REVIEW ARTICLE

Estimation of patient-specific absorbed and effective doses to healthy organs undergoing myocardial perfusion using olinda/exm and idac dose codes

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ABSTRACT

Objective: Radioisotopes are administered in varying amounts to patients orally and intravenously for treatment and diagnostic procedures in nuclear medicine. It is an established fact that radionuclides have both therapeutic and harmful effects on humans. Hence, the need for individual patient dosimetry is an important factor in optimizing patient-specific doses. The study objective is to estimate the internal radiation doses to the selected patients undergoing Tc99m - MIBI scan using computer codes.

Material and Methods: Technetium 99m MIBI was administered to the ten randomly selected patients for the rest study. Whole-body planar scintigraphy at a different time was performed on a dual-head gamma camera. SPECT-CT gamma camera is installed in the nuclear medicine department at Nuclear Medicine, Oncology, and Radiotherapy Institute, Islamabad. The injected activity ranged from 821 to 993 MBq. The absorbed and effective doses for all selected patients are measured using OLINDA/EXM version 2.0 and IDAC DOSE VERSION 2.1 computer codes.

Results: The obtained results show that this is the highest mean absorbed dose received by kidneys and intestine using Olinda /exm and idac dose, respectively. The mean effective dose for Tc99m-MIBI from Olinda/exm for selected patients was found to be 5.52 µSv/MBq and 6.8 µSv/MBq assessed for idac dose software. The results from both the codes are compared to ICRP 128 publication and show a significant correlation within the recommended limits with ICRP dose guidelines. These results are considered key to greater accuracy in internal dose calculation and very useful for patients, education, and research studies.

Keywords: Olinda, idac-dose, technetium 99m MIBI, internal dosimetry, nuclear medicine, SPECT/CT. OLINDA/EXM, IDAC-DOSE.

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Introduction

Radiopharmaceuticals are administered in nuclear medicine for therapeutic as well as diagnostic purposes. Estimation of internal radiation doses for various body organs is beneficial to optimize the given dose to patients and to maintain the critical organs at safe levels. Different models are being used to estimate the doses within the body such as International Commission on Radiological Protection (ICRP), Medical Internal Radiation Dose Committee (MIRD), and Radiation Dose Assessment Resource (RADAR). In nuclear medicine, the most widespread method used for internal dose calculation is the MIRD [1-6].

Various ICRP and MIRD models are similar in terms of their conclusion and defining equations, but they use different terminology and notation. Most of the MIRD system results are directed toward nuclear medicine patients, whereas the ICRP systems are directed toward protecting radiation workers. MIRD development is based on different methodologies and standard methods to perform internal dose calculations in nuclear medicine. The development of ICRP is based on radiological protection from radiation and the estimation of doses for several radiopharmaceuticals [7-9].

Manual calculation of internal doses makes it difficult to use various mathematical formulae and models compared to the computer program. Computer codes offer many advantages, such as speeding up the absorbed dose calculation to all target organs. These codes used many radionuclides at one time and performed accurate results for different target regions simultaneously. Internal dosimetry codes were designed mainly to do dose measurements using different models of data. Fundamental dose calculations could be made in seconds instead of hours with these codes. Many computer codes such as MIRDOSE, OLINDA/EXM, IDAC-DOSE, PLEIADES, MABDOSE, OEDIPE, AIDE, and CALRADDOSE [10-18] are being developed. These are used to calculate the internal dose per unit administered activity of various radiopharmaceuticals.

Work regarding internal radiation doses to the different body organs has been cited in the literature, but mostly manual calculation is used to estimate the internal doses. In the present work, a comparative study is conducted by using two different computer codes OLINDA/EXM version 2.1 and IDAC-DOSE version 2.1 for internal dose assessment. These software are fast and reliable for estimating the organ doses to different parts of the body and also give results for many radionuclides administered to the patient [10]. The study aims to determine the absorbed dose and effective dose to the randomly selected patients undergoing a Tc99m-MIBi scan using two software codes.

Computer codes used for dose assessment

Organ Level Internal Dose Assessment (OLINDA 1.0) for internal dose calculation in nuclear medicine was the updated version of MIRDOSE software and based on Oak Ridge National Laboratory (ORNL) models [11]. This version used geometric shapes to describe the different body tissues and estimate the absorbed and effective doses using tissue weighting factors in the International Commission of Radiation Protection (ICRP) 26 and 60 publication. The updated version OLINDA/EXM 2.1 was used in the present work for absorbed and effective dose estimation. Olinda Utilizes stylized mathematical phantoms developed under the MIRD schema [12]. This version contains radionuclide decay data based on ICRP 107 and tissue weighting factor based on ICRP 103 [19]. IDAC-Dose was based on the stylized family of anatomical phantoms described by Cristy and Eckerman [13].

In OLINDA/EXM 2.1 code, radionuclides of choice can be selected with several different phantoms, including adult males and females, various pediatric phantoms, and special models are being used. The code replaced the ORNL model of Olinda 1.0 with Non-Uniform Rational B-Spline (NURBS) model using data from ICRP89 [20]. Both versions of the Olinda software used the RADAR method for internal dose estimation and calculated the absorbed dose to the different organs using the general equation [7], which are

$$D = N_S \times DF \tag{1}$$

D is the absorbed dose in the target region. N is the total number of disintegrations that occurred in the source organ per unit injected activity and is known as a cumulated activity. DF is the dose factor that is equal to S factor used in the MIRD method and depends on the radionuclide data.

Internal Dose Assessment by Computer Dose (IDAC Dose 1.0) is another dosimetry program created by Lennart Johansson used to estimate doses to the body's different tissues in nuclear medicine. The code was endorsed by the ICRP to perform dose calculations from different radiopharmaceuticals in ICRP Publications [21,22]. A new version of this code IDAC-Dose version 2.1, was used in the present work considering 83 different source organs and 47 target regions. The computer program used the radioisotope decay data based on ICRP-107 while defining the effective doses present in ICRP Publication 60 and 103 [23,24]. This new version of the software can estimate the absorbed dose to the different body organs from 1,252 different radionuclides of 97 elements using Cristy Eckerman stylized family phantoms [13].

These codes are simple, reliable, user-friendly, and recent computer software versions are used to assess the internal doses. These codes contain many sources and target organs useful for estimating the internal doses to the different parts of the body. Both the software include dose factors and only require the Residence time to calculate the internal doses.

Materials and Methods

Technetium 99m-MIBI was administered to the randomly selected patients and whole-body planar (anterior and posterior views) scanning at a different time was performed on the SPECT/CT system. The dual-head GE SPECT/CT system was installed in the nuclear medicine department at Nuclear Medicine, Oncology, and Radiotherapy Institute, Islamabad. MIRD method is used to absolute measured activity in the source region. Two computer codes OLINDA/EXM 2.0 and IDAC DOSE 2.1 were used to estimate the internal doses to different organs of selected patients. The residence time for activity in the

Table 1. *Relevant information of selected patients.*

Patients	Gender	Age (years)	Weight (Kg)	Activity (MBq)
1	M	60	72	990.13
2	F	61	59	975.11
3	F	25	56	970.15
4	M	54	74	820.50
5	F	56	69	986.76
6	F	69	59	982.11
7	F	66	52	919.40
8	M	71	50	828.29
9	F	68	53	940.80
10	M	67	51	916.16

source organ was used as the input parameter in software to estimate internal doses.

Patients' Selection; Ten patients with myocardial perfusion were randomly selected for the rest study. In this work, the absorbed doses from 10 source organs were estimated to be 17 target organs. The relevant information regarding the selected patients considering age, gender, weight, and injected activity is summarized in Table 1.

Whole Body Scanning: After the administration of Tc99m - MIBI activity, the whole-body planar scanning (anterior and posterior views) was performed with dual-head SPECT/CT, GE Discovery 670 system at 15 minutes, 2 hours, 4 hours, and 24 hours. The whole-body scan was performed to examine the source organs and activity assessment in source organs injection. For the rest study, the patient's acquisitions were made after the direct injection of activity. Imaging was done at the speed of 14 cm/min and a 20% energy window adjusted around the photopeak of Tc-99m was used.

Image Analysis: To acquire the total number of counts in the source region, the ROI around source organs was manually created using Xeleris 4.0 software. Additional ROIs are also drawn beside each organ to determine the background activity. Original counts of the source are determined by the subtraction of background activity from source activity. Heart, gall bladder, liver, lungs, Intestine, urinary bladder, thyroid, spleen, kidneys, and salivary glands are used as source organs in the present study.

Activity Estimation: The conjugate view imaging method is applied for the estimation of activity in the source region by using a calibration factor to convert counts into activity [7]. The activity obtained using the following equation which is based on the conjugate view method is

$$A_J = \sqrt{\frac{I_a I_P}{e^{-u_e t}}}\frac{f_j}{C} \qquad (2)$$

Where

$$F_j = \frac{(\mu_j t_j/2)}{Sinh(\mu_j t_j/2)} \qquad (3)$$

In the above expression, A is the organ activity in MBq, IA and IP are the obtained count rates in the anterior and posterior views, respectively (counts/time), t is the source thickness (18.5), μ_e (cm^{-1}) is the effective linear attenuation coefficient (0.143/cm), C is the system calibration factor (1902 counts/time per unit activity), and Fj represents a self-attenuation correction source region estimated from source region attenuation coefficient (μe) and source thickness using eq. 3. (0.98) [24–26]. The MIRD method is used for the correction of background activity [8].

Residence Time Estimation: Residence time is determined by using equation 4.

$$\tau_h = \frac{\tilde{A}}{A_0} \qquad (4)$$

where Ã is the cumulated activity and A0 is the injected activity. After getting residence time, it has been incorporated into the software to get the required results. Residence time is used for getting the total absorbed dose and effective dose to the target organs and is an essential parameter to find out the results from the respective software. Residence time has a significant impact on achieving accurate, personalized, and enhanced reliability of dose calculations. The unit of residence time is (MBq-hr/MBq).

Results and Discussion

Residence time of source regions: Figure 1 shows whole-body anterior and posterior images taken at 15 minutes, 2 hours, 4 hours, and 24 hours after administering Tc99m-MIBI activity to patients. Table 2 shows the residence time of Tc99m-MIBI activity in 10 source organs. In the present study, the intestine is a common organ in all patients where the highest residence time of Tc99m-MIBI activity

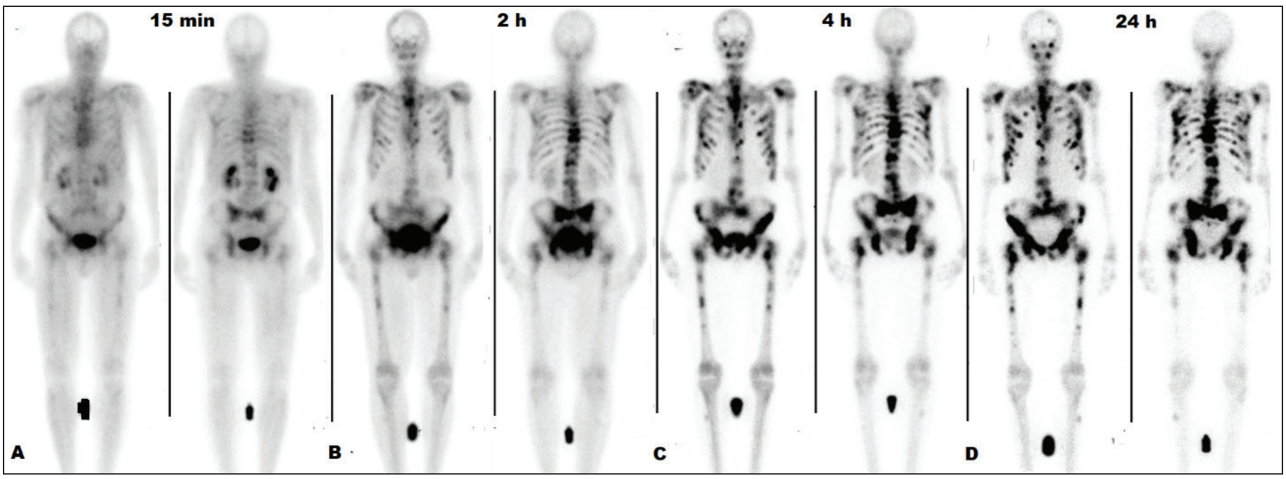

Figure 1. *Images of selected patients at different time.*

Table 2. Residence time (h) of Tc99m-MIBI activity in given source regions of 10 patients.

Patients	Heart	Liver	Intestine	S.G	Thyroid	Kidneys	Spleen	G.B	U.B	Lungs
1	0.1134	0.4529	2.5741	0.0572	0.0439	0.4078	0.0927	0.1611	0.071	0.1651
2	0.1212	0.5102	2.9668	0.0514	0.0255	0.5837	0.1242	0.2551	0.047	0.236
3	0.1255	0.3959	2.8054	0.0394	0.0231	0.5035	0.0815	0.2305	0.1962	0.3036
4	0.1	0.451	2.9455	0.0471	0.0421	0.5836	0.109	0.1006	0.0249	0.1826
5	0.1162	0.4707	3.0351	0.0361	0.0215	0.5604	0.081	0.0785	0.021	0.1894
6	0.1251	0.4862	2.7632	0.0496	0.0384	0.4377	0.0851	0.173	0.0763	0.1773
7	0.1032	0.3723	2.2525	0.0576	0.0242	0.3234	0.0919	0.1606	0.0698	0.1194
8	0.1192	0.5546	2.0936	0.0551	0.0364	0.4798	0.1092	0.1027	0.0595	0.2357
9	0.1238	0.4944	2.5651	0.0517	0.0294	0.4637	0.0885	0.1377	0.09	0.2094
10	0.1271	0.564	2.1498	0.0543	0.0362	0.4835	0.099	0.1202	0.0616	0.2387

Table 3. Absorbed dose into 17 Target regions using Idac-dose computer.

Target regions	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Adrenals	10.45	13.3	12.3	12.6	11.08	11.4	9.28	11.3	11.02	10.7
Brain	0.0858	0.0813	0.0957	0.0756	0.085	0.102	0.113	0.0834	0.112	0.0843
Breasts	11.123	-	-	1.31	-	-	-	1.35	-	1.3
G.B	16.7	21.4	23.02	14.3	16.02	20.02	17.02	14.1	18.01	14.2
Heart	6.28	7.64	8.53	6.56	7.8	7.6	6.61	7.25	8.14	7.36
Kidneys	22.72	30.5	31	30	33.8	28.01	21.03	25.53	28.01	24.72
Liver	8.7	11	10.3	9.18	10.4	10.5	8.46	9.64	10.5	9.55
Lungs	2	4.5	5.23	3.64	3.5	2.1	2.9	4.16	4.2	4.11
Muscles	0.952	1.8	1.65	1.11	1.62	1.48	1.24	1.05	1.47	1.34
Pancreas	17.1	20.8	20.2	18.9	20.3	19.03	15.08	17.01	18.02	15.35
R.M	2.3	2.9	3.9	2.7	3.8	3.5	3.1	2.53	3.5	2.31
S.I	15	17.2	20	17	21	19.03	15.43	14.08	18.2	12.81
Spleen	11.7	14.6	11.1	13.2	12.05	11.7	11.2	12.7	12	11.52
Stomach	8.7	10.4	14.4	10	11.9	11.2	9.8	9.08	10.2	8.11
Thymus	12	1.63	1.1	1.6	2.5	1.3	1.3	1.67	1.72	1.71
Thyroid	22.2	13.5	14.5	21.5	6.85	23.3	15	18.81	18.02	18.73
U.B	3	2.6	8.7	2.15	7.5	7.35	6.1	2.62	7.15	2.45

is seen. The mean residence time for the intestine is 2.61 ± 0.5. The source organs show activity variation at different times after injection. The initial activity in the liver was cleared after two hours and at the same time, the gall bladder activity passed through the intestine. The hepatobiliary system and the urinary tract were the major routes through which Tc99m-MIBI activity was eliminated from the human body.

Absorbed Doses to Target Regions: The absorbed doses from 10 source organs were estimated to be 17 target organs which are adrenals, heart, liver, kidneys, lungs, brain, thyroid, breasts, spleen, stomach, small intestine, red marrow, muscles, urinary bladder, pancreas, thymus, and gall bladder wall by using Olinda and Idac dose software. The injected activity to selected patients ranged from 821 to 993 MBq given in Table. The obtained results from both software show that the kidney and intestine received higher and the brain received lower doses compared to other organs of the body. The absorbed doses for gall bladder, pancreas, and heart were also measured for Tc99m-MIBI activity. Tables 3 and 4 show the absorbed dose (µGy/MBq) for 17 target regions using Olinda and Idac dose code.

The mean absorbed dose received by kidneys is 27.53 ± 7.0 µGy/MBq, ranged from 20 to 40 µGy/MBq, and 14.18 ± 5.8 µGy/MBq, ranged from 4.5to 38 µGy/MBq using Idac dose and Olinda code, respectively. The estimated mean absorbed dose for the intestine is 17 ± 4 µSv/MBq, ranged from 12.81to 21 µSv/MBq using Idac dose software and 23.96 ± 3 µSv/MBq, ranged from 11.1 to 29.21 µSv/MBq in Olinda software. The measured absorbed dose received by the brain ranged from 0.0756 to 0.113 µGy/MBq and 0.11 to 0.152 µGy/MBq using Idac dose and Olinda computer code.

The mean measured absorbed dose received by the gall bladder ranged from 14.1 to 23.02 µGy/MBq using Idac

Table 4. Absorbed doses to 17 Target regions using Olinda/exm computer code.

Target organs	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Adrenals	5.62	11.07	8.9	11.03	10	6.68	7.78	5.31	9.36	9.34
Brain	0.14	0.149	0.122	0.11	0.11	0.142	0.152	0.136	0.148	0.136
Breasts	9.12	-	-	5.31	-	-	-	4.61	-	4.3
G.B	15.01	28.02	25	20.5	16.07	20.03	19.2	11.05	19.22	13.3
Heart	3.4	8.55	8.55	3.59	3.7	3.64	3.01	3.56	3.8	3.85
Kidneys	4.56	38.04	16.31	15.7	17.03	6.35	11.06	4.9	15.01	13
Liver	5.84	12.02	5.03	7.16	7.4	7.03	6.12	6.08	7.71	7.02
Lungs	1.95	5.09	2.56	2.22	2.42	2.28	1.82	2.23	2.51	2.1
Muscles	2.1	3.8	2.5	1.98	1.68	2.8	1.99	3.05	1.7	2.43
Pancreas	8.55	12.6	10.91	10.4	12.04	10.03	9.13	7.38	10.06	8.15
R.M	1.24	2.55	2.35	1.58	2.37	2.04	1.82	1.18	2.2	1.4
S.I	21.02	29.21	27.61	25.7	29.02	26.03	21.02	17.02	25.03	18.02
Spleen	5.31	10.95	8.57	14.5	9	6.7	7.63	5.68	8.4	6.71
Stomach	3.02	10.27	5.82	3.8	6.26	5.36	4.84	2.95	5.65	3.37
Thymus	1.38	2.1	2.86	5.58	1.84	1.93	1.47	1.51	1.98	1.61
Thyroid	5.72	4.13	3.81	5.56	3.48	5.7	3.7	4.11	4.58	5.15
U.B	3.1	3.73	6.14	2.41	3.29	3.96	3.4	2.57	4.06	2.72

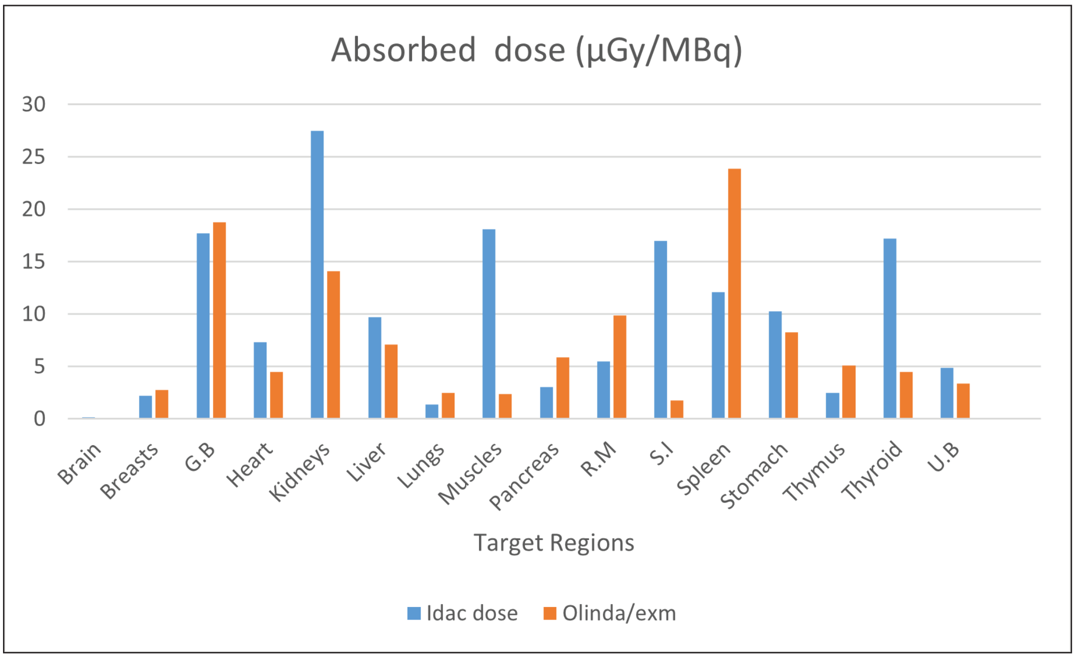

***Figure 2.** Absorbed dose comparison using Olinda/exm and Idac dose computer code.*

dose software and 13.3 to 25 µGy/MBq using Olinda code; similarly, the absorbed dose received by Pancreas is ranged from 15.8 to 20.8 µGy/MBq using Idac dose software and 7.38 to 12.6 µGy/MBq Olinda code, respectively. The absorbed dose received by the heart was 4.28 µGy/MBq to 8.53 using Idac dose software and 3.4 to 8.55 µGy/MBq.

The measured absorbed doses with Idac Dose software and Olinda software are within the recommended limits. The obtained results from randomly selected patients using both software show good agreement with ICRP 128 publication [21]. For clarity, the comparison of absorbed doses for selected patients from both software is shown in Figure 2.

Effective dose from Tc99m-MIBI: The effective dose coefficient (µSv/MBq) for all patients is estimated from Tc99m-MIBI activity using both software. Table 5 shows the effective doses using Idac dose and Olinda software. For clarity of the results the doses of selected patients obtained from both the software are shown in graphical order in Figure 3.

The mean measured effective dose to the selected patients undergoing myocardial perfusion from Idac Dose

Table 5. Effective dose for patients using both software.

Patients	Activity (MBq)	Effective dose (µSv/MBq) (IDAC DOSE)	Effective dose (µSv/MBq) (OLINDA/EXM)
1	990.13	5.8	4.67
2	975.11	6.72	6.85
3	970.15	7.8	6.37
4	820.50	6.55	5.53
5	986.76	7.6	5.99
6	982.11	7.28	5.96
7	919.40	5.90	5.08
8	828.29	6.2	4.09
9	940.80	7.14	6.07
10	916.16	5.8	4.65

software was 6.8 µSv/MBq in the range of 5.8 to 7.8 µSv/MBq. The mean measured effective dose of patients from Olinda software was 5.52 in the range of 4.09 to 6.85 µSv/MBq. These doses are comparable to ICRP-given data. The measured effective doses with both software are within the recommended limits.

The obtained mean effective dose from randomly selected patients using both the software show good agreement with the ICRP 128 publication (7.9 µSv/MBq at rest study). The difference between the patient's effective doses and absorbed doses of various organs with published data is due to the distribution of the radiopharmaceuticals in the various organs. The results obtained from Idac dose were higher as compared to Olinda software; however, the measured effective doses with both software's for selected patients were within the recommended limits. Figure 4

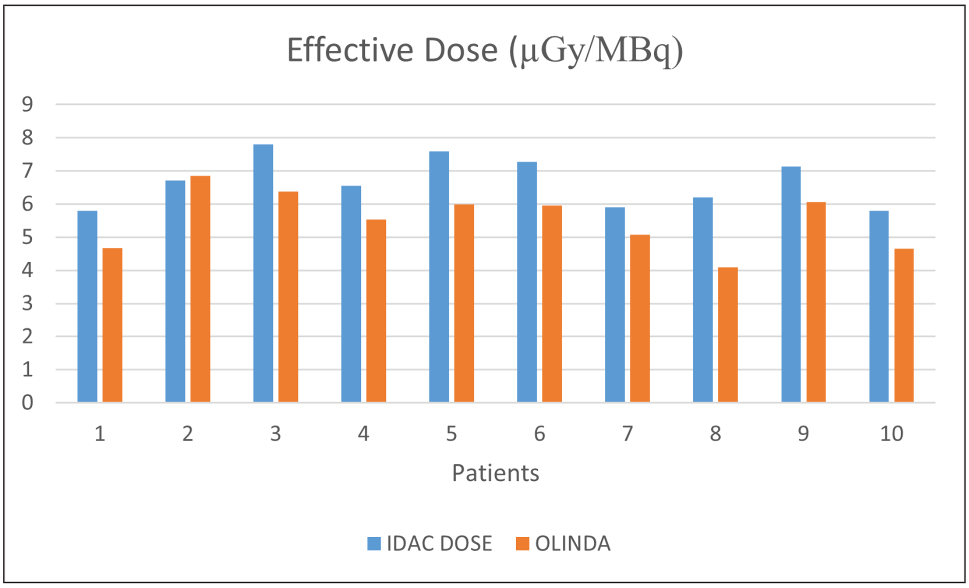

***Figure 3.** Effective dose for patients using both software.*

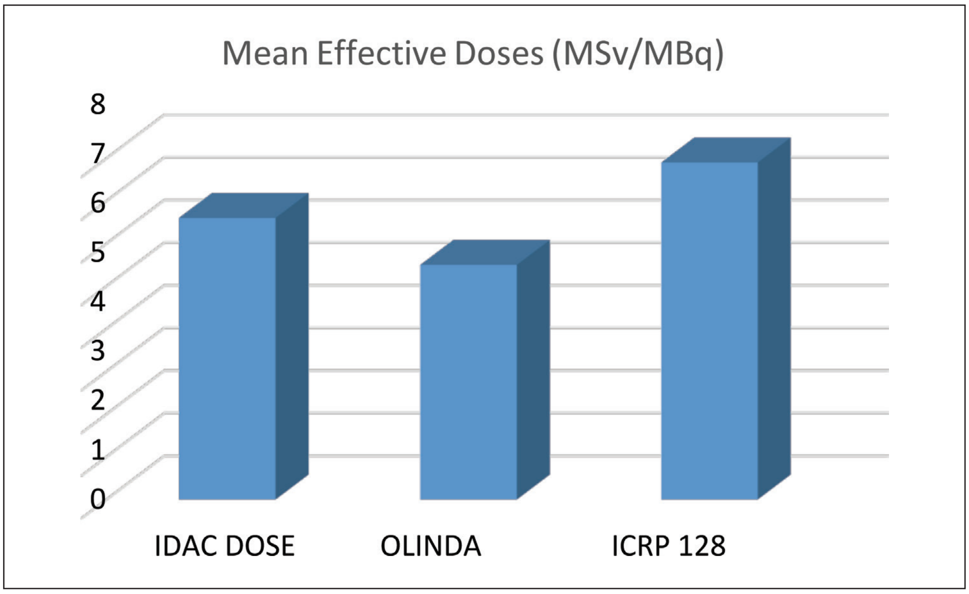

***Figure 4.** Mean effective doses between Idac-Dose, Olinda, and ICRP 128.*

represents the mean effective doses between both of software's and ICRP 128. The acceptable dose difference between ICRP 128 and both of the software is just because ICRP 128 uses Cristy and Eckerman phantom (organ masses) for organ doses [27] were not used in software.

Conclusion

The important condition of calculating absorbed dose from internally deposited radioisotopes is the measurement of the biodistribution of radiopharmaceuticals. Different models and methods have been developed for dose calculation but their accuracy is an important parameter in dosimetry. The more accurately the absorbed dose is estimated, and then, it would be possible to deliver the maximum prescribed dose to the tumor, while the minimum to the surrounding healthy tissues.

In the present study, biokinetic data were obtained from injected activity of Tc99m MIBI which is an important parameter to estimate the doses of selected patients. Ten randomly selected patients were planarly imaged using a dual head gamma camera after the administration of Tc99m MIBI activity. Two computer codes Olinda and Idac dose were used to estimate the absorbed doses to different organs of the body and effective doses to all selected patients. The obtained results from both the software were compared between each other and with ICRP publication 128. The result from both the codes shows a significant correlation and is within the recommended limits with ICRP dose guidelines. These results are considered key to greater accuracy in internal dose calculation very useful for physician knowledge, patients, education, and research studies. Absorbed doses for target organs were estimated with both computer codes and found comparable to published data. The difference between the patient's absorbed doses of various organs is due to the distribution of the radiopharmaceuticals in the various organs and it is also dependent upon the injected activity. However, the measured effective doses with both software's for selected patients were within the recommended limits [22]. The IDAC-Dose2.1 program is free software for research studies while Olinda software is widely accepted for dosimetry purposes.

Conflict of interests

The authors declare that there is no conflict of interest regarding the publication of this article.

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Consent for participate

Not applicable.

Ethical approval

Ethical committee of institute approved the current study.

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