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Assessment of Organ Doses for Patients undergoing ^{99m}Tc-MIBI Myocardial Perfusion Imaging.

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ABSTRACT:

Radiation absorbed doses associated with myocardial perfusion imaging (MPI) using ^{99m}Tc-MIBI has been determined at the **Radioisotopes Institute of the Abdou Moumouni University**. Thirty patients undergoing MPI were scanned and image quantification was done using Mediso Inter View XP® software. The average administrated activities of ^{99m}Tc-Sestamibi were 370 MBq (10 mCi) in stress condition and 1110 MBq (30 mCi) in rest condition with one day protocol. The radionuclide activities in the heart, liver, kidneys and urinary bladder were determined using the conjugate view method. The uptake of 99mTc-MIBI in the heart, liver and kidneys were respectively about 2.17% ±0.64, 6.53% ±1.47 and 5% ±0.52, 10 minutes after injection. The cumulative activities for the heart, liver, kidneys and urinary bladder were respectively 21.97 MBq.h, 63.11 MBq.h, 36.61 MBq.h, 79.48 MBq.h for the stress and 68.23 MBq.h, 239.79 MBq.h, 101.69 MBq.h and 223.1 MBq.hin the rest conditions. The organs absorbed doses in this study were 3.06 mGy for kidneys, 0.75 mGy for liver, 0.75 mGy for the heart, and 20.46mGy for bladder.

Key Words: Internal dosimetry, myocardial perfusion imaging, organ dose, SPECT, MIRDOSE, OLINDA.

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INTRODUCTION:

Image quantification in nuclear medicine with planar or tomographic methods is used to estimate activity in human subjects for the calculation of radiation dose in individuals to study pharmacokinetics for approval of radiopharmaceuticals [(1,2)]. Sufficient data must be obtained to characterize all significant phases of radiopharmaceutical uptake and elimination in all important source regions, as explained by ***Siegel et al***. [(3)].

In contrast to diagnostic radiology where normally only the organs or tissues of diagnostic interest and their surroundings are irradiated, nuclear medicine investigation causes radiation exposure of the whole body. The uptake of the radiopharmaceutical in organs and tissues under investigation varies from 1-2% up to almost 100% depending on what investigation is performed [(4)].

Performing quantitative imaging for dosimetry analyses may represent a significant time and financial burden on a medical facility, but such efforts are essential to establish reliable absorbed dose calculations to assess tumor response to radiation and to evaluate normal tissue toxicity, for treatment planning in Radionuclide therapy [(5)].

Myocardial Perfusion Imaging (MPI) has been performed in the Nuclear Medicine Department of Radio-Isotopes Institute since 2005. It is the most frequent examination performed in the Department but assessment of the radiation doses to patients associated with the practice over the years has not been undertaken.

The aim of this study is to assess the radiation dose to patient undergoing ^{99m}Tc-Sestamibi MPI at Nuclear Medicine Department of **Radioisotopes Institute, Abdou Moumouni University**.

MATERIAL AND METHODS:

In this study, 30 patients comprising 16 men and 14 women with average age of 47.6 years were selected. Maximum and minimum ages of the patients were 60 years and 23 years respectively. Average weight, height and body mass index of the patients were 80.6 ±15.8 kg, 169 ±8.87 cm and 27.99± 5.28 kgcm^{-2} respectively. The study received approval by the National Ethics Committee of Niger and consent form was signed by all the patients included in the study.

^{99m}Tc-sestamibi was prepared in the hot laboratory of the Department and administered intravenously to the patient at maximum heart rate of the patient during stress condition. The administered activity was 370 MBq for the stress phase and 1110 MBq for rest phase.

Mediso gamma camera system equipped with LEHR collimator was used to acquire anterior and posterior planar whole-body images of the patients at 10 minutes,20 minutes, 2 hours and 4 hours after administration of the ^{99m}Tc-Sestamibi through injection. The acquisitions were done for both stress and rest phases.

The images were presented in 256 × 1024 matrix for whole-body scan and 256 × 256 for smaller area scans. The scan acquisition speed was 250 mm per minute. InterViewXP® ROIs tools **(6)** were used to get the counts statistics after scanning patients and drawing regions of interest (ROIs) around the source organs of heart, liver, kidneys and bladder. Conjugate view method was used to convert the measured counts of activity (cts) into radionuclide activities (µCi) for different source organs for each patient.

Radionuclide activity in source region was determined as (3):

$$A_j = \sqrt{\frac{I_A I_P}{e^{-\mu_e t}}}\,\frac{f_j}{C} \qquad (1a)$$

$$f_j = \frac{(\mu_j t_j / 2)}{\sinh(\mu_j t_j / 2)} \qquad (1b)$$

Where I_A and I_P are the observed counts in the anterior and posterior projections (counts/time), t is the overall patient thickness, μ_e is the effective linear attenuation coefficient, C is system calibration factor, and $f_j$is the source self-attenuation correction which represents a correction for the source region attenuation coefficient (μ_j) and source thickness (t_j).

Computed tomography (CT) scan images of ten of the selected patients were obtained and used for the determination of body and organ thicknesses. Cumulative radionuclide activity for the heart, liver and kidney after administration of the^{99m}Tc-Sestamibiwere estimated by integrating the time-activity curves over 4 hour time period and the bladder was estimated over 2 hour time period. The absorbed doses for were estimated by determining the time integrated activity coefficient using Equation (1c).

The absorbed doses were estimated with MIRD DOSE [6] and OLINDA [7] dosimetry software and comparative analysis performed between the two methodologies.

$$\tau = \frac{\tilde{A}}{A_0} \quad (1c)$$

Thicknesses of the patients' body and organs were measured from the CT scans to correct the source self-attenuation. CT of the thorax was used for assessing the thickness of the heart and abdomen CT for kidney and liver, while Pelvic CT was used for the bladder.

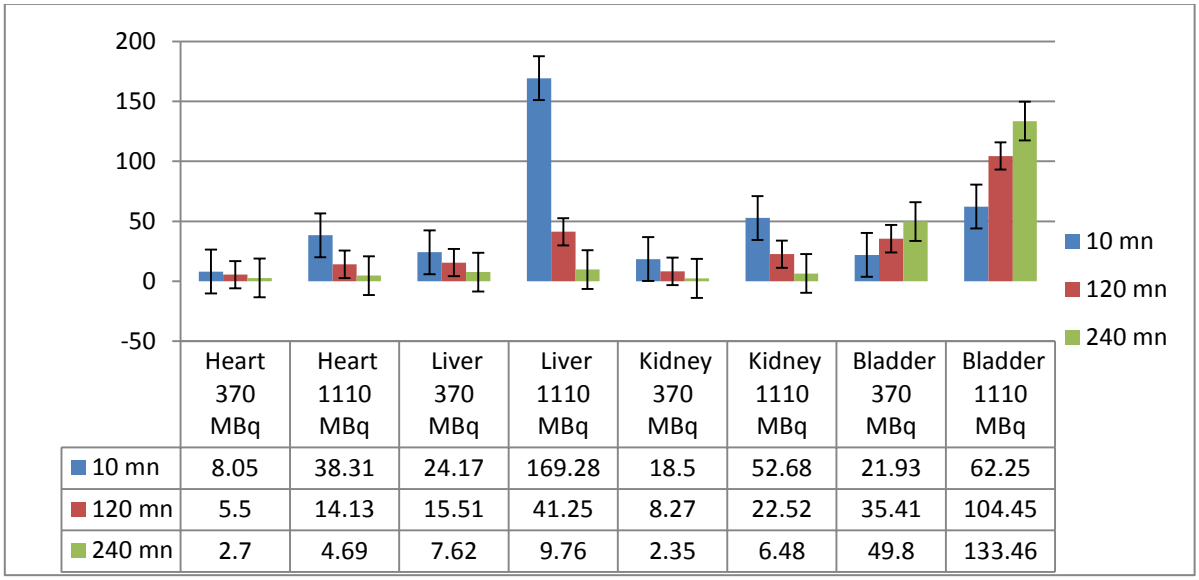
RESULTS:

Regions of interest were drawn over organs of interest in scanned images of the patients using Inter View XP® software. Counts of activity statistics for the heart, liver kidney and bladder were measured from the ROI tool. Figure 1 presents estimated radionuclide activities in the organs at specific time points.

While the radionuclide concentration in the heart, liver and kidneys were seen to be decreasing over time, the bladder was observed to accumulate the activity due to the temporary storage of urine until patients urinated. The liver is observed to accumulate more activity comparable to the kidneys and heart. The measured body and organs thicknesses are presented in ***Table 1***.

Table 1: Measured body and organ thicknesses.

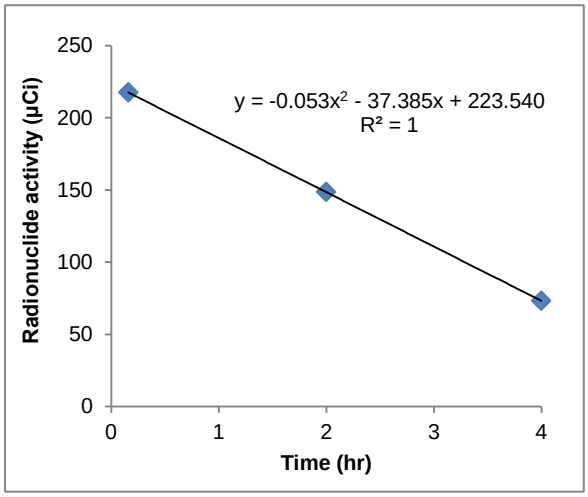
	Average thickness (cm)	
	Organ	Body section
Kidney	5.5 ±0.57	21.0 ±1.40
Bladder	8.5 ±0.83	23.0 ± 1.84
Heart	9.7 ± 1.01	21.9 ±1.28
Liver	15.7 ±1.41	21.9 ± 1.53



	Heart 370 MBq	Heart 1110 MBq	Liver 370 MBq	Liver 1110 MBq	Kidney 370 MBq	Kidney 1110 MBq	Bladder 370 MBq	Bladder 1110 MBq
10 mn	8.05	38.31	24.17	169.28	18.5	52.68	21.93	62.25
120 mn	5.5	14.13	15.51	41.25	8.27	22.52	35.41	104.45
240 mn	2.7	4.69	7.62	9.76	2.35	6.48	49.8	133.46

Fig 1: Mean radionuclide activity in heart, kidneys, liver and bladder. Bladder mean radionuclide activity is for 10 mn, 20 mn and 120 mn.

Cumulative radionuclide activity in the heart, liver, kidney and bladder after injection of 370 MBq and 1110MBq activity of ^{99m}Tc-Sestamibi are presented in Figure 2A&Figure 5B respectively.



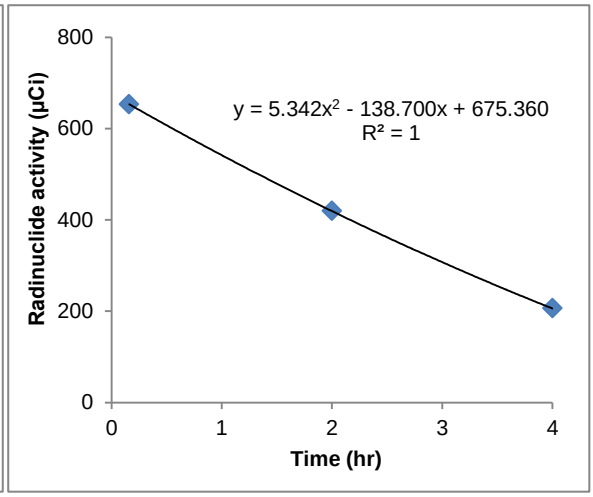
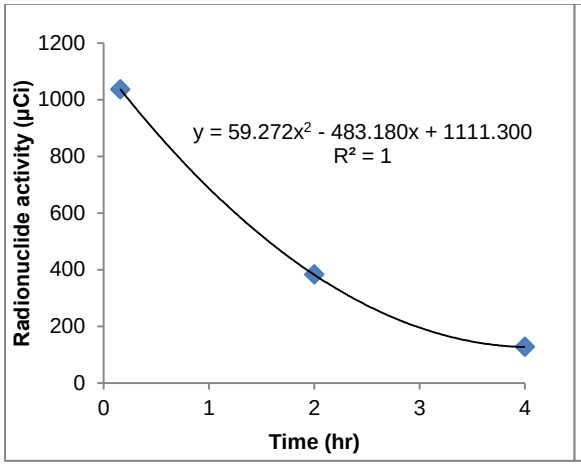


Fig. 2a: Activity-time curve for the heart at 10 mCi activity.	**Fig. 2b:** Activity-time curve for the heart at 1 mCi activity.



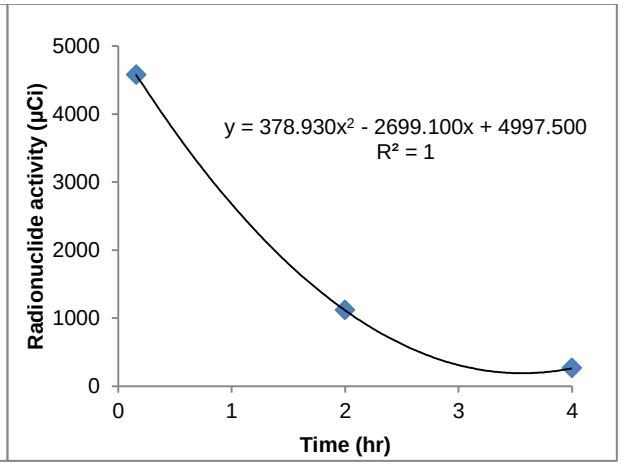
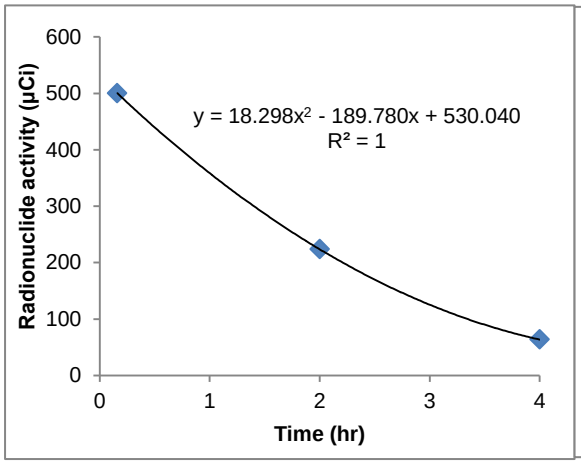


Fig. 3a: Activity-time curve for the liver at 10 mCi activity.

Fig. 3b: Activity-time curve for the Liver at 30 mCi activity.



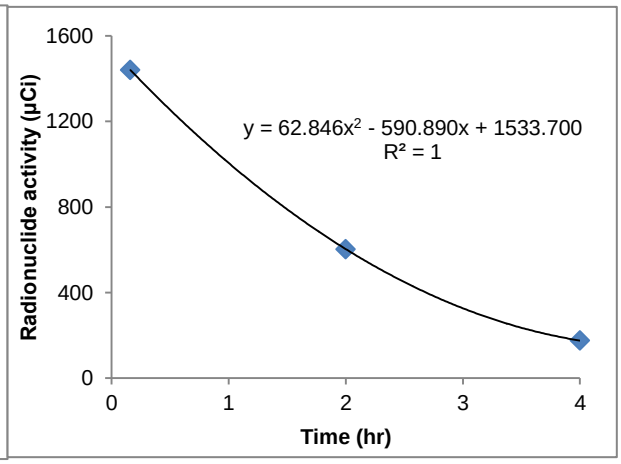
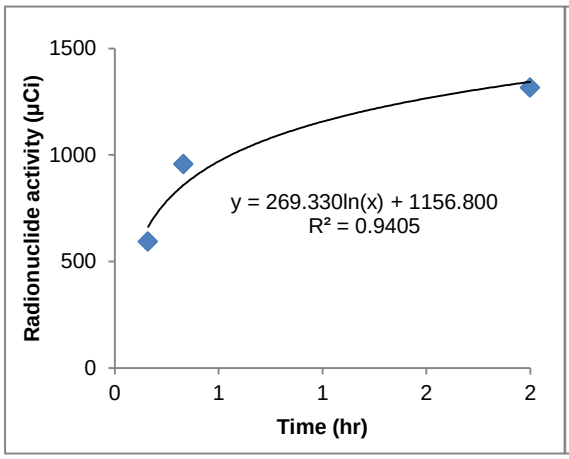


Fig. 4a: Activity-time curve for the Kidney at 10 mCi activity.

Fig. 4b: Activity-time curve for the kidney at 30 mCi activity.



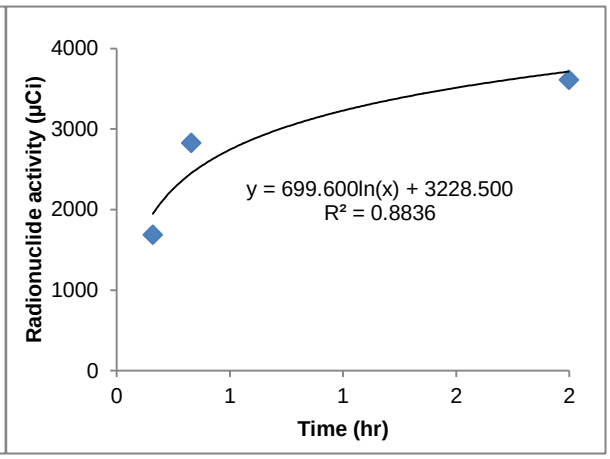


Fig. 5a: Activity-time curve for the bladder at 10 mCi activity.

Fig. 5b: Activity-time curve for the bladder at 30 mCi activity

Fitting of the time-activity curves produced equations 2a – 5b.

$$A_{h10} = -0.534t^2 - 37.385t + 223.540 \quad (2a)$$

$$A_{h30} = 5.342t^2 - 138.700t + 675.360 \quad (2b)$$

$$A_{l10} = 59.272t^2 + 483.18t + 1111.300 \quad (3a)$$

$$A_{l30} = 378.930t^2 - 2699.100t + 4997.500 \quad (3b)$$

$$A_{k10} = 18.298t^2 - 189.780t + 530.040 \quad (4a)$$

$$A_{k30} = 62.846t^2 - 590.890t + 1533.700 \quad (4b)$$

$$A_{b10} = 269.330\ln(t) + 1156.800 \quad (5a)$$

$$A_{b30} = 699.61\ln(t) + 3228.5 \quad (5b)$$

Integral of the time-activity expressions (t = 0 to t = 4 hrs)for the 370 MBq and 1110 MBq administered radionuclide activities produced cumulative radionuclide activities of 21.97 MBq.h and 68.23 MBq.h for the heart, 63.11 MBq.h and 239.79 MBq.h for the liver, 36.61 MBq.h and 101.69 MBq.h for the kidney respectively. Correspondingly, integral of the time-activity curve for the bladder, taken at t = 0 to t = 2 hrs, produced cumulative activities of 79.48 MBq.h and 223.1 MBq.h.

Table 2: Time integrated activity coefficient for the heart, liver, kidneys and bladder.

Source organ	**Cumulative activity (MBq.h)**		**Time integrated activity coefficient (h)**		
	For 370 MBq	For 1110 MBq	For 370 MBq	For 1110MBq	Average
Heart	21.97 (R^2=1.00)	68.23 (R^2=1.00)	0.0593	0.0614	0.0604
Liver	63.11 (R^2=1.00)	239.79 (R^2=1.00)	0.1705	0.2160	0.1932
Kidneys	36.61 (R^2=1.00)	101.69 (R^2=1.00)	0.0989	0.0916	0.0952
Urinary Bladder	79.48(R^2=0.94)	223.1 (R^2=1.00)	0.2148	0.2009	0.2079

Integrated time activity coefficients are noted not to change because of the quantity of administered activity but based on the type of radionuclide tracer used. Organ absorbed doses per unit of administered activity (µGy/MBq) estimated with MIRDOSE and OLINDA are presented in ***Table 3***. Heart, liver, kidneys and bladder were used as source organs and lung, spleen, testes and ovaries as target organs. Comparison of the dose estimates for the two methods shows that most of the deviations are less than 10% except for kidneys which is about 15%.

Table 3: Absorbed dose per administered activity with MIRD Dose and our study.

Target Organs	Absorbed dose per administered activity $\times 10^{-6}$(µGy/MBq)					
	Female Patients			Male Patients		
	MIRDOSE 3	STUDY	Error (%)	MIRDOSE 3	STUDY	Error (%)
Bladder	53.7	55.30	1.6	53.7	57.2	3.5
Kidneys	23.1	8.29	-14.8	23.1	7.25	-15.85
Liver	8.19	2.02	-6.17	8.19	3.63	-4.56
Heart	4.95	2.02	-2.93	4.95	1.93	-3.02
Thyroid	2.22	6.02	3.8	2.22	2.63	0.41
Spleen	8.62	4.90	-3.72	8.62	4.6	-4.02
Lung	2.75	2.48	-0.27	2.75	3.9	1.15
Testes	-	-	-	7.90	3.25	-4.65
Ovaries	62.4	54.6	-7.8	-	-	-

The absorbed dose per unit administrated activity was found to be relatively high in the urinary bladder for both female and male patients as indicated in ***Table 4***. This is probably due to the overestimation during quantification and of course lack of hydration.

Ovaries in females received higher doses comparative to testes in males. The absorbed doses to organs per unit administered activity in this study were found to be comparable to the results from MIRD Dose 3 and within accepted tolerances ***(Table 5)*.**

Table 4: Absorbed organ dose per 370 MBq administered during stress.

Target Organs	MIRD Dose 3 Vs Study			
	Female		Male	
	MIRDOSE3 (mGy)	STUDY (mGy)	MIRDOSE3 (mGy)	STUDY (mGy)
Bladder	**19.87**	**20.46**	**19.87**	**21.16**
Kidneys	8.54	3.06	8.54	2.68
Liver	3.03	0.74	3.03	1.34
Heart	1.83	0.74	1.83	0.71
Thyroid	0.81	2.22	0.81	0.97
Spleen	3.18	1.81	3.18	1.70
Lung	1.01	0.91	1.01	1.44
Testes			2.92	1.20
Ovaries	**23.08**	**20.20**		

Table 5: Absorbed organ dose per 370 MBq administered during stress.

Target Organs	Tc MIBI supplier vs study with OLINDA software		
	MIBI supplier	Female	Male
	(mGy)	Study(mGy)	Study(mGy)
Bladder	3.62	**20.46**	**21.16**
Kidneys	3.06	3.06	2.68
Liver	3.40	0.74	1.34
Heart	2.66	0.74	0.71
Thyroid	1.62	2.22	0.97
Spleen	2.14	1.81	1.70
Lung	1.62	0.91	1.44
Testes	1.37		1.20
Ovaries	2.89	**20.20**	

DISCUSSIONS:

Thickness of the heart presented in the table1 was found to be comparable to the measurement of 5.54 cm by ***Larsson et al*** in their study [9].

The dosimetry provided by the supplier was completely super imposable on our study except the dose received by the bladder and ovaries certainly due to the lack of hydration of our patients during myocardial perfusion imaging [11].

The study has indicated that absorbed doses to the organs for patients undergoing MPI are within accepted tolerances except for bladder and ovaries; this is probably due to overestimation during quantification and lack of hydration.

The estimated radionuclide activities in the organs was done with conjugated view method at 10 minutes, 120 minutes and 240 minutes for heart, liver and kidneys while 10 minutes, 20 minutes and 120 minutes for bladder. The radionuclide concentration in the heart, liver and kidneys were seen to be decreasing over time, the bladder was observed to accumulate the activity due to the temporary storage of urine until patients urinated.

The liver is observed to accumulate more activity comparable to the kidneys and heart. In this study, we obtained 2.17% of heart stress uptake 10 minutes after injection of 370 MBq of Sestamibi which was relatively high according to the uptake published by **the supplier** which was 1.5% [11].

Integral of the time-activity expressions (t = 0 to t = 4 hrs) for the 370 MBq and 1110 MBq administered radionuclide activities produced cumulative radionuclide activities of 21.97 MBq.h and 68.23 MBq.h for the heart, 63.11 MBq.h and 239.79 MBq.h for the liver, 36.61 MBq.h and 101.69 MBq.h for the kidney respectively. Correspondingly, integral of the time-activity curve for the bladder, taken at t = 0 to t = 2 hrs, produced cumulative activities of 79.48 MBq.h and 223.1 MBq.h.

The time integrated activity coefficient for the organs obtained in this study, did not deviate significantly from estimated time integrated activity coefficient found by ***Rohe et al (2).*** Time integrated activities are noted not to change because of the quantity of administered activity, but based on the type of radionuclide tracer used.

MIRD DOSE 3 and OLINDA were two methods used for organ absorbed doses per unit of administered activity (µGy/MBq) estimation. Heart, liver, kidneys and bladder were used as source organs and lung, spleen, testes and ovaries as target organs.

Comparison of these two methods showed that most of the deviations are less than 10% except for kidneys which was about 15%.

The absorbed dose per unit administrated activity for urinary bladder was found to be relatively high for both female and male patients. This was probably due to the overestimation during quantification and of course lack of hydration. Ovaries in females received higher doses comparative to testes in males.

The absorbed doses to organs per unit administered activity in this study were found to be comparable to the study from MIRD DOSE 3 published by **Stabin et al** [10] and within accepted tolerances.

We recommend to the nuclear medicine department to impose oral hydration on all patients undergoing MPI in order to reduce the doses received by the bladder. This is necessary for patient protection and serves as part of quality assurance in the practice.

CONCLUSIONS:

The absorbed doses to heart, liver, kidney and bladder for patients undergoing MPI are within accepted tolerances except for bladder and ovaries. This is probably due to overestimation during quantification; lack of hydration.

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