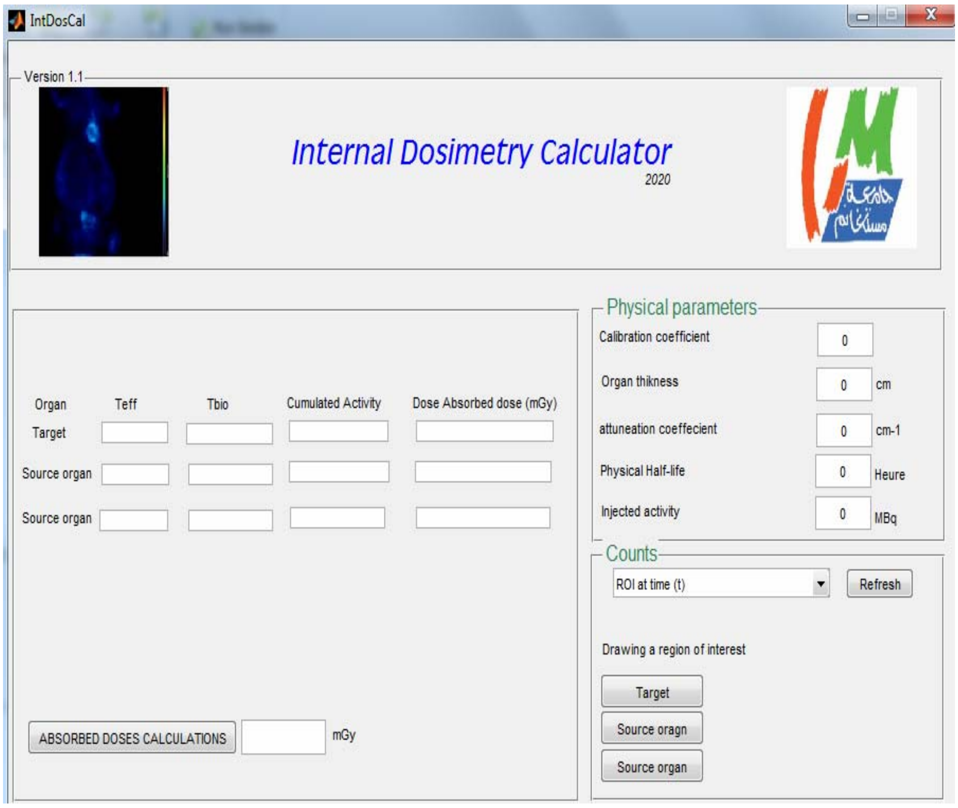

Fig. 1. IntDosCalc interface for the display of different in/out parameters.

Figures 2, 3, and 4 show the calculation activities (mCi) in the right kidney, left kidney, and bladder at different duration after radiopharmaceutical injection time at 0.2 h, 1 h, 1.45 h, and 3 h.

Figure 5 shows the activity in the right kidney target organ post-administration of the radionuclide with A_0 = 11.53 mCi as a function of time after injection. After fitting, we obtain exponential attenuation of activity:

$$A(t) = 2.31\mathrm{e}^{-1.37t} \tag{6}$$

The integration of equation (6) as a function of time in the range $[0,\infty)$ gives a cumulated activity around 1.39 mCi·h.

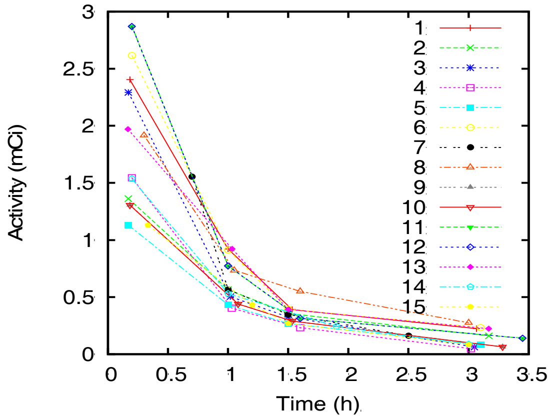

Fig. 2. Activity A(mCi) for ^{99m}Tc-MDP as function of time in right kidney;
1 to 15 represents the index of different SPECT data.

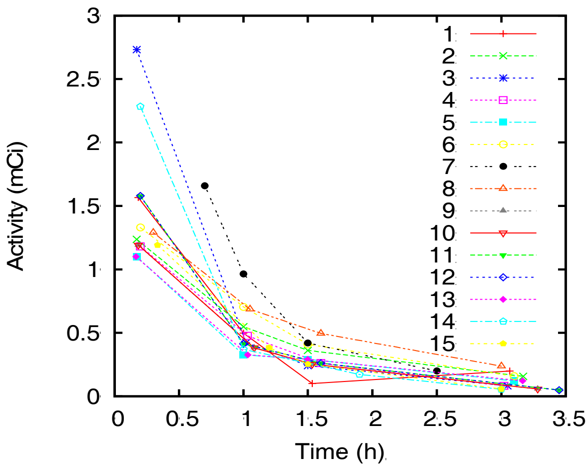

Fig. 3. Activity A(mCi) for ^{99m}Tc-MDP as function of time in left kidney;
1 to 15 represents the index of different SPECT data.

Figure 6 shows the time-activity curve of the left kidney post-administration as a function of. The exponential fit was used to obtain the bio kinetic behavior given by the equation:

$$A(t) = 1.74e^{-1.31t} \tag{7}$$

When the integration has been applied in the organ ROI to obtain the area of the time-activity curve, the resulting value then represents the cumulated activity equal to 1.10 mCi·h.

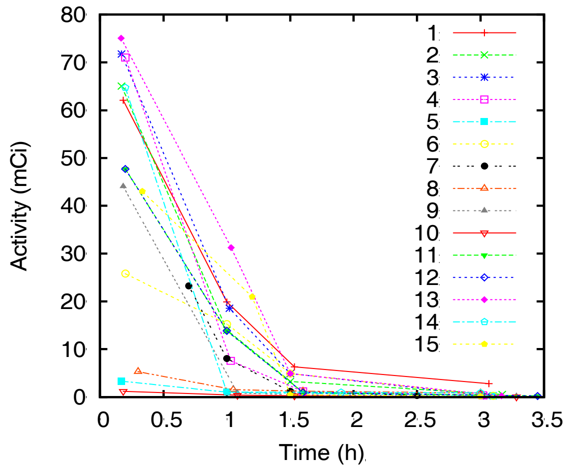

Fig. 4. Activity A(mCi) for ^{99m}Tc-MDP as function of time in bladder; 1 to 15 represents the index of different SPECT data.

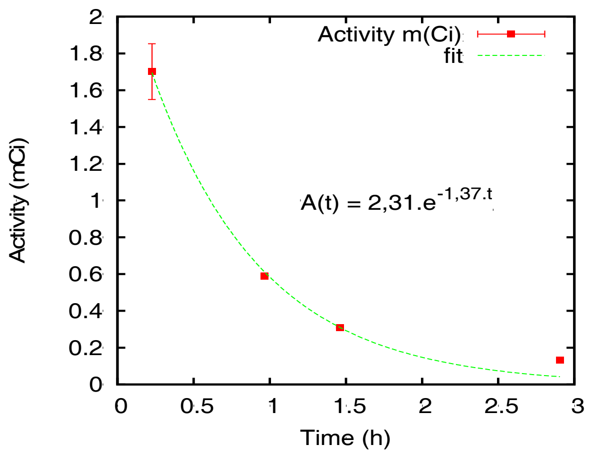

Fig. 5. Time-activity fitting curve for right kidney post administration of ^{99m}Tc-MDP.

Figure 7 illustrates the activity for the bladder as a function of time obtained by our Matlab code. In this case, from the same fitting method of the curve, we obtain a value of 22.58 mCi·h, that represents the cumulated activity for the bladder, according to the equation:

$$A(t) = 60.52\mathrm{e}^{-1.97t} \quad (8)$$

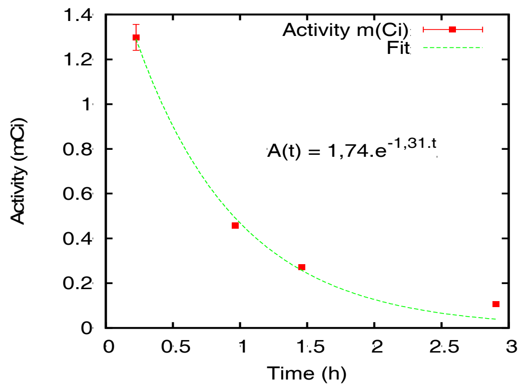

Fig. 6. Time-activity fitting curve for left kidney post administration of ^{99m}Tc-MDP.

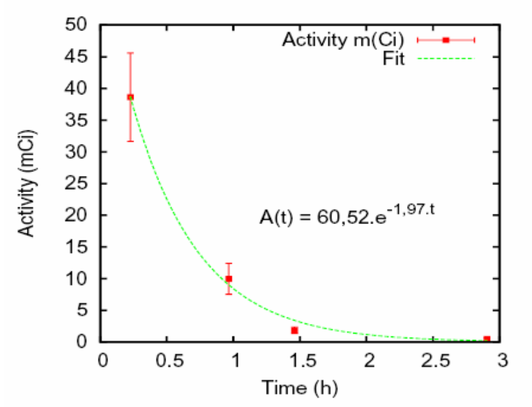

Fig. 7. Time-activity fitting curve for bladder post administration of MDP.

Table 1

Comparison of cumulated activity $\tilde{A}_h(t)$ (mCi·h) for the organ sources obtained by different integration methods in each tissue

Target organ	Trapezoidal area method	Polygonal area method	Difference (%)
Right kidney	1.39	1.07	23.02
Left kidney	1.10	0.78	29.00
Bladder	22.58	29.82	24.27

Internal dose calculation can be performed according to MIRD formalism to obtain average effective half-time and biological half-time estimated at the target organs in adult models. Such an outcome is estimated numerically following equation (4) by the results reported in Table 2, where the biological half-time and effective half-life was calculated from the decay constants obtained by SPECT imaging data at various time points. The results from the data give 4 to 5 min as a biological half-time, and a medium-to-high effective half-life and in the bladder around 105 min.

Table 2

Biological parameters estimation in the target organs in case of bone scan procedures

Target organ	**Effective half life T_{eff} (h)**	**Biological half-life T_{bio} (h)**
Right kidney	0.083	0.085
Left kidney	0.066	0.067
Bladder	1.357	1.754

Table 3

Residence time, accumulated activity and absorbed dose per unit of injected activity estimated on right, left kidneys and bladder target organs after injection of administrated activity (A_0) of ^{99m}Tc-MDP

Estimated parameter	**Right kidney**	**Left kidney**	**Bladder**
Cumulated activity (mCi·h)	1.390	1.100	22.580
Residence time (h)	0.120	0.090	1.950
Absorbed dose per unit of injected activity (mGy)	0.006	0.007	0.393

CONCLUSIONS

In this study, we have opted to provide software called IntCalDos using MATLAB to calculate an average absorbed dose in the target organs in specific nuclear medicine studies such as a bone scan, for example, based on ^{99m}Tc-MDP. To better specify the effect of gamma radiation on the target organs, the values of the absorbed dose in the kidneys, bladder, and the biological parameters were obtained according to the MIRD formalism. Therefore, it was observed that the internal absorbed dose in target organs such as the kidney and bladder were around 0.07 and 0.393 mGy per unit of injected activity (mCi), respectively, for photon energy equal to 140 KeV. The obtained data help nuclear medicine physicians to ensure the dose estimation for radiation safety and the biological effects of radiation at different critical organs. In future studies, new diagnostics techniques such as PET-CT and nuclear therapy procedures will be investigated for other target organs of the human body using more energetic radionuclides will be further discussed.

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