Program for Determining the Dosimetric Contribution of Tc-99m Biokinetics in Estimating the Dose to the Heart of a Male Adult

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Abstract

Purpose: To calculate the contribution of absorbed dose by organs in the biokinetics of Tc-99m when used for radiodiagnosis of the adult male heart employing a Matlab program. **Methods:** The absorbed self-dose of the adult male heart and absorbed dose by organs in the biokinetics of the heart when administering Tc-99m are estimated using the MIRD formalism and the Cristy-Eckerman representation, which have been employed to develop the algorithm in Matlab. **Results:** The results indicate that electron capture emissions of 1.446 (mGy/MBq) and Auger electrons of 0.062 (mGy/MBq) are entirely directed towards the target organ (heart) and contribute 29.33% and 1.25% respectively to its total dose. Additionally, the dosimetric contributions of biokinetic organs correspond to characteristic radiation emissions and gamma photons at 2.578 (mGy/MBq) for Tc-99m, representing 52.29% of its total dose. **Conclusion:** These dosimetric contributions are significant in estimating the total absorbed dose by the heart in adult males and should not be disregarded.

Keywords: Biokinetics, internal dosimetry, medical internal radiation dose formalism, Tc-99m

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Introduction

The advancements in medical physics diagnostics have emerged due to the technological advancements in the field of internal dosimetry,[1-3] where it is important to estimate the absorbed dose of the target organ and biokinetics. This requires the use of mathematical equations and models that simulate the human metabolism and the physical characteristics of the patient. These equations have been developed over time in the field of internal dosimetry, and in this article, we have used the medical internal radiation dose (MIRD) formalism and Cristy-Eckerman representations. These equations are widely used in the field of internal dosimetry,[4-6] for example, to estimate the absorbed dose of the thyroid during uptake studies, through the biokinetics of radiopharmaceuticals containing I123 (iodide) or Tc-99m (pertechnetate) for the thyroid of children aged 1 and 5 years.[7-9]

In medicine, one of the best methods to confirm the diagnosis and determine the severity and consequences of a disease is through studies using radioactive isotopes. The only potential risk of exams with radioactive isotopes comes from the small radiation dose received by the patient.[10-12]

Radiodiagnosis for patients typically involves intravenous injection or oral ingestion of low amounts of radiolabeled substances, commonly referred to as tracers or radiopharmaceuticals. These tracers rapidly distribute throughout the body, including the heart, and are detected using a gamma camera. The resulting images are collected on a computer for subsequent analysis.[13-16]

This procedure is also employed to verify the increase in blood flow to the heart muscle following a bypass operation or similar procedures, as well as to determine the prognosis after a heart attack (myocardial infarction).[17]

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This study presents a MATLAB algorithm using the MIRD formalism and Cristy-Eckerman publications to calculate the dosimetric contributions of organs in the biokinetics of Tc-99m radiopharmaceuticals with chloride markers, to estimate the absorbed dose by the heart in male adult patients during radiodiagnostic procedures.

Materials and Methods

This article utilizes the MIRD methodology, also known as MIRD, which was established by the US Nuclear Medicine Society in 1960 to assist the medical community in estimating organ and tissue doses due to the incorporation of radioactive material. This method allows for the calculation of the dose deposited in a target organ from one or more source organs within the body.[18]

The dosimetric contributions (in the adult heart) due to gamma photons and characteristic radiation emitted by Tc-99m are obtained using the following equation:

$$D_T = \sum_S \tau(A_0) . S(T \leftarrow S)$$

where

D_T: total dose

τ: residence time [s]

A_0: initial activity [Bq]

S(T←S): Snyder factor from source organ to target organ.

The specific absorbed fractions, Φk (g-1), for the adult heart were obtained from the publication by Cristy-Eckerman in this study.[19]

Values of the energy variation (Δ) are determined using the following equation:

$$\mathbf{D}(\mathbf{T} \leftarrow \mathbf{S}) = \frac{\mathbf{A}}{\mathbf{m}_T} \sum \Delta_i \Phi_i (T \leftarrow S)$$

For photons from Tl-201, the energy values are obtained using the table of their energy values.[20]

where

A: activity [Bq]

m_T: mass of target organ [kg]

Δ_i: energy variation depending on the type of radiation [MeV].

$\Phi_i(T \leftarrow S)$: Fraction of energy absorbed in the target organ by radiation emission i from the source organ.

Its units are [mGy/MBq].

The values of residence times (τ) for chloride (25% uptake in the heart) are obtained.[20]

The dosimetric contribution to the adult heart due to particles emitted by Tc-99m (conversion electrons and auger electrons) is obtained from the following MIRD equation.

$$\frac{D\ particles}{Ao}(T \leftarrow S) = \left(\frac{\bar{E}\ particle \tau_f}{m\ f}\right) x\ 2.13\ rad\ /\ \mu Ci$$

where

$\bar{E}_{particle}$ (it includes the total local energy deposition): Electrons from the decay processes of the radionuclide and photons whose energy deposition is comparable to the range of such electrons (internal conversion and electron capture).

In the elaboration of the MATLAB algorithm, the following equations have been used:

Snyder factor:

$$S(T \leftarrow S) = \sum_i \Delta_i \Phi_i (T \leftarrow S)$$

This equation is used to determine the product of the specific absorbed fraction ratio.

$\Phi(\mathbf{T} \leftarrow \mathbf{S}) = \dfrac{\Phi(T \leftarrow S)}{m_T}$ and the variation in energy, according to the type of emission.

$$\mathbf{D}(\mathbf{T} \leftarrow \mathbf{S}) = \frac{\mathbf{A}}{\mathbf{m}_T} \sum \Delta_i \Phi_i (T \leftarrow S)$$

where

D(T←S): The variation in energy is determined according to the type of emission.

$$\tau = \frac{\tilde{A}}{A_0}$$

Thus, the equation defining absorbed dose per the unit activity is established.

$$\frac{D_T}{A_0} = \sum_S \tau . S(T \leftarrow S)$$

To calculate these equations, certain characteristics of the radiopharmaceuticals used for the diagnosis of the heart, such as the type of emission and the biokinetic model, are required for Tc-99m.[20-22]

The biokinetic model of Tc-99m for the target organ (heart) is composed of organs of the human body, some of which are the kidneys, thyroid, gallbladder, small intestine, lower large intestine, upper large intestine, and liver; the other organs in the biokinetics for Tc-99m are expressed together with their respective residence time values on the RADAR website.[23,24]

As mentioned, we will use the Cristy-Eckerman formalism for the specific absorbed fractions values, which considers a semi-ellipsoid geometry for the heart.[19]

Finally, the RADAR (medical procedure radiation dose calculator) journal is used as a reference for comparing the results.[25]

Description of the algorithm in MATLAB

When working with interfaces in MATLAB, everything is managed based on the functions and handlers of the objects (handles), which make up the user interface.[26]

To carry out the algorithm, it is necessary to perform partial calculations to find the dose. The programming of functions is performed, with the most relevant function named "PreCalculo." This function takes as input parameter "val," which identifies the radiopharmaceutical to be used, then "idOrg Fuente," which identifies the selected organ, the list of organs (NombOrgan) selected from the radiopharmaceutical used, and the last parameter is "MC," which is the value of the heart mass. This function returns the following results:

D_gamma (gamma dose), *D_xray* (Dose of X-rays), *D_ce* (electron charge dose), *D_auger* (dosis auger), *fs_gamma* (Snyder factor for gamma radiation), *fs_xray* (the Snyder factor for X-rays), *ListFrAbs* (list of absorbed fractions).

All functions are called from the "PreCalculo" function, and finally all results are returned as a structure.

[D_gamma, D_xray, D_ce, D_auger, fs_gamma, fs_xray, ListFrAbs]

The algorithm operates according to the scheme presented in Figure 1, and to calculate: The absorbed dose, a series of ordered steps are followed, which are explained in Figure 2.

It should be noted that using software such as MATLAB brings several benefits due to its easy access and user-friendly interface. It is generally easy for medical personnel to learn, as the function names are familiar and easy to remember. In addition, the files are written for quick comprehension, not only by computer scientists but also by medical professionals, engineers, and scientists. In the area of internal dosimetry, other programs are often used to determine the dose and fractions absorbed by the organs under study.[27-30]

Results

After executing the MATLAB interface, the absorbed fractions and Snyder factors are obtained for each organ in the biokinetics, as well as for gamma and X-ray radiations of the respective radiopharmaceuticals. In addition, the absorbed dose per unit of activity is also calculated and displayed below.

In Table 1, the absorbed fractions of photon emissions and radiation X from all organs in the biokinetics are presented when Tc-99m is used.[22]

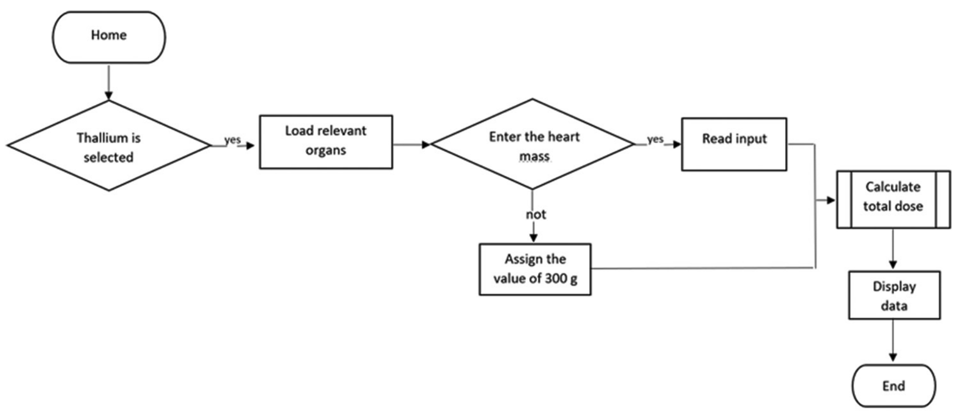

Figure 1: The flowchart that summarizes the MATLAB algorithm

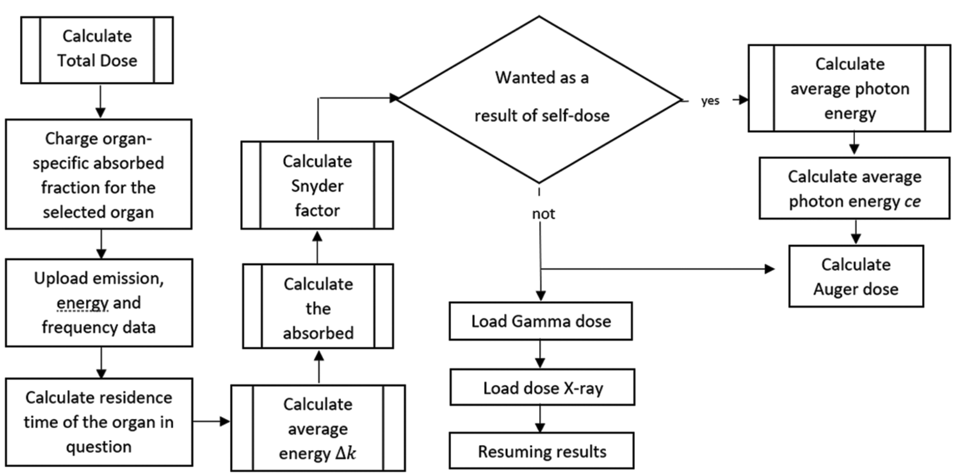

Figure 2: Flowchart to calculate the absorbed dose per unit of total activity

In Table 1, the absorbed fractions of photon γ emissions and radiation X from all organs in the biokinetics are presented when Tc-99m is used.

Table 1: Specific absorbed fraction of Tc-99m (Chloride) emissions in the adult heart using the Cristy-Eckerman representation and medical internal radiation dose formalism (g^{-1})

Organs	Fraction absorbed	
	Photons γ	Radiation x
Gallbladder	1.0384×10^{-5}	9.7083×10^{-8}
Small intestine	5.431×10^{-7}	3.1964×10^{-10}
Lower large intestine	2.0597×10^{-6}	1.6450×10^{-9}
Upper large intestine	2.9662×10^{-6}	2.9415×10^{-9}
Liver	2.3169×10^{-5}	8.808×10^{-6}
Kidney	8.1845×10^{-6}	4.6212×10^{-8}
Thyroid	4.3169×10^{-6}	6.2736×10^{-9}
Heart	3.9169×10^{-3}	4.5576×10^{-3}
Rest of the body	2.9261×10^{-5}	3.672×10^{-5}

Table 2: Absorbed dose of Tc-99m (tetrofosmin) emissions in the adult heart using the Cristy-Eckerman representation and the medical internal radiation dose formalism. (mGy/MBq)

Emissions	$\frac{D(C\leftarrow C)}{A_0}$	$\frac{D(C\leftarrow i)^a}{A_0}$	Total dose
Photons γ, *n* (%)	0.776 (15.74)	2.578 (52.29)	4.93
Radiation x, *n* (%)	0.067 (1.36)		
e-CE, *n* (%)	1.446 (29.33)	—	
e-Auger, *n* (%)	0.062 (1.25)		

[a]The dosimetric contribution of all organs in the biokinetics, except for the heart, is obtained. These data are calculated assuming a heart mass of 300 g, but this value is considered a variable in the MATLAB program so that the user can input their own value

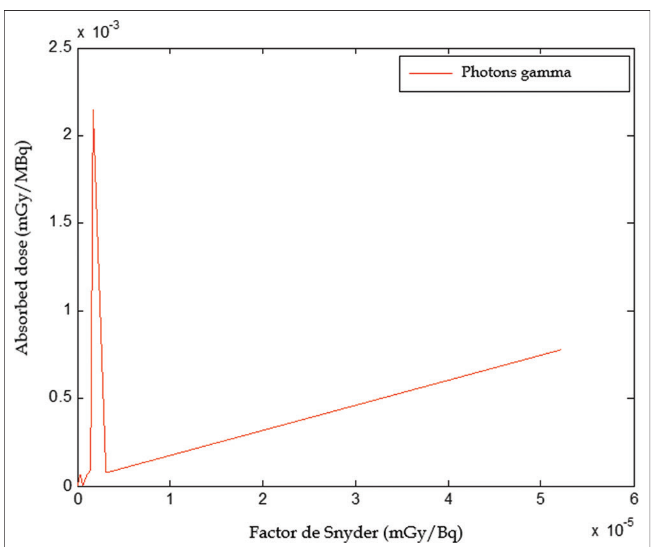

Figure 3: Absorbed dose versus Snyder factor

In Figure 3, we examine the absorbed dose by the organs in the biokinetics of Tc-99m from gamma photon emissions versus their corresponding Snyder factors.

Discussion

After programming the MIRD and Cristy-Eckerman information into the MATLAB algorithm, all results obtained in this article were immediately accessible and made available to medical personnel who require it. It is worth noting that programming always contributes to science.

In the heart of a male adult, the absorbed dose of Tc-99m (tetrofosmin) is 4.93***x*10^{-3}** mGy/MBq; 47.68% of this dose corresponds to its self-dose (29.33% to internal conversion, 1.25% to auger electrons, 15.74% to gamma photons, and 1.36% to characteristic radiation). The remaining 52.29% corresponds to dosimetric contributions from organs in the biokinetics.

The results obtained in Table 2, for the radiopharmaceutical Tc-99m, are in complete agreement with those reported by RADAR,[22] due to the large amounts used for Tc-99m, which reduces the algorithm's error in its interactions.

From the dose contribution of the organs in the biokinetics of Tc-99m (tetrofosmin); the highest dose corresponds to the bladder: **$D(C\leftarrow V)/A_0$ = 0.09*x*10^{-3}** mGy/MBq and the lowest dose is to the kidney:

$D(C\leftarrow R)/A_0$ = 0.07*x*10^{-3} mGy/MBq.

The contribution of the absorbed dose from organs in biokinetics in relation to the particle dose is quite high due to the high energies of photons and characteristic radiation emissions of Tc-99m, as well as their respective frequencies of emission.

The results published in the internal dosimetry association are consistent with this article,[19] which demonstrates that the absorbed dose by the organs in the biokinetics of a male adult using Tc-99m is higher than the absorbed dose when using other radiopharmaceuticals such as Tl-201.

Conclusions

The results obtained from this study reveal that the dosimetric contributions from the biokinetic organs when using Tc-99m are of great importance in estimating the total dose to the heart of an adult male. These dosimetric contributions correspond to the emissions of characteristic radiation and gamma photons, resulting in a dose of 2.578 (mGy/MBq) for Tc-99m when used with tetrofosmin, which corresponds to 52.29% of its total dose.

Due to the significance of the dose, it cannot be ignored, and physicians who use this radiopharmaceutical must consider the characteristics or other diseases related to the biokinetic organs of their patients.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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