Dosimetric evaluation of $^{131}I/^{123}I$ (iodides) and ^{99m}Tc (pertechnetate) in the thyroid of neonates using Cristy-Eckerman/Segars anthropomorphic representations

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Abstract

Using the MIRD formalism, and the Cristy-Eckeman/Segars anthropomorphic representations, the study estimates the absorbed dose in the thyroid of newborns, for these representations. Radiopharmaceuticals (RFM) $^{131}I/^{123}I$ (iodides) and ^{99m}Tc (pertechnetate) are used during their diagnostic procedures. The dose results will allow exploring the dosimetric impact generated by the use of these RFM as well as their representations. The study indicates:The higher dose absorbed by the thyroid gland in newborn patients due to the compounds $^{131}I/^{123}I$(iodide) and ^{99m}Tc(pertechnetate), calculated in the anthropomorphic representations of Cristy-Eckerman and Segars, is mainly due to their self-dose, generated by the electrons released by these compounds.The relative difference in total dose to the newborn thyroid gland using the Cristy-Eckerman and Segars anthropomorphic representations for the compounds $^{131}I/^{123}I$(iodide) and ^{99m}Tc(pertechnetate) was 0.72%, 1.82%, and 1.33%, respectively. Regardless of the RFM selected, replacement of Cristy-Eckerman phantoms by Segars phantoms does not reflect significant changes in the estimated absorbed dose to the newborn thyroid.Regardless of the Cristy-Eckerman or Segars anthropomorphic representation, the lowest dose to a newborn's thyroid is obtained when using ^{99m}Tc (pertechnetate). The residence times for this RFM contribute to that dose.

Keywords: MIRD dosimetry, Cristy-Eckerman/Segars plots, lungs.

1.-Introduction

The radiopharmaceutical compound ^{131}I/ ^{123}I (iodide),and ^{99m}Tc (pertechnetate) ,are used in newborn patients during thyroid uptake studies; they are distributed in your organs according to their biokinetics. .Biokinetic data for radiopharmaceuticals (RFM) were published by the International Commission on Radiological Protection (ICRP), publication 53 [1], updated in ICRP 128 [2] and ICRP-80 [3].

Biological effects due to RFM are estimated by measuring its absorbed dose. Medical internal radiation dosimetry (MIRD) is a methodology used to estimate the absorbed dose in a target organ from one or more source organs. [4]

In the MIRD methodology, the absorbed dose is based on its specific absorbed fractions (SAF) calculated on the anthropomorphic computational phantoms and using Monte Carlo methods. The SAF which associated with the pharmaceutical residence time, determine the absorbed dose. [5]

MIRD phantoms are mathematical representations of the human body. Here, the organs are defined by stylized geometric bodies that describe their sizes and shapes. [6,7].

Crysty and Eckerman in 1980 [8], introduced a series of stylized phantoms of various ages. Includes newborn, 1, 5, 10, 15-year old, and adult phantoms based on reference anthropological data from publication ICRP-23 [9]. It was published in report ORNL/TM-8381 in 1987 [10]. The report contained a full compilation of SAFs calculated from the ORNL phantoms series.

MIRD phantoms were enhanced with more realistic body models using digital image-based voxels [11]. Its use is accompanied by modified organ masses according to ICRP data [12].

Segars [13], developed enhanced adult male and female phantoms. Segars' phantom were based on non-uniform rational b-spline (NURBS) modeling techniques that define male and female reference models [14,15].

This new set of phantoms was included in the Radiation Dose Assessment resource (RADAR) [16], where SAF photons (in addition to electrons) were also included.

The replacement of the Cristy-Eckerman phantoms with the Segars phantom, an updated and improved phantom, raises concerns about the dosimetric impact of these RFMs, when applied to the thyroid of neonates.

According to Kramer et al. [17] the doses to the organs depend on the geometric similarity of the anatmy of the human body, the elemental composition and density of organs and tissues, and the method of radiation transport used.

To investigate the dosimetric consequences generated by the substitution of the anthropomorphic Cristy-Eckerman phantoms by the Segars phantom, during studies of the thyroid of a newborn , their absorbed doses should be compared in each of these representations.

The objective of the study is to determine the absorbed doses in the thyroid of newborn patients using the MIRD formalism and the anthropomorphic representations of Cristy-Eckerman and Segars; use in their studies radiopharmaceuticals compound $^{131}I/\ ^{123}I$ (iodide),y ^{99m}Tc (pertechnetate). The dose results found for these RFM and their representations will allow exploring their dosimetric impact between them. The results will also make it possible to determine which compound delivers the lowest dose.

2.-Materials and Methods

The radiopharmaceuticals I^{131}(NaI) , I^{123}(NaI) and Tc^{99m} (NaTcO4), located mainly in the thyroid gland, are considered to be quite specific markers of the thyroid. The gland is revealed as an image in the midline of the neck with a butterfly-like shape [18,19]

Both radioactive iodine and technetium can be administered orally and intravenously (MIRD /Dose Estimate Report N^{a}5,1975).

Photons and particles emitted by radioisotopes have a different interaction mechanism with matter; they also have different ranges in tissues.

To estimate the absorbed dose in the thyroid of a newborn (target organ) due to the dosimetric contributions of the organs that are part of the biokinetics (source organs), we will use the MIRD (Medical Internal Radiation Dosimetry) equation for the Cristy - Eckerman/Segars expressed in equation (1) :

$$\frac{D_{photon}(Thy)}{A_o} = \left\{ \sum_{i \neq lthy} \sum_{j} \Delta_j \Phi_j(thy \leftarrow i)\tau_i + \sum_{j} \Delta_j \Phi_j(thy \leftarrow thy)\tau_{thy} \right\} \times 270 \ mGy/MBq \qquad (1)$$

On the right hand side of the equations, the absorbed dose represents the dose to the thyroid, due to source organ i. The following term is the absorbed dose to the thyroid due to its own organ (autodose),

$\Phi j\ (thy \leftarrow i)\ g^{-1}$, is the fraction of energy emitted by organ i (biokinetic organs) that is absorbed by the thyroid per unit mass of the thyroid, for photon energies "j" of ^{131}I, ^{123}I and ^{99m}Tc. The $\Phi j\ (thy \leftarrow i)$ is also known as the specific absorbed fraction. (SAF) Such SAFs for the Cristy-Eckerman and Segars representations are given in [10] [16] respectively.

τi is the residence time of the radiopharmaceutical $^{131}I\ /^{123}I$(iodides) y ^{99m}Tc (pertechnetate) in source organ i. Residence times of radiopharmaceuticals mentioned in each organ biokinetics, given in

Tables 1 and 2 ,to newborns (25% uptake), biokinetic data available in ICRP-53 [1] o en web page (HPS, 2013a) [20].

Δj is the average energy of the photon j emitted by ^{131}I , ^{123}I y ^{99m}Tc per decay , given in Table 3 ,were obtained from [21] or web page (HPS, 2013b) [22].

For charged particles, the absorbed doses to the tiroides were calculated using equation (2):

$$\frac{D_{particle\ (\ thy \leftarrow thy)}}{A_o} = 2{,}13 \times \left[\bar{E}_{particle} \frac{\tau_{thy}}{m_{thy}} + \bar{E}_{particle} \frac{\tau_{TB}}{m_{TB}} \right] \times 270 \ \ mGy/MBq \qquad (2)$$

Here, $\bar{E}_{particle}$ is the average energy of the particle emitted by the I^{131} , I^{123} and Tc^{99m} , are given in Table 4 [21,22] τ_{thy} and τ_{TB} are residence time of the I^{131}, I^{123} and Tc^{99m} in the thyroid and total body ; while m_{thy} and m_{TB} is the mass of the thyroid and total body of a newborn respectively.Biokinetic data available in ICRP-53 [1]

Values of the thyroid mass and total body, of a newborn for representations C-E/Segars, are given in table 5, and were obtained from ORNL / TM-8381 / V1[10] and ICRP-89 [12] respectively. For practical purposes, the mass values can be considered the same for both representations.

Table 1.- Residence time (hours) and biokinetics of the I^{123} , I^{131} (iodides) to newborns (25% uptake) (HPS, 2013a)

Organ biokinetic Iodine	**Thyroid**	**Stomach**	**Small intestine**	**Kidney**	**Bladder content**	**Rest of the body**
I^{123} : τ_i (hours)	2,94	1,08	1,08	0,062	0,833	5,03
I^{131} : τ_i (hours)	60,72	1,66	1,66	0,095	1,32	7,76

Table 2.- Residence time (hours) and biokinetics of Tc^{99m} (pertechnetate) to newborns (25 % uptake) (HPS, 2013a)

Organ Biokinetic Radiopharm	**Thyroid**	**Stomach content**	**ULI content**	**Kidney**	**Bladder content**	**Rest ofthe body**
Tc^{99m} :τ_i (hours)	0,037	0,154	0,743	0,033	0,345	4,32

Table 3.- Nuclear Data for the emitted photons (MeV) the most significant I^{123} , I^{131} and Tc^{99m} (HPS, 2013b)

RFM	Photons	E_k (Me V)	n_k/des	$\Delta_k = 2{,}13\ n_k\ E_k$ $(\frac{rad-gm}{\mu Ci-hr})$
I^{123}	Radiact. gamma	**0,159**	**0,833**	0,2821
		0,529	0,0139	0,0157
	Characteristic radiation	0,0272|	0,246	0,01415
		0,0275	0,460	0,0269
		0,0310	0,160	0,01056
I^{131}	Radiact. gamma	0,080	0,026	0,0044
		0,284	0,06	0,0363
		0,364	0,817	0,6334
		0,637	0,0717	0,097
		0,723	0,0177	0,027
	Characteristic radiation	0,0295	0,0138	0,00088
		0,0298	0,0256	0,0016
		0,0336	0,009	0,0006
Tc^{99m}	Radiact. gamma	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

Table 4.- Nuclear Data for emitted particles (MeV) the most significant I^{123} , I^{131} and Tc^{99m} (HPS, 2013b)

RFM	Particles	E_k (MeV)	n_k /des	$n_k E_k$ (MeV/des)	$\bar{E}_{particle} = \sum n_k E_k$ (MeV/des)
I^{123}	Conversion electrons	0,1272	0,136	0,0173	0,0206
		0,1540	0,0177	0,0027	
		0,1580	0,0035	0,00055	
	Auger electrons	0,0032	0,94	0,0030	0,0058
		0,0227	0,1235	0,0028	
I^{131}	Beta radiation	0,0694	0,021	0,00145	0,1818
		0,0966	0,073	0,007	
		0,1916	0,899	0,1722	
		0,283	0,0048	0,00135	
	Conversion electrons	0,0456	0,0354	0,0016	0,0076
		0,359	0,0025	0,00089	
		0,3299	0,0155	0,0051	
		0,2497	0,003	0,00075	
	Auger electrons	0,0034	0,051	0,00017	0,000317
		0,0246	0,006	0,000147	
Tc^{99m}	Conversion electrons	0,1195	0,088	0,01052	0,01439
		0,1216	0,0055	0,00067	
		0,1375	0,0107	0,0015	
		0,1396	0,0017	0,00024	
		0,140	0,0019	0,00026	
		0,0016	0,746	0,0012	
	Auger electrons	0,0022	0,102	0,00022	0,00054
		0,0155	0,0207	0,00032	

Table 5.- Values of mass (g) thyroid and total body of a newborn phantoms , for Cristy - Eckerman representation [10] and Segars (ICRP-89 [12])*

Organ of Phantoms	Mass (g) of Phantoms
Thyroid	1,29 (1,30)*
Total Body (TB):	
TB Nominal	3400 (3500)*
TB actual	3600

*For calculation purposes, the masses for both representations can be considered equal.

3.-Results

Tables 6 shows the absorbed dose in the thyroid of Newborns,due to photons and particles of radiopharmaceuticals $^{131}I/^{123}I$(iodides) and ^{99m}Tc(pertechnetate) during studies uptake thyroid newborn explored for the reference phantoms of Segars and Cristy-Eckerman.Tables 7 and 8 , biokinetics organs corresponding

Table 6.- Radiation dose in the thyroid of the Newborns patient using $^{131}I/^{123}I$(iodides) and ^{99m}Tc(pertechnetate) for Segars and Cristy-Eckerman representations

Compound	Emission	D(Thy←Thy)/A_0 mGy/MBq		D(Thy←i)/A_0 (mGy/MBq)			TOTAL Segars/C-E mGy/MBq
		C-E	Segars		C-E^{o}	Segars^{oo}	
^{131}I (Iodide)	Photons X+γ	130,48 (2,47%)	92,98 (1,77%)		0.101 (0,002 %)	0.109 (0,002%)	**5250/5288 (0,72%)***
	Electrons	5157,0 (97,5%)	5157.0 (98,23%)				
	Self-dose	5287,5 (99,98 %)	5249,9 (99,99%)	ΣDose Org Biokinetics	0,101 (0,002 %)	0.109 (0002%)	
^{123}I (iodide)	Photons X+γ	4,9 (12,38 %)	4,19 (10,78%)		0.037 (0,094 %)	0.037 (0,095%)	**38,85/39,57 (1,82%)***
	Electrons	34,63 (87,52 %)	34,625 (89,12%)				
	Self-dose	39,53 (99,89 %)	38,82 (99,92%)	ΣDose Org. Biokinetics	0.037 (0,094 %)	0.037 (0,095%)	
Tc^{99m} (pertechnetate)	Photons	0,026 (8,71%)	0,022 (7,41%)		0.0186 (6,18%)	0.0189 (6,36%)	**0,297/0,301 (1,33%)***
	Electrons	0,256 (85,05 %)	0,256 (86,2%)				
	Self-dose	0,282 (93,69 %)	0,278 (93,61%)	ΣDose Org. Biokinetics	0,0186 (6,18%)	0,0189 (6,36%)	

Table 7.- Absorbed dose for the organs of biokinetics in the Cristy–Eckerman representation

RFM	D(thy ← i)/Ao	x-character. radiation	Gamma radiation	Gamma Radiation+X	Total Dose (mGy/MBq),
^{131}I	D (thy ← bladder) /Ao D (thy← TB) /Ao D (thy ← stomach)/Ao D (thy← kidney)/Ao D (thy← SI)/Ao	0,273E-6 0,113E-2 0,820E-5 0,267E-6 0,210E-5	0,876E-3 0,941E-1 0,35E-2 0,174E-3 0,168E-2	0,00088 0,095 0,0035 0,000174 0,00169	**0,101**
^{123}I	D (thy ← bladder) /Ao D (thy← TB) /Ao D (thy ← stomach)/Ao D (thy← kidney)/Ao D (thy← SI)/Ao	0,81E-5 0,128E-1 0,103E-3 0,250E-5 0,20E-4	0,697E-3 0,220E-1 0,127E-2 0,400E-4 0,384E-3	0,0007 0,0345 0,0014 0,000043 0,00040	**0,037**
^{99m}Tc	D (thy ← bladder) /Ao D (thy← TB) /Ao D (thy ← stomach)/Ao D (thy← kidney)/Ao D (thy← SI)/Ao D (thy ← LLI) /Ao D (thy← ULI) /Ao	0,00E+0 0,908E-3 0,30E-9 0,18E-8 0,116E-8 0,283E-8 0,30E-8	0,715E-4 0,168E-1 0,11E-3 0,357E-4 0,132E-3 0,102E-3 0,421E-3	0,000072 0,0177 0,00011 0,000036 0,000132 0,000102 0,00042	**0,0186**

TB:total body,SI:small intestine; LLI: Lower large intestine ULI: Upper large intestine

Table 8.- Absorbed dose for the organs of biokinetics in the Segars representation

RFM	D(thy ← i)/Ao	X-character. Radiation	Gamma radiation	Gamma Radiation+X	Total Dose (mGy/MBq),
^{131}I	D (thy ← bladder) /Ao D (thy← TB) /Ao D (thy ← stomach)/Ao D (thy← kidney)/Ao D (thy← SI)/Ao	0,00000 0,113E-2 0,799E-4 0,98E-6 0,507E-5	0,642E-3 0,934E-1 0,11E-1 0,249E-3 0,212E-2	0,00064 0,095 0,0110 0,00025 0,00213	**0.109**
^{123}I	D (thy ← bladder) /Ao D (thy← TB) /Ao D (thy ← stomach)/Ao D (thy← kidney)/Ao D (thy← SI)/Ao	0,000E+0 0,128E-1 0,655E-3 0,614E-5 0,974E-4	0,91E-4 0,219E-1 0,264E-3 0,59E-4 0,674E-3 0,674E-3	0,000091 0,0347 0,00092 0,00007 0,00077 0,000764	**0,0370**
^{99m}Tc	D (thy ← bladder) /Ao D (thy← TB) /Ao D (thy ← stomach)/Ao D (thy← kidney)/Ao D (thy← SI)/Ao D (thy ← LLI) /Ao D (thy← ULI) /Ao	0,000E+0 0,908E-3 0,162E-5 0,183E-5 0.182E-7 0,286E-6 0,14E-7	0,307E-4 0,167E-1 0.34E-3 0,279E-4 0,232E-3 0,40E-3 0,192E-3	0,000031 0,0177 0,00034 0,0000297 0,000232 0,00040 0,00019	**0,0189**

4.-Discussion

The anatomical phantoms of the new generation of Segars clearly represent a significant improvement in the anatomical realism of the organs and in the proximity of the organs it is better modeled, while in stylized models of C-E, the separation of spaces of organs occurs by the simplicity of the forms used to model them, [23].

The higher dose absorbed by the thyroid in newborn patients explored with 131I/123I(iodide) calculated in the anthropomorphic representations of Cristy-Eckerman and Segars, is mainly due to its **self-dose** contribution, delivered mainly by electrons

released by the iodides and which, in turn, are associated with the value of their residence time presented in the thyroid and in the total body ("rest"). (Tables 1 and 6).

The dosimetric contribution due to the biokinetic organs is very small (0.002% of the total dose). (Table 6). The relative difference in the total dose dose to the newborn thyroid gland using the when using Cristy-Eckerman and Segars anatomical representations para dichos radiofármacos,was 0,72%, and 1,82% respectivamente(Table 6)

The higher dose absorbed by the thyroid in newborn patients explored with ^{99m}Tc(pertechnetate) when using the Cristy-Eckerman/Segars representations, is mainly due to its **self-dose** contribution , delivered mainly by electrons released by pertechnetate and which, in turn, , are associated with the value of their residence time presented in the thyroid and in the total body ("rest"). (Tables 2 and 6).

The dosimetric contribution of the biokinetic organs of the radiopharmaceutical for both representations is small, and is mainly due to the total body ("rest") (Tables 7 and 8). The relative difference in total dose when using Cristy-Eckerman and Segars anatomical representations para dicho radiofarmaco was 1,33%.(Table 6).

Regardless of the radiopharmaceutical used for examinations in the thyroid of a newborn patient, the substitution of the Cristy-Eckerman anthropomorphic representation for the Segars does not reflect significant changes in the calculation of the absorbed dose in the thyroid.

The probable explanation for the behavior of the representations is due to:

The geometric and anatomical differences presented by the Cristy-Eckerman and Segars representations mean that the SAF due to the x and ɤ photons of the RFMs used is slightly the same. The absorbed fractions for the total body (TB) or "rest" are the same for both representations . These situations lead to insignificant relative differences in the total dose to the newborn's thyroid (and in the dose to its biokinetic organs) for both representations [8] [16] [24].

The lowest dose absorbed by the thyroid of a newborn was obtained when ^{99m}Tc (pertechnetate) was used, mainly due to its self-dose with approximately 94% of the total dose, and due to its biokinetic organs, with the 6, 0 of your total dose (Table 6).

5.-Conclusiones

The higher dose absorbed by the thyroid gland in newborn patients due to the compounds ^{131}I/^{123}I(iodide) and ^{99m}Tc(pertechnetate), calculated in the anthropomorphic representations of Cristy-Eckerman and Segars, is mainly due to their **self-dose**, generated by the electrons released by these compounds.

The relative difference in total dose to the newborn thyroid gland using the Cristy-Eckerman and Segars anthropomorphic representations for the compounds $^{131}I/^{123}I$(iodide) and ^{99m}Tc was 0.72%, 1.82%, and 1.33%, respectively.

Regardless of the RFM selected, replacement of Cristy-Eckerman phantoms by Segars phantoms does not reflect significant changes in the estimated absorbed dose to the newborn thyroid.

Regardless of the Cristy-Eckerman or Segars anthropomorphic representation, the lowest dose to a newborn's thyroid is obtained when using 99mTc (pertechnetate). The residence times for this RFM contribute to that dose.

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