DOSIMETRY OF RADIOPHARMACEUTICALS USED IN ADULT PATIENTS WITH SUSPECTED PULMONARY EMBOLISM

DOSIMETRÍA DE RADIOFARMACOS UTILIZADOS EN PACIENTES ADULTOS CON SOSPECHA DE EMBOLIA PULMONAR

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Abstract

The absorbed dose of radiopharmaceuticals is estimated in adults with suspected pulmonary embolism explored by ventilation/perfusion studies. For pulmonary ventilation studies ^{81m}Kr, ^{133}Xe, ^{99m}Tc (Technegas)-aerosol and ^{99m}Tc (DTPA)-aerosol are used. For perfusion agents, ^{99m}Tc(MAA), ^{99m}Tc (MSA) (macroaggregates and albumin microspheres) are used. For the dose calculation, the MIRD methodology and the anthropomorphic representation of the biokinetic organs of Cristy-Eckerman are used. In ventilation/perfusion studies, the lowest dose absorbed by the lungs with suspected embolism is due to ^{81m}Kr/^{99m}Tc (MSA), and the highest dose is due to ^{99m}Tc (Technegas)/^{99m}Tc (MAA) calculated for activities of 150 MBq for perfusion agents and 40 MBq for ventilation agents.

Keywords: Internal dosimetry, radiopharmaceuticals, ventilation, pulmonary embolism.

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Resumen

Se estima la dosis absorbida de radiofármacos en adultos con sospecha de embolia pulmonar explorada por estudios de ventilación/perfusión. Para estudios de ventilación pulmonar se utilizan ^{81m}Kr, ^{133}Xe, ^{99m}Tc (Technegas) -aerosol y ^{99m}Tc (DTPA) -aerosol. Para agentes de perfusión se utilizan ^{99m}Tc (MAA) y ^{99m}Tc(MSA) (macroagregados y microesferas de albumina). Para el cálculo de dosis se utiliza la metodología MIRD y la representación antropomórfica de los órganos biocinéticos de Cristy-Eckerman. En estudios de ventilación/perfusión la menor dosis absorbida por los pulmones con sospecha de embolia se debe a ^{81m}Kr/^{99m}Tc (MSA), y la dosis más alta se debe a ^{99m}Tc(Technegas)/^{99m}Tc(MAA), calculada para actividades de 150 MBq para agentes de perfusión y 40 MBq para agentes de ventilación.

Palabras clave: Dosimetría interna, radiofármacos, ventilación, embolia pulmonar.

Introduction

Nuclear medicine is a mature medical specialty where radioisotopes are used to diagnose and to treat diseases, as well as to carry out scientific research. In order to obtain images a small amount of a pharmaceutical compound with a radioisotope (radiopharmaceutical or radiotracer) is administrated by inhalation, ingestion or injection [1, 2].

The radiopharmaceuticals that interact directly with human metabolism are distributed among the organs and tissues of the body according to their biokinetics (biokinetic organs). Radiations emitted by the radiopharmaceuticals interact with organs and tissues of the body, and the absorbed dose depends upon the amount of the administrated radioactive material, the radionuclide decay scheme and its bio kinetics. In order to calculate the absorbed dose in the organs and tissues are used the biokinetic models and the radiopharmaceutical data that are available in the literature [3–8].

So far the internal dose cannot be measured directly, and none operational quantity has been defined to stand in their place. Calculation of the absorbed dose requires mathematical evaluation using mathematical equations and models that simulate human metabolism [9].

There are several methods used for the internal dosimetric calculation; however, the MIRD (Medical Internal Radiation Dose) procedure is mostly used. With MIRD the absorbed dose in an organ is calculated due to radiation received from one or more source organs in the organism [10, 11].

To estimate the absorbed dose in adult pulmonary studies ^{81m}Kr, ^{133}Xe, ^{99m}Tc-Technegas (carbon suspension)-aerosol, and ^{99m}Tc- (DTPA)-aerosol radiopharmaceuticals are used to evaluate the pulmonary ventilation (air distribution in the respiratory ducts). To evaluate the distribution of blood flow in the lungs (perfusion) are used macro aggregates (MAA) or ^{99m}Tc labeled albumin microspheres (MSA). For diagnosis purpose in adults with suspected pulmonary embolism, the study should combine pulmonary ventilation/perfusion [12, 13].

The objective of this work is to determine the procedure that delivers the minimum radiation dose to adult patients with suspected of pulmonary embolism whose study is carried out with radiopharmaceuticals used for Ventilation/Perfusion diagnosis study. The doses were calculated using the MIRD methodology and anthropomorphic representation of Cristy and Eckerman [14].

Materials y Methods

The ^{99m}Tc is disintegrated by isomeric transition by gamma emission, γ, with an energy of 140 keV and a half-life of 6 hours. The ^{81m}Kr decays by isomeric transition emitting γ with an energy of 190 keV and a half-life of 13 s, gamma radiation can transfer energy directly to one of the most tightly bound electrons, expelling it from the atom, a process named internal conversion. The Xe^{133} is essentially a β-emitter that decays emitting γ radiation of 81 keV fundamentally, and a half-life of 5.2 d. [15].

Photons and particles emitted by radioisotopes have a different interaction mechanism with matter; they also have different ranges in the tissues. Therefore, the MIRD procedure was applied using the lungs (target organ) where the absorbed dose per unit of activity was calculated using equation 1.

$$\frac{Dphotons(Lungs)}{A_o} = \left\{ \sum_{i \neq lung} \sum_{j} \Delta_j \Phi_j \left(lungs \leftarrow i\right) \tau_i + \sum_{j} \Delta_j \Phi_j \left(lungs \leftarrow lungs\right) \tau_{lung} \right\} \times 270 mGy/MBq \tag{1}$$

On the right side of the equation, the absorbed dose represents the dose to the lungs due to the source organ i and its self-dose. In the equation, Δ_j is the average energy of photon j emitted by ^{99m}Tc, ^{133}Xe o ^{81m}Kr by decay, Φj (lungs $\leftarrow$ i) is the fraction of energy of the photon j, emitted by the organ i that is absorbed by the lung per unit mass of the lung; it is also known as the Specific Absorbed Fraction (SAF) [14], and τ_i is the residence time of the radiopharmaceutical in the source organ i. The absorbed dose, in the lungs due to conversion electrons and Auger electrons was calculated using equation 2.

$$\frac{D_{particle}(Lungs \leftarrow lungs)}{A_o} = \left(2.13 \bar{E}_{\ particle} \frac{\boldsymbol{\tau}_{lungs}}{\mathbf{m}_{lungs}} \right) \times 270\ mGy/MBq \tag{2}$$

Here, $\bar{E}_{particle}$ is the average energy of the particle, τ_{lungs} residence time of the radiopharmaceuticals in the lungs; while m_{lungs} is the mass of the lungs of an adult.

The most significant residence times for ^{81m}Kr, ^{133}Xe, ^{99m}Tc (technegas), the ^{99m}Tc (MAA) in the biokinetic organs used in dose calculations are shown in Table 1 [6, 16]. This table includes times of residence for ^{99m}Tc (DTPA)-aerosol and ^{99m}Tc (MSA) [17].

The dosimetric behavior of radiopharmaceuticals is related to the residence times of the organs of their biokinetic, which in turn, related to differences in biological and physical excretion mechanisms.

^{99m}Tc	TB	Lung	Liver	Kidney	Blader
	(excl. bladder)				content
(MAA)	7.610	4.890	1.040	0.018	0.217
^{99m}Tc	Lungs	ULI(cont)		Stomach	Remain
(Technegas)	8.0	0.024		cont	tissue
				0.019	0.069
					SI content
					0.016
^{133}Xe	Lungs	Remain tissue			
(5 minutes)	0.013	0.533			
Kr^{81m}	Lungs				
(gas)	0.00528				
^{99m}Tc	Lung	Bladder content		Remainder	Kidney
(DTPA)	Wahout	(2.4hs-void)		of body	0.0394
aerosol	1.58	0.606		0.502	
^{99m}Tc	Lung	Stomatch	Kidney	Bladder	
(MSA)	4.28	0.429	0.672	0.202	

TB: Whole Body: SI: Small intestine; ULI: Upper large intestine.

TABLE 1. *Residence time in hours used as organs of biokinetic [6, 16, 17]*

In the Tables 2 and 3 are shown the characteristics of photons, and particles emitted in the decay of ^{99m}Tc, ^{133}Xe and ^{81m}Kr [16] that were used in the dose calculation.

The mass of the organs included in adult biokinetics used in the calculations indicates that the mass of the lungs is 1000 g and the mass of the whole body (TB) is 73700 g. [6, 14].

For diagnostic purposes in adults with suspected pulmonary embolism, the study should combine pulmonary ventilation/perfusion (V/P) agents [12, 13].

In the ventilation/perfusion studies normally are used 150 MBq for perfusion agents and 40 MBq for ventilation agents [18–22].

The absorbed dose due to ventilation/perfusion studies (V/P) was calculated using equation 3:

$$V/P = 150MBq\,\mathrm{x}\,\mathbf{P_D}[mGy/MBq] + 40MBq\,\mathrm{x}\,\mathbf{V_D}[mGy/MBq] \quad (3)$$

$\mathbf{P_D}$ and $\mathbf{V_D}$ are the doses absorbed by the lungs due to the P (perfusion) and V (ventilation) agents given in mGy/MBq.

Dose results due to V/P agents are given in mGy.

Results

Using the MIRD methodology and the biokinetic characteristics of the pulmonary ventilatory agents ^{81m}Kr, ^{133}Xe, ^{99m}Tc (tecnegas), ^{99m}Tc (DTPA) - aerosol, and perfusion agents ^{99m}Tc (MAA) and ^{99m}Tc (MSA), the absorbed doses per unit of activity administered to the lungs are determined for each of these agents. Their autodose and the organ dosimetric contributions of their biokinetics are determined.

	Photons	E_k (MeV)	n_k part/dis	Δ_k=2.13 n_k E_k (rad – g) μCi - h
^{99m}Tc	Gamma Radiation	0.1405	0.8906	0.2665
		0.1426	0.0002	0.0001
	Characteristic radiation	0.0183	0.021	0.0008
		0.0184	0.040	0.0016
		0.0206	0.012	0.0005
^{133}Xe	Gamma Radiation	0.1606	0.0007	0.0002
		0.0796	0.0027	0.0004
		0.0810	0.3800	0.0656
	Characteristic radiation	0.0306	0.1410	0.0092
		0.0310	0.2620	0.0173
		0.0350	0.0940	0.0070
^{81m}Kr	Gamma Radiation	0.1905	0.6761	0.274
	Characteristic radiation	0.0127	0.098	0.0027
		0.0126	0.0507	0.00136
		0.0141	0.0150	0.00044

TABLE 2. *Nuclear data of emitted photons (MeV) of ^{99m}Tc ,^{133}Xe and ^{81m}Kr more significant [16].*

	Particles	E_k (MeV)	n_k part/dis	n_k E_k Mev/dis	E particle = $\sum n_k E_k$ Mev/dis
^{99m}Tc	Conversion electrons	0.1195	0.0880	0.01052	0.01446
		0.1216	0.0055	0.00067	
		0.1375	0.0107	0.0015	
		0.1396	0.0017	0.00024	
		0.1400	0.0019	0.00026	
		0.1404	0.0004	0.00006	
		0.1421	0.0003	0.00004	
		0.0016	0.7460	0.00120	
	Auger electrons	0.0022	0.102	0.00022	0.00054
		0.0155	0.0207	0.00032	
^{133}Xe	Beta	0.0750	0.0081	0.00061	0.1001
		0.1005	0.9900	0.09949	
	Conversion electrons	0.0436	0.0041	0.00018	0.03284
		0.0450	0.5510	0.02479	
		0.0753	0.0820	0.00617	
		0.0798	0.0169	0.00135	
		0.0808	0.0044	0.00035	
	Auger electrons	0.0035	0.5100	0.00178	0.00326
		0.0255	0.0582	0.00148	
^{81m}Kr	Conversion electrons	0.1761	0.2690	0.0473	0.051
		0.1885	0.0251	0.00475	
	Auger electrons	0.0106	0.0110	0.166 x10^{-4}	4.54 x10^{-4}
		0.0107	0.0064	0.68 x10^{-4}	
		0.0108	0.0342	3.7 x10^{-4}	

TABLE 3. *Nuclear data emitted particles (MeV) of ^{99m}Tc ,^{133}Xe and ^{81m}Kr [16].*

Table 4 shows the absorbed dose in the lungs, due to photons and radiopharmaceutical particles during perfusion and ventilation studies. Show the absorbed dose, due to photons and particles, in the adult lung during perfusion and ventilation study.

RFM	emissions	D(lung ← lung)/A_o	D(lung ← i)/A_o	Total mGy/MBq
^{99m}Tc (MAA)	Radiation:γ + X	0.0203(30.2 %)	0.00048 (7.0 %)	0.067
	e^-CI + e^- Auger	0.04217(62.9 %)	-	
	Self-dose	0.06250 (93.0 %)		
^{99m}Tc (MSA)	Radiation: γ + X	0.0178 (32.4 %)	0.000346 (0.6 %)	0.055
	e^- CI + e^- Auger	0.0369 (67 %)		
	Self-dose	0.0547 (99.4 %)		
^{99m}Tc Technegas	Radiation: γ + X	0.0338 (32.8 %)	0.00007 (0.1 %)	0.103
	e^-CI + e^- Auger	0.0690 (67.0 %)	-	
	Self-dose	0.1028 (99.8 %)		
^{99m}Tc (DTPA)	Radiation: γ + X	0.0065 (32.2 %)	0.00019 (1 %)	0.0202
	e^-CI + e^- Auger	0.0135 (66.8 %)		
	Self-dose	0.020 (99.0 %)	-	
^{133}Xe	Radiation: γ + X	0.00001 (0.5 %)	0.00012 (11 %)	0.0011
	β+e^-CI + e^- Auger	0.00097 (88.3 %)		
	Self-dose	0.00098 (89 %)		
^{81m}Kr	Radiation: γ + X	0.00003 (15 %)		0.00020
	e^-CI + e^- Auger	0.00017 (85 %)		
	Self-dose	0.00020 (100 %)		

TABLE 4. *Absorbed dose per unit of activity administered in the lungs of the adult patient due to perfusion agents ^{99m}Tc(MAA) and ^{99m}Tc (MSA), and ventilation agents ^{133}Xe, ^{81m}Kr, ^{99m}Tc (Technegas), and ^{99m}Tc (DTPA)-aerosol.*

Table 5 shows the absorbed dose per unit of activity administered in lungs of the adult patient with suspected pulmonary embolism undergoing a perfusion/ventilation study.

Equation:	*V/P = 150 MBq x$\mathbf{P_D}$ [mGy/MBq]+ 40 MBq x$\mathbf{V_D}$ [mGy/MBq]							
Agents P	^{99m}Tc(MAA)				^{99m}Tc (MSA)			
Agents V	^{99m}Tc (DTPA)	^{99m}Tc (Technegas)	^{133}Xe	^{81m}Kr	^{99m}Tc (DTPA)	^{99m}Tc (Technegas)	^{133}Xe	^{81m}Kr
Absorbed dose (mGy)	10.85	14.17	10.09	10.06	9.05	12.37	8.29	8.26

*^{99m}Tc (DTPA) / ^{99m}Tc (MAA) =150MBq × 0.067 mGy/MBq + 40MBq × 0.020 mGy/MBq = 10.85mGy

TABLE 5. *Radiation dose in the lungs during Ventilation/Perfusion patients with suspicion of pulmonary embolism for activities of 150MBq (perfusion), and 40 MBq (ventilation).*

Discussion

Table 4 shows that in perfusion studies the lowest dose received by the lungs is due to ^{99m}Tc (MSA). In ventilation studies the lower dose is when ^{81m}Kr is used.

Table 5 shows that the lowest absorbed dose by the lungs with suspected pulmonary embolism is due to ^{81m}Kr / ^{99m}Tc (MSA), while the highest absorbed dose is due to ^{99m}Tc (Technegas) / ^{99m}Tc (MAA).

The dose received by the lungs due to ^{99m}Tc (MAA) is 0.067 mGy/MBq, the 93 % of it corresponds to its self-dose (63 % to electrons and 30 % to photons); the rest is due to organs involved in the biokinetic: the liver, kidneys, bladder, and the rest of the tissue the most exposed organ is the liver with 0.0007mGy/MBq. The absorbed dose by the lungs due to ^{99m}Tc(MSA) is 0.055 mGy/MBq; the 99.4 % corresponds to its self-dose, the rest of the organs involved in biokinetics correspond to the stomach wall as the most exposed organ 0.0002 mGy/MBq.

The absorbed dose by the lungs due to ^{99m}Tc (Technegas) is 0.103 mGy/MBq, the 99.8 % corresponds to its self-dose (67 % to electrons and 32.8 % to photons), the most exposed biokinetic organ is stomach wall with 0.00001 mGy/MBq. Likewise, the absorbed dose in the lungs due to ^{99m}Tc(DTPA) is 0.0202 mGy/MBq , the 99.0 % corresponds to its self-dose (67 % to electrons and 32 % to photons), and the most exposed biokinetic organ is the bladder with 0.00002 mGy/MBq . Finally, the absorbed dose in the lungs due to ^{81m}Kr is 0.0002 mGy/MBq, it represents the 100 % of its self-dose (85 % to electrons and 15 % to photons); and for ^{133}Xe (rebreathing for 5 min) the absorbed dose is 0.0011 mGy/MBq, the 89 % corresponds to its self-dose (66.4 % corresponds to beta, 20 % to electronic conversion and 2.2 % to Auger electrons).

In all cases the radiations emitted by the radioisotopes Kr^{81m}, Xe^{133} and Tc^{99m} (characteristic radiation, gamma, conversion electrons and Auger electrons) conversion electrons are found, in addition to

the ^{133}Xe beta which most contribute to the self-dose of the lungs in adults.

The dosimetric contributions of the organs that are part of the biokinetic are greater when using ^{133}Xe with 11 %, followed by ^{99m}Tc (MAA) with 7 %.

Among the modalities to detect pulmonary embolism, both the V/Q scan and the CTPA (computed tomography pulmonary angiography) expose the patient to ionizing radiation as shown in table 5, in general, carries larger radiation doses than the scan V/Q [23].

Conclusions

Using the MIRD methodology and the Cristy-Eckerman representation for adult lungs, the dose to the lungs was calculated. The dose calculation includes the self-dose in the lungs and the dose due to the source organs involved in the biokinetic of ^{133}Xe, ^{81m}Kr, ^{99m}Tc (DTPA, MAA, MSA and Technegas).

The highest absorbed dose by the lungs comes from its self-dose due to the charged particles produced during the decay of the ^{99m}Tc,^{81m}Kr y ^{133}Xe.

The lowest absorbed dose by the lungs with suspected pulmonary embolism is due to ^{81m}Kr/^{99m}Tc (MSA), and the highest dose is due to ^{99m}Tc(Technegas)/^{99m}Tc (MAA) calculated for usually recommended activities of 150 MBq for agents' perfusion and 40 MBq for ventilation.

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