Original article

An approach to develop a diagnostic reference level in gamma camera imaging for bone scan

Dilhani MNAK,[1] Vijitha R[1], Tudugala R[1]

[1]Department of Radiography and Radiotherapy, Faculty of Allied Health Sciences, General Sir John Kotelawala Defence University, Ratmalana, Sri Lanka

Article Information

Corresponding Author
MNAK Dilhani

Email: anjaleekaveesha@gmail.com

https://orcid.org/0009-0008-0746-5886

https://doi.org/10.4038/sljms1.v1i2.36

Received 08 November 2024
Revised version 01 February 2025
Accepted 10 February 2025

Conflicts of Interest: None

Abstract

Background: In a Gamma Camera Unit, bone scans are the most commonly performed imaging procedure. Diagnostic reference levels (DRLs) play a crucial role in optimizing radiation exposure for patients and staff, while maintaining high-quality diagnostic images.

Objective: The objective of this study is to optimize the patient radiation dose by establishing a DRL for gamma camera imaging for bone scan performed at two hospitals in Colombo, Sri Lanka.

Methods: A total of 134 imaging procedures were sourced and compiled from the hospital database for this study. 84 gamma camera imaging procedures were selected from Apeksha Hospital, Maharagama (Hospital No.1) and 50 procedures were selected from Asiri Surgical Hospital, Colombo (Hospital No.2), from September 2022 to November 2022. According to the recommendation of the International Commission of Radiological Protection (ICRP), the median value of the administered activity value was considered to develop DRL.

Results: The median values of the administered activity for the two hospitals were 587 MBq for Hospital No.1and 586 MBq for Hospital No.2. The developed DRL values for bone scan in gamma camera imaging are 587 MBq (15.865 mCi) for Hospital No.1 and 586 MBq (15.839 mCi) for Hospital No.2. There is a 0.026 mCi difference in administered activity observed between two institutes.

Conclusions: There were significant correlations observed between the administered activity and patient's body mass index, and between the administered activity and patient's clinical indication.

Keywords: gamma camera, diagnostic reference level, bone scan, administered activity

Cite this article as: Dilhani MNAK, *et al.* An approach to develop a diagnostic reference level in gamma camera imaging for bone scan. SLJMS 2024; 1(2): 71-78.

Introduction

The number of imaging procedures performed each year around the globe has significantly increased due to the revolutionary contributions of imaging technologies in diagnostic radiology and nuclear medicine.[1] Gamma camera imaging, also known as scintigraphy, is a popular diagnostic technique that uses radiotracers to see and examine the images of the human body by detecting gamma rays emitted from the injected or inhaled radionuclides. This technique is widely used in medical imaging to investigate the function and metabolism of organs, diagnose diseases and monitor the effectiveness of treatments. Imaging modalities in diagnostic radiology and nuclear medicine now enable the early identification of diseases like cancer, heart disease, and neurological disorders. Despite this advancement, the ionizing radiation used in these imaging techniques can pose risks to both patients and medical staff.

The International Commission on Radiological Protection (ICRP) introduced Diagnostic Reference Levels (DRLs) in 1996 to minimize dosage variability in clinical practice. A type of testing level called the DRL can be applied to a quantity that is straightforward to measure, often an absorbed dose in the air or in tissue equivalent material at the surface of a standard phantom or patient representative (ICRP 1996). The DRL can be used to protect patients from undue radiation exposure. This can be accomplished by encouraging the use of an optimal dose to obtain diagnostic images for specific procedures. In order to successfully implement DRLs in imaging procedures, dose monitoring should be undertaken on a regular basis and corrective measures should be taken if radiation doses persistently exceed the developed DRL values. In addition, all medical radiation specialists should be familiar with the concept of DRL and how to effectively implement it.[2,3]

DRLs are not specific to any patient, despite being derived from a thorough analysis and interpretation of exposure values received from several patients who were chosen based on local, national or regional criteria like age, gender and body weight. According to the ICRP's guidelines, the DRL is not always sufficient to maximize radiation protection. Therefore, in addition to concentrating on the optimization of radiation, a particular imaging modality also evaluates the diagnostic quality of the image. A particular DRL value for a particular imaging procedure guides us to make sure we use an optimized radiation level for imaging procedures while keeping the quality of the images.[4]

Optimization of radiation doses is very important in radiation medicine. The ICRP has been recommended to develop DRLs for all imaging facilities that use ionizing radiation especially for most radiological procedures.[5] Many countries have already established DRLs for their nuclear medicine facilities. There is no single study related to DRLs in nuclear medicine. Therefore, this study aims to develop a DRL in gamma camera imaging for bone scans which is mostly performed in nuclear medicine with gamma cameras.

Methodology

This study was an observational analytical study conducted at two hospitals: Apeksha Hospital, Maharagama, Sri Lanka and Asiri Surgical Hospital, Colombo, Sri Lanka. Only gamma camera imaging procedures were selected for a period of three months starting from September 2022 to November 2022. A total of 84 imaging procedures were selected from Apeksha Hospital, Maharagama (Hospital No.1) and 50 imaging procedures were selected from Asiri Surgical Hospital, Colombo (Hospital No.2). Patients aged between 20 and 80 years and the weight less than 100 kg were included in this study. The patients with repeated scans, reported claustrophobia and uncompleted imaging procedures were excluded from this study.

Since all the data were retrieved from stored data, the Ethical Review Committee of the Faculty of Medicine at General Sir John Kotelawala Defence University waived the need for ethical approval. The permissions were obtained from the directors and the relevant authorities of the respective hospitals to conduct this study. The gamma camera imaging procedures which were performed according to the guidelines of the National Council on Radiation Protection and Measurements (NCRP) were considered in this study. The study was not directly involved with the patients, but the relevant details of the patient such as age, weight, height, clinical indication and administered activity were collected from the Bedhead Ticket (BHT) and the data base of the relevant procedure. ^{99m}Tc radioisotope was used in these imaging procedures.

Data obtained from the study was statistically analyzed using authoritative software, SPSS (version 18). The DRLs were analyzed using the descriptive statistical data gathered from each patient. The normality of the data was checked. The correlations between administered activity with the patient's BMI, administered activity and clinical indication were analyzed by the Pearson correlation test.

Results

This study only included whole-body bone scan procedures carried out in the gamma camera imaging unit between September 2022 and November 2022, using data gathered from Apeksha Hospital. A total of 84 imaging procedures were selected. Looking at the patients' ages in each relevant gamma camera imaging procedure, the mean value is reported as 57.73 years, and the maximum and minimum ages are 77 years, and 29 years, respectively. In addition, the mean value of the patient's weight is reported as 59.94 kg, and the maximum and minimum weights are 100 kg, and 35 kg, respectively. The sum of administered activity is reported as 49142 MBq and the mean value is 585 MBq. The median administered activity value, 587 MBq (15.865 mCi) is taken as the developed DRL for Hospital No.01 according to the ICRP recommendation.

The correlation matrix for age, weight, height, BMI and administered activity is shown in Table 2.

The Pearson correlation coefficient between BMI and administered activity is 0.51, indicating a strong positive correlation between the two variables. (Figure 1).

The relationship between the administered activity and clinical indication is shown in Table 3. The patients with breast metastasis have consistent highest dose. The highest value of administered activity for the 95th percentile (670 MBq) and 75th percentile (620 MBq) was obtained for CA prostate patients at Apeksha Hospital.

Looking at the collected data from Asiri Surgical Hospital, Colombo, Sri Lanka, 50 whole-body bone scan procedures were gathered during the period from September 2022 to November 2022 for this study. The mean value of age is 67.28 years, and the maximum and minimum ages are 86 years and 42 years, respectively.

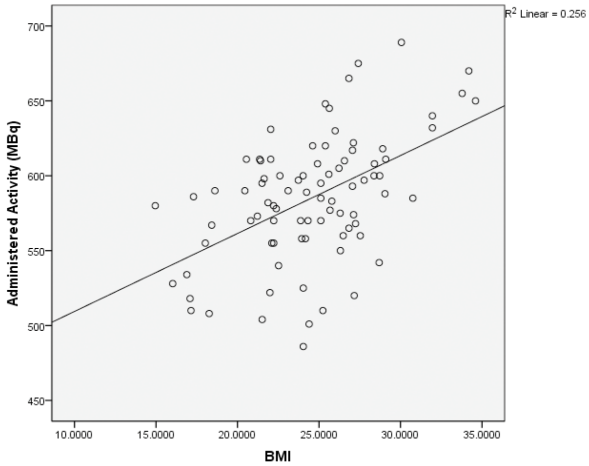

Figure 1. Scatter plot of administered activity against patient BMI for Hospital No. 01.

Table 1. Descriptive statistics for the gamma camera procedures in Hospital No.01

Statistical Metric		*Age (Y)*	*Weight (kg)*	*Height (m)*	*BMI (kg/m²)*	*Administered Activity (MBq)*
Mean		57.73	59.94	1.56	24.53	585.02
Median		58.00	60.00	1.55	24.76	587.00
Mode		58.00	60.00	1.48	25.11	570.00
Std. Deviation		11.08	11.23	.07	4.11	42.21
Variance		122.73	126.13	.01	16.85	1781.30
Range		48.00	65.00	.33	19.65	203.00
Minimum		29.00	35.00	1.41	14.95	486.00
Maximum		77.00	100.00	1.74	34.60	689.00
Sum		4849.00	5035.00	131.25	2060.33	49142.00
Percentiles	25.00	49.25	53.25	1.50	22.00	560.00
	50.00	58.00	60.00	1.55	24.76	587.00
	75.00	65.75	67.00	1.61	27.10	610.75

Table 2. Correlation matrix for all parameters of data collected from Hospital No.01

		Age (Y)	*Weight (kg)*	*Height (m)*	*BMI (kg/m²)*	*Administered Activity (MBq)*
Age (Y)	Pearson Correlation	1.00	0.11	0.05	0.10	0.12
	Significant. (2-tailed)		0.33	0.63	0.37	0.26
	N	84.00	84.00	84.00	84.00	84.00
Weight (kg)	Pearson Correlation	0.11	1.00	0.45**	0.85**	0.56**
	Significant. (2-tailed)	0.33		0.00	0.00	0.00
	N	84.00	84.00	84.00	84.00	84.00
Height (m)	Pearson Correlation	0.05	0.45**	1.00	-0.08	0.20
	Significant. (2-tailed)	0.63	0.00		0.47	0.07
	N	84.00	84.00	84.00	84.00	84.00
BMI	Pearson Correlation	0.10	0.85**	-0.08	1.00	0.51**
	Significant. (2-tailed)	0.37	0.00	0.47		0.00
	N	84.00	84.00	84.00	84.00	84.00
Administered Activity (MBq)	Pearson Correlation	0.12	0.56**	0.20	0.51**	1.00
	Significant. (2-tailed)	0.26	0.00	0.07	0.00	
	N	84.00	84.00	84.00	84.00	84.00

** Correlation is significant at the 0.01 level (2-tailed).

Table 3. The relationship between the administered activity and clinical indication in Hospital No.01

	Administered Activity (MBq)							
Clinical Indication	*Mean*	*Median*	*Minimum*	*Maximum*	*Standard Deviation*	*Percentile 25*	*Percentile 75*	*Percentile 95*
CA Bowel	542	542	542	542	.	542	542	542
CA Breast	580	580	501	675	40	555	605	648
CA Breast (mets)	670	670	670	670	.	670	670	670
CA L/LL	486	486	486	486	.	486	486	486
CA Prostate	601	601	504	689	38	584	620	670
CA R/Femur	617	617	617	617	.	617	617	617
CA Renal	585	585	585	585	.	585	585	585
Multiple lytic lesions in spine	570	570	570	570	.	570	570	570
RCC	586	558	534	665	70	534	665	665

CA – Carcinoma, L/LL – Left Lower Lobe, RCC – Renal Cell Carcinoma

The mean value of weight is 66.08 kg, and the maximum and minimum weights are 85 kg and 51 kg, respectively. The sum of the administered activity is 29799 MBq, the median value is reported as 586 MBq, and the mean administered activity is 595.98 MBq. The median value of the administered activity of 586 MBq (15.839 mCi) is taken as the developed DRL for Hospital No.02 according to the ICRP recommendation (Table 4).

The correlation matrix for age, weight, height, BMI and administered activity is shown in Table 5. The Pearson's correlation coefficient between BMI and administered activity is 0.193. There was no significant relationship between BMI and administered activity. (Figure 2).

The relationship between the administered activity and clinical indication for the collected data from Hospital 02 is shown in Table 6. During this study period, only CA breast and CA prostate patients underwent gamma camera imaging procedures. The highest administered activity was obtained in CA prostate patients.

Finally, the administered activity at the two hospitals was compared using the Mann Whitney test. If P value is <0.05, the difference between the two medians is statistically significant. The calculated (2 tailed) P value is 0.35. There is no significant difference between two hospitals on administered activity (Table 7).

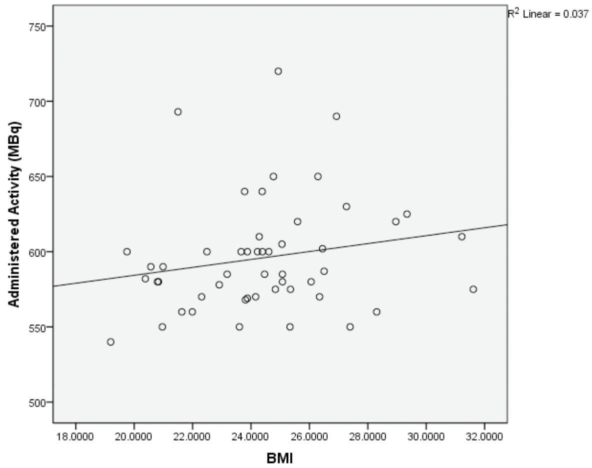

Figure 2. Scatter plot of administered activity against patient BMI for Hospital No.02.

Table 4. Descriptive statistics for gamma camera procedures in Hospital No.02

Statistical Metric		*Age (Y)*	*Weight (kg)*	*Height (m)*	*BMI (kg/m²)*	*Administered Activity (MBq)*
Mean		67.28	66.08	1.65	24.43	595.98
Median		69.00	67.00	1.65	24.39	586.00
Mode		72.00	65.00[a]	1.70	23.88	600.00
Standard Deviation		10.77	7.42	.09	2.75	37.66
Variance		115.96	55.05	.01	7.58	1418.51
Range		44.00	34.00	.40	12.42	180.00
Minimum		42.00	51.00	1.43	19.20	540.00
Maximum		86.00	85.00	1.83	31.61	720.00
Sum		3364.00	3304.00	82.35	1221.31	29799.00
Percentiles	25	59.75	61.00	1.61	22.45	570.00
	50	69.00	67.00	1.65	24.39	586.00
	75	74.25	70.25	1.71	26.12	610.00

Table 5. Correlation matrix for all parameters of data collected from Hospital No.02

		Age (Y)	*Weight (kg)*	*Height (m)*	*BMI (kg/m^2)*	*Administered Activity (MBq)*
Age (Y)	Pearson Correlation	1.00	0.07	0.24	-0.16	0.13
	Significant. (2-tailed)		0.62	0.09	0.25	0.38
	N	50.00	50.00	50.00	50.00	50.00
Weight (kg)	Pearson Correlation	0.07	1.00	0.50**	0.53**	0.56**
	Significant. (2-tailed)	0.62		0.00	0.00	0.00
	N	50.00	50.00	50.00	50.00	50.00
Height (m)	Pearson Correlation	0.24	0.50**	1.00	-0.47**	0.39**
	Significant. (2-tailed)	0.09	0.00		0.00	0.01
	N	50.00	50.00	50.00	50.00	50.00
BMI	Pearson Correlation	-0.16	0.53**	-0.47**	1.00	0.19
	Significant. (2-tailed)	0.25	0.00	0.00		0.18
	N	50.00	50.00	50.00	50.00	50.00
Administered Activity (MBq)	Pearson Correlation	0.13	0.56**	0.39**	0.19	1.00
	Significant. (2-tailed)	0.38	0.00	0.01	0.18	
	N	50.00	50.00	50.00	50.00	50.00

** Correlation is significant at the 0.01 level (2-tailed).

Table 6. The relationship between the administered activity and clinical indication in Hospital No.02.

	Administered Activity (MBq)							
Clinical Indication	*Mean*	*Median*	*Minimum*	*Maximum*	*Standard Deviation*	*Percentile 25*	*Percentile 75*	*Percentile 95*
CA Breast	586	575	550	650	33	560	610	650
CA Prostate	603	600	540	720	40	580	605	693

Table 7. Descriptive statistics for administered activities in both hospitals

	Administered Activity (MBq)								
Hospital No	*Count*	*Mean*	*Median*	*Mode*	*Maximum*	*Minimum*	*Percentile 25*	*Percentile 75*	*Percentile 95*
1	84.00	585.02	587.00	570.00	689.00	486.00	560.00	610.50	655.00
2	50.00	595.98	586.00	600.00	720.00	540.00	570.00	610.00	690.00

Discussion

In medical imaging, DRLs are essential for the determination of whether radiation doses given to patients are appropriate or how much radiopharmaceuticals are used during specific radiological procedures. These standards serve as means of determining if the dosage is within acceptable bounds or departs noticeably from the standard. DRLs are essentially quantitative markers that make it easier to identify situations in which the radiation dose or radiopharmaceutical quantity is higher than or lower than expected for standard medical imaging procedures. As such, their function in optimizing radiation exposure and guaranteeing patient safety in clinical settings is crucial.[4] The objective of this study is to develop a DRL value for a whole-body scan in gamma imaging. The ICRP recommended quantity for the gamma camera imaging procedures is administered activity. In this study, two institutes with gamma camera facilities were considered. The pre-injected dose (administered activity) of radiopharmaceuticals has a mean of 585.02 MBq and a median of 587 MBq. The values are ranged from 486 MBq to 689 MBq while the 25th percentile is 560 MBq and 75th percentile is 610 MBq. According to the range of this administrative activity, the median value of 587 MBq is set as the developed DRL for administered activity at Apeksha Hospital, Maharagama, Sri Lanka. When looking at Asiri Surgical Hospital, Colombo, Sri Lanka, the pre-injected dose of radiopharmaceuticals has a mean of 595.98 MBq and a median of 586 MBq. The values range from 540 MBq to 720 MBq while the 25th percentile is 570 MBq and 75th percentile is 610 MBq. According to the range of this administrative activity, the median value of 587 MBq is set as the developed DRL for administered activity. Meanwhile this study has also identified that there is a significant correlation between the administered activity and patient's BMI for Hospital No.1 but no significant correlation was found for Hospital No.2.

In 2019 the Achievable Administered activities have published for non-cardiac nuclear medicine studies and DRLs for positron emission tomography, PET/CT and gamma camera. Three years of survey, from January 1, 2015 to December 31, 2017 was conducted. They collected data from 3,135 distinct facilities across 13 different diagnostic examinations and radiopharmaceutical combinations. The frequency distribution for ^{99m}Tc-HDP/MDP whole-body bone scans shows two separate superimposed bell-shaped curves. The lower curve is centered around 777 MBq, while the higher curve is centered around 962 MBq. According to their study, DRL was reported as 988 MBq for whole body bone scan.[1]

According to the data were gathered from 33 Austrian hospitals equipped with nuclear medicine (NUC) technology. Of these hospitals, data were reported for 60 SPECT devices, 21 PET/CT devices, and 23 scintigraphy devices.[6]

The median value of DRL was reported as 663 MBq. 3rd quartile of the activity was 727 MBq and the values ranged from 402 MBq to 985 MBq. Compared with these studies, our study shows less DRL value.

In order to develop DRLs for each hospital, the median value of administered activity value was selected according to the ICRP recommendations.[12] The median value of administered activity was considered to develop DRL value because it does not depend on the outliers of the data. The DRL values can vary from place to place, for example between hospitals or between countries. In the Sri Lankan context, there is no single study about DRLs in nuclear medicine to compare with the current study. This study is an initiative towards developing DRLs in nuclear medicine in Sri Lanka.

Conclusion

The DRL values were calculated successfully for the gamma camera units in two hospitals with the use of measured administered activity values associated with gamma camera imaging procedures performed in those hospitals. The two DRL values obtained were 587 MBq and 586 MBq, respectively for hospital 01 and hospital 02. Meanwhile this study has also concluded that there is a significant correlation between the administered activity and patients' BMI for Hospital No.1 and no significant correlation was found for Hospital No.2.

The data collection period was a limitation factor encountered due to the workload. However, future work will address this limitation. Consequently, this study serves as a valuable first step towards establishing a national DRL. This institutional DRL can be utilized as a dose optimization tool, ensuring optimal diagnostic quality during gamma camera imaging procedures. Additionally, the next phase of this study will encompass all nuclear imaging procedures to develop national DRLs for nuclear medicine in Sri Lanka.

Author contributions

All authors equally contributed to the study.

References

1. Becker MD, Butler PF, Siam M, Gress DA, Ghesani M, Harkness BA, Yoo DC, Oates ME. US PET/CT and gamma camera diagnostic reference levels and achievable administered activities for noncardiac nuclear medicine studies. *Radiology.* 2019; **293**(1): 203-11.

2. Hwang JY, Choi YH, Yoon HM, Ryu YJ, Shin HJ, Kim HG, Lee SM, You SK, Park JE. Establishment of local diagnostic reference levels of pediatric abdominopelvic and chest CT examinations based on the body weight and size in Korea. *Korean Journal of Radiology*. 2021; **22**(7): 1172.

3. Wulandari PI, Talumantak KB, Iffah M, Ryangga D, Ariwidiastuti CI. Diagnostic reference levels: a review. *J. Med. Sci. Clin. Res*. 2018; **6**: 508-14.

4. Ramanathan V, Senarathna HS, Gunaratna HU, Bandara PM, Horadigala CJ. Establishment of institutional diagnostic reference level for coronary angiography procedures in Sri Lanka. *Radiation Protection Dosimetry.* 2023; **199**(19): 2311-7.

5. Abe K, Hosono M, Igarashi T, Iimori T, Ishiguro M, Ito T, Nagahata T, Tsushima H, Watanabe H. The 2020 national diagnostic reference levels for nuclear medicine in Japan. *Annals of Nuclear Medicine.* 2020; **34**: 799-806.

6. Wachabauer D, Beyer T, Ditto M, Gallowitsch HJ, Hinterreiter M, Ibi B, Malle P, Mirzaei S, Smetana F, Staudenherz A, Warwitz B. Diagnostic reference levels for nuclear medicine imaging in Austria: a nationwide survey of used dose levels for adult patients. *Zeitschrift für Medizinische Physik.* 2022; **32**(3): 283-95.

7. Bebbington NA, Haddock BT, Bertilsson H, Hippeläinen E, Husby EM, Tunninen VI, Söderberg M. A Nordic survey of CT doses in hybrid PET/CT and SPECT/CT examinations. *EJNMMI Physics.* 2019; **6**(1): 24.

8. Becker MD, Butler PF, Bhargavan-Chatfield M, Harkness BA, Metter D, MacFarlane CR, Ghesani M, Wilcox P, Oates ME. Adult gamma camera myocardial perfusion imaging: diagnostic reference levels and achievable administered activities derived from ACR accreditation data. *Journal of the American College of Radiology* 2016; **13**(6): 688-95.

9. Botwe BO, Schandorf C, Inkoom S, Faanu A, Rolstadaas L, Goa PE. National indication-based diagnostic reference level values in computed tomography: Preliminary results from Ghana. *Physica Medica.* 2021; **84**: 274-84.

10. Masoomi M, Al-Shammeri I, Al-Kandari L, Elrahman H, Al-Shammeri J. National Diagnostic Reference Level (DRL) for nuclear medicine computed tomography-positron emission tomography hybrid imaging studies for kuwait population: second phase dose audit-2019. *BJR| Open.* 2021; **3**(1): 20210020.

11. Tulik M, Tulik P, Kowalska T. On the optimization of bone SPECT/CT in terms of image quality and radiation dose. *Journal of Applied Clinical Medical Physics.* 2020; **21**(11): 237-46.

12. https://www.icrp.org/docs/ICRP%202017%20Annual%20Report.pdf