Open Journal of Radiology, 2022, 12, 155-162
https://www.scirp.org/journal/ojrad
ISSN Online: 2164-3032
ISSN Print: 2164-3024

Assessment of Patient and Staff Annual Effective Doses at a Nuclear Medicine Department during Bone Scans

Essam H. Mattar

Department of Radiological Sciences, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia
Email: emattar@ksu.edu.sa

How to cite this paper: Mattar, E.H. (2022) Assessment of Patient and Staff Annual Effective Doses at a Nuclear Medicine Department during Bone Scans. *Open Journal of Radiology*, **12**, 155-162.
https://doi.org/10.4236/ojrad.2022.124016

Received: September 6, 2022
Accepted: November 7, 2022
Published: November 10, 2022

Copyright © 2022 by author(s) and Scientific Research Publishing Inc.
This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).
http://creativecommons.org/licenses/by/4.0/
Open Access

Abstract

The current research aims to assess the staff and patients' effective doses during Nuclear medicine (NM) bone scans procedures. The administered activity was utilized to quantify the patients' effective doses, while personnel's effective doses were quantified using thermoluminescent detectors (TLD-100). The average administered activity was 650 (440 to 1440) MBq procedures using SPECT gamma camera system. The average annual staff effective dose (mSv) was estimated to be 2.3 (0.1 to 4.9). The typical patient's effective dose was 4.9 (3.6 to 6.0) mSv per procedure. Staff exposure within the yearly effective dose limits. Patients' exposure optimization is required based on patient weight. Estimating staff eye lens doses is suggested to confirm that the yearly effective radiation doses are within the safety range.

Keywords

Staff Exposure, Patient Dosimetry, Nuclear Medicine, Radiology

1. Introduction

Radioisotopes are used in nuclear medicine (NM) to diagnose conditions affecting a patient's particular organs, stage diseases, and tissues or to treat them simultaneously (theranostic). Radioisotope-based diagnostic methods are becoming commonplace [1]. As well as being employed in pre-clinical medicine, it is also used in basic sciences like biology and drug development. The yearly number of NM procedures exceeds 40.0 million, with 65% performed for oncology-related aspects, and the demand for radioisotopes is rising at a rate of up to 5% [2]. A radioactive amount is administered to the patient when utilizing radiopharmaceuticals for diagnostic purposes, and the radioactivity in the organ may then be analyzed as either a 2D or a 3D image. 99mTc, which is utilized in around 80% of all NM examinations, is the radionuclide that's often used in medical imaging [2] [3]. The 99mTc, a synthetic element, has practically perfect properties for NM imaging. The reasonable half-life (t/2) = 6 hours, isomeric decay, and reasonable energy (140 keV) [1].

Scintigraphy, or bone imaging using radionuclides, is a diagnosing process utilized to analyze bone disorders and malignant metastasis throughout the body to detect the spread of cancer, pathological disorders, or to measure how well a patient is responding to therapy. Of all the radioactive imaging techniques, a bone scan is one of the ones that is done the most frequently. Bone imaging with a radionuclide is a rapid, reasonably appraised diagnostic examination employed in assessing several pathologic diseases and is generally accessible in many imaging facilities. Although radiation is not evenly distributed globally, the number of diagnostic nuclear medicine exams yearly is rising [3] [4] [5]. For most NM examinations, the mean effective dose per NM examination ranges from 0.3 to 20.0 mSv [6]-[13]. The development of the 99Mo/99mTc generating set and γ-camera in the 1950s allowed for the performance of bone scanning techniques by clinicians [14] (Stefanofic, 2001). The primary sources of the collective dose in diagnostic nuclear medicine procedures are the 99mTc bone scan, ^{201}TL cardiovascular investigations, and iodine thyroid scans [1]. 99mTc methylene diphosphonate (MDP) is the primary substance utilized for bone scanning. MDP flows in the bloodstream for two to three hours after intravenous (IV) administration preceding entire body scanning [15]. Bone scintigraphy has a vital role in the diagnosis of calcaneus fractures (CF) [16]. The average effective dose per bone scan procedure, according to Ali *et al.*, was 4.2 mSv [8] [9]. The researchers reported that the patient's body weight had no bearing on the given activity. Due to the significant amount of given activity, patients were exposed to harmful radiation levels. The practice and patient safety must be improved by establishing operational standards [9]. NM involves handling radioactive substances that can expose staff to radiation both internally and externally as a result of radiopharmaceutical elusions and preparation in specially protected laboratory (hot lab). The staff was also exposed to ionizing radiation for the period of administering 99mTc to patients and after the scanning that poses radiogenic hazard for NM personnel [6] [7] [8] [9]. Therefore, depending on workload and procedure approach, areas of the body not covered with the leaded apron might be exposed to unavoidable exposure resulted from ionizing radiation sources. According to reports, staff members may receive a wide range of effective doses ranging from 1.0 to 19.0 mSv yearly [8] [10] [17] [18]. The level of exposure is determined by the radionuclide, its activity, and the sort of job that the individual doses within the department [7]. The international commission on radiological protection (ICRP) has reduced the yearly dose limit for the lens of the eye for occupational exposures (ICRP, 2011) to 20.0 mSv from the previous value (150.0 mSv), thus it is critical to assess its influence on the current radiation protection and safety programs. Because open radiation sources are used in NM, radiation shielding is a problem.

Additionally, UNSCEAR, encouraged member states to provide data regarding patients and staff exposure due to the lack of reported values [1]. Limited studies were reported regarding occupational exposure during nuclear medicine examination in Saudi Arabia [10] [17]. The prior investigations revealed significant dosage variability due to variations in scanning methodology, perception methods, and NM technologist expertise. This main objective of this research is to assess the effective doses that patients and staff received during bone scan scintigraphy examinations.

2. Materials and Methods

This study quantified patients and occupational exposure for 100 bone scan procedures and three NM technologists. Before the scan, individuals can be requested to take off any jewelry, metal accessories, or other items from their bodies. The patient is given a 5.0 mCi injection of 99mTc-methyl diphosphonate (MDP) into the vein three hours before data gathering is started. Patients are encouraged to stay hydrated and told to drink 0.5 to 1 liter of water between the time of the injection and the delayed imaging. After scanning, patients are instructed to limit their time in public to six hours.

2.1. Radiopharmaceutical Administration

The standard dose for patients undergoing whole-body bone scan procedures is five mCi. 99mTc is eluted for Mo/Tc generator in an evacuated sterile vile with known volumes of 5 or 9 ml, which are available. MDP pharmaceutical is mixed with the eluted 99mTc after measuring the dose using a multidose calibrator. The multidose vial is well sealed to prevent air from entering. Oxidation can happen to 99mTc-MDP radiopharmaceuticals. The radiopharmaceutical is tested for quality before being administered, and dosages are precisely determined.

2.2. Imaging Protocol

Photons are distributed evenly over the detector. The patient for this study was positioned in the center of the single-head gamma camera, lying above the couch. The data were acquired while the patient was in this position for 15 minutes, followed by 15 minutes in the prone position, for the front and back scans of the skeletal system, at a scan speed of 17 cm per min, and 190 cm scan length.

2.3. Occupational Dosimetry

During 100 bone scan exams, the occupational dose was quantified for three NM technologist. The NM exams were clinically indicated for bone metastases brought on by prostate and breast cancer. This investigation utilized 45 thermoluminescence dosimeters (TLD-100) (LiF: Mg, Ti). The TL signals were registered from

150˚C to 265˚C with a rate of heating 10˚C/s.

3. Results and Discussion

Skeletal scintigraphy or bone scan procedures are NM departments' most common imaging procedures. Thus evaluation of the patient's doses for the NM personnel is essential in evaluating the protection measures and the projected radiation risks. **Table 1** shows the average and diversity of patients' age (years), effective radiation dose (mSv), and administered radiopharmaceutical activity (MBq) per procedure. Whereas the average administered, activity was 750 (440 to 1400) MBq The average administered activity is Previous studies reported the administered activity during bone imaging (MBq) of 99mTc-MDP routinely changes amid 740.0 to 1110.0, with scanning classically executed during two to five hours after intravenous administration of the radiopharmaceutical [8] [9]. The typical dose for a skeletal scanning determined by the amount of the injected radioactivity, radioactive element and the duration contact time with the patient. **Figure 1** showed a comparison of patients' doses during the bone scan with research findings reported formerly [18] [19] [20]. The variation in patient dose was attributed to the variation in patient weight since the administered activity in all departments was based on the standard formula. The average annual staff effective dose was estimated to be 2.3 mSv, ranging from 0.1 to 4.9 mSv. NM technicians received external doses mostly from radioactive patients rather than from making and injecting radiopharmaceuticals [21]. According to the International Atomic Energy Agency (IAEA), exposed personnel in NM facilities should get an average yearly effective dose (mSv) between three to five and 5.0 mSv [22]. The typical dosage for a scan was based on the amount of patient contact necessary in addition to the delivered activity and isotope. Any diagnostic examination requiring ionizing radiation must be justified and carried out to yield the required diagnostic data for the lowest practical radiation dosage (and, thus, the lowest risk) to the patient, personnel, and general public [19].

Technologists received higher radiation doses than other nuclear medicine department workers. The more extended period spent with the technician by the patient with administered activity both before and during the scanning operation may cause greater dosages. A similar conclusion has been made in the past, namely that patients with administered radioactivity, as contrasted to the preparation and administration of radioisotopes, are the primary source of external doses for NM technologists [23]-[28]. Compared with previously published studies, it seemed unlikely that the staff's yearly dosages would go beyond the limit. Since staff processed radioisotopes, examined patients and managed the gamma camera, technicians made up the most prominent professional category exposed to ionizing radiation in the NM department (19.0 mSv), according to previously published studies [24] [29] [30]. Previous findings indisputably demonstrate that the workload and protective equipment affect the staff dosage for technologists (leaded glasses aprons) (**Figure 2**).

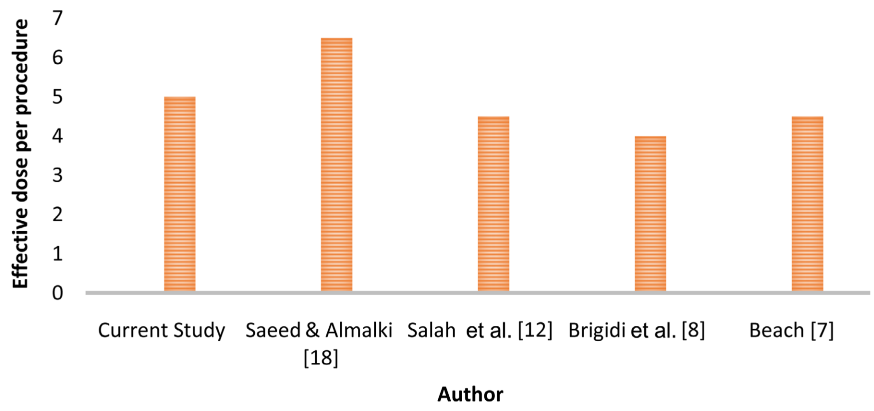

Figure 1. Comparing patients' effective dosages to investigations that have already been published.

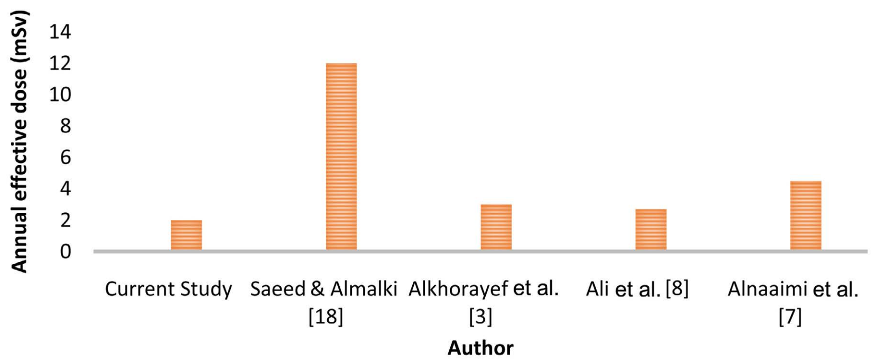

Figure 2. Annual effective dose (mSv) at nuclear medicine department in comparison with previously published studies.

Table 1. Patients demographic data (age and weight), administered activity.

Procedure	No of Patients	Age (yrs)	Weight (kg)	Injected activity (Mbq)	Patient effective dose (mSv)
Bone scan	100	53 (17 - 80)	64 (29 - 110)	650 (440 - 1400)	4.9 (3.6 - 6.0)

4. Conclusion

Patients received a radiation dosage that was equivalent to that in earlier investigations. The variation of patient doses during skeletal scans with 99mTc is due to variation in patient weight. The majority of the NM departments use a comparable amount of radioactivity. Since all procedures were carried out for justified clinical indications and referred by a competent physician, optimizing scan parameters is a necessary to sustain minimal doses. The staff's annual exposure is well below the recommended level. Eye lens measurement is recommended to protect the lens against cumulative doses from ionizing radiation. Effective dose reduction methodologies include using leaded shields, increasing distance, minimizing patient contact time after injection, and reducing workload. Staff are required to conform to radiological protection procedures to assure safety against radiogenic hazards. Staff eye lens dose monitoring is recommended to assure that the annual equivalent dose within the dose limits.

Acknowledgements

The author would like to extend his sincere appreciation to the Researchers Supporting Program at King Saud University, Riyadh, Saudi Arabia, for funding this work under the project number (RSP2022R210).

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (2011) Report of the United Nation Scientific Committee on the Effect of Atomic Radiation. United Nations, New York.

[2] European Commission (2021) Staff Working Document on a Strategic Agenda for Medical Ionising Radiation Applications (SAMIRA). European Commission, Brussels.

[3] IAEA (2015) Feasibility of Producing Molybdenum-99 on a Small Scale Using Fission of Low Enriched Uranium or Neutron Activation of Natural Molybdenum. Technical Reports Series No. 478, International Atomic Energy Agency, Vienna.

[4] Edam, A.I., Sulieman, A., Tamam, N., Abuelhaia, E., Salih, I., Sam, A.K., Yousef, M., Alkhorayef, M., and Bradley, D.A. (2021) Current Sudan Protective Practice in Diagnostic Nuclear Medicine and Patient Dose. *Radiation Physics and Chemistry*, **178**, Article No. 108997. https://doi.org/10.1016/j.radphyschem.2020.108997

[5] Guira, O., Ouédraogo, A., Zoungrana, L., Bognounou, R., Traoré, S., Tondé, A. and Drabo, J. (2020) Quality of Diabetes Annual Management in the Internal Medicine Department in Yalgado Ouédraogo Teaching Hospital, Ouagadougou. *Open Journal of Internal Medicine*, **10**, 256-262. https://doi.org/10.4236/ojim.2020.103027

[6] Alnaaimi, M., Sulieman, A., Tamam, N., Alkhorayef, M., Alduaij, M., Mohammedzein, T., Alomair, O.I., Alashban, Y., Salah, H., Abd-Elghany, A.A., Omer, H., and Bradley, D.A. (2021) Estimation of Patient Effective Doses in PET/CT-^{18}F-Sodium Fluoride Examinations. *Applied Radiation and Isotopes*, **178**, Article No. 109965. https://doi.org/10.1016/j.apradiso.2021.109965

[7] Alnaaimi, M., Alkhorayef, M., Omar, M., Abughaith, N., Alduaij, M., Salahudin, T., Alkandri, F., Sulieman, A. and Bradley, D.A. (2017) Occupational Radiation Exposure in Nuclear Medicine Department in Kuwait. *Radiation Physics and Chemistry*, **140**, 233-236. https://doi.org/10.1016/j.radphyschem.2017.02.048

[8] Ali, W., Sulieman, A., Tamam, N., Boshara, N.A., Aldhebaib, A., Alkhorayef, M., Khandaker, M.U. and Bradley, D.A. (2021) Estimation of Patients Organ Doses and Staff Exposure during Bone Scan Examination. *Radiation Physics and Chemistry*, **188**, Article No. 109693. https://doi.org/10.1016/j.radphyschem.2021.109693

[9] Ali, W.M., Sulieman, A., Salah, H., Almohammed, H.I., Alkhorayef, M. and Bradley, D.A. (2021) Short-Term Retention of ^{99m}Tc Activity in Bone Scintigraphy. *Radiation Physics and Chemistry*, **178**, Article No. 108907. https://doi.org/10.1016/j.radphyschem.2020.108907

[10] Alkhorayef, M., Sulieman, A., Mohamed-Ahmed, M., Al-Mohammed, H.I., Alkhomashi, N., Sam, A.K. and Bradley, D.A. (2018) Staff and Ambient Radiation Dose Resulting from Therapeutic Nuclear Medicine Procedures. *Applied Radiation and Isotopes*, **141**, 270-274. https://doi.org/10.1016/j.apradiso.2018.07.014

[11] Edam, A.I., Sulieman, A., Sam, A.K., Salih, I., Alkhorayef, M. and Bradley, D.A. (2020) Quality Control of Radiopharmaceuticals and Diagnostic Nuclear Medicine Equipment. *Radiation Physics and Chemistry*, **167**, Article No. 108247. https://doi.org/10.1016/j.radphyschem.2019.03.051

[12] Salah, H., *et al.* (2019) Effective Radiation Dose Evaluation in Nuclear Medicine Examination. *International Research Journal of Public and Environmental Health*, **6**, 97-104.

[13] Mettler Jr., F.A., Mahesh, M., Bhargavan-Chatfield, M., Chambers, C.E., Elee, J.G., Frush, D.P., Miller, D.L., Royal, H.D., Milano, M.T., Spelic, D.C., Ansari, A.J., Bolch, W.E., Guebert, G.M., Sherrier, R.H., Smith, J.M. and Vetter, R.J. (2020) Patient Exposure from Radiologic and Nuclear Medicine Procedures in the United States: Procedure Volume and Effective Dose for the Period 2006-2016. *Radiology*, **295**, 418-427. https://doi.org/10.1148/radiol.2020192256

[14] Stefanović, L. (2001) Poceci i razvoj vizualizacione dijagnostike u nuklearnoj medicini. (The Beginnings and Development of Diagnostic Imaging in Nuclear Medicine.) *Medicinski Pregled*, **54**, 289-296.

[15] Bombardieri, E., Aktolun, C., Baum, R.P., Bishof-Delaloye, A., Buscombe, J., Chatal, J.F., Maffioli, L., Moncayo, R., Morteímans, L. and Reske, S.N. (2003) Bone Scintigraphy: Procedure Guidelines for Tumour Imaging. *European Journal of Nuclear Medicine and Molecular Imaging*, **30**, B99-B106. https://doi.org/10.1007/s00259-003-1347-2

[16] Bathily, E., Ndong, B., Diop, O., Djigo, M., Gueye, K., Kokou, A., Thiaw, G., Mbaye, G., Diouf, L., Soumboundou, M., Djiboune, A., Sy, P., Ndoye, O., Diarra, M. and Mbodj, M. (2020) Contribution of Bone Scintigraphy in the Diagnosis of a Calcaneus Fatigue Fracture in a Case at the Nuclear Medicine Department of Idrissa Pouye General Hospital (HOGIP) in Dakar. *Open Journal of Medical Imaging*, **10**, 62-71. https://doi.org/10.4236/ojmi.2020.101006

[17] Al-Mohammed, H.I., Sulieman, A., Mayhoub, F.H., Salah, H., Lagarde, C., Alkhorayef, M., Aldhebaib, A., Kappas, C. and Bradley, D.A. (2021) Occupational Exposure and Radiobiological Risk from Thyroid Radioiodine Therapy in Saudi Arabia. *Scientific Reports*, **11**, Article No. 14557. https://doi.org/10.1038/s41598-021-93342-1

[18] Saeed., M.K. and Almalki, Y. (2021) Assessment of the Occupational Dose and Radiogenic Risk in Diagnostic Radiology and Nuclear Medicine Examinations. *International Journal of Radiation Research*, **19**, 365-372. https://doi.org/10.52547/ijrr.19.2.15

[19] Beach, K. (2006) National Radiation Laboratory Ministry of Health PO Box 25099. Christchurch.

[20] Brígido, O., Barreras, A., Montalván, A. and Hernández, J. (2015) Radiation Risk to Patients from Nuclear Medicine Procedures in Cuba. *X Congreso Regional Latinoamericano IRPA de Protección y Seguridad Radiológica*, *Radioprotección*: *Nuevos Desafíos para un Mundo en Evolución*, Buenos Aires, 12-17 April 2015.

[21] Alkhorayef, M., Mayhoub, F. Salah, H., Sulieman, A., Al-Mohammed, H.I., Almuwannis, M., Kappas, C. and Bradley, D.A. (2020) Assessment of Occupational Exposure and Radiation Risks in Nuclear Medicine Departments. *Radiation Physics and Chemistry*, **170**, Article No. 108529.

https://doi.org/10.1016/j.radphyschem.2019.108529

[22] IAEA (2008) Radiation Protection of Workers and the Public in Nuclear Medicine. IAEA Human Health Campus: Medical Physics. http://nucleus.iaea.org/HHW/MedicalPhysics/NuclearMedicine/RadiationProtection/RadProtWorkAndPublic/index.html

[23] Smart, R. (2004) Task-Specific Monitoring of Nuclear Medicine Technologists' Radiation Exposure. *Radiation Protection Dosimetry*, **109**, 201-209. https://doi.org/10.1093/rpd/nch301

[24] Piwowarska-Bilska, H., Birkenfeld, B., Gwardyś, A., Supińska, A., Listewnik, M., Elbl, B. and Cichoń-Bańkowska, K. (2011) Occupational Exposure at the Department of Nuclear Medicine as a Work Environment: A 19-Year Follow-Up. *Polish Journal of Radiology*, **76**, 18-21.

[25] Ali, M., Alameen, S., Bashir, A., Saeed, A., Salah, H., Tamam, N., Sulieman, A. and Bradley, D.A. (2022) Estimate of Effective Dose for Adult Patients from Nuclear Medicine Examinations in Sudan. *Radiation Physics and Chemistry*, **200**, Article No. 110330. https://doi.org/10.1016/j.radphyschem.2022.110330

[26] Sulieman, A., *et al.* (2018) Lens Dose and Radiogenic Risk from ^{99m}Tc Nuclear Medicine Examinations. *Journal of Radioanalytical and Nuclear Chemistry*, **318**, 797-801. https://doi.org/10.1007/s10967-018-6178-5

[27] Sulieman, A. (2015) Establishment of Diagnostic Reference Levels in Computed Tomography for Paediatric Patients in Sudan: A Pilot Study. *Radiation Protection Dosimetry*, **165**, 91-94. https://doi.org/10.1093/rpd/ncv109

[28] Guira, O., Bognounou, R., Zoungrana, L., Tonde, A., Nagalo, A., Traore, R. and Drabo, J. (2020) Spectrum of Hypertriglyceridemia at the Onset of Type 2 Diabetes in Ouagadougou. *Open Journal of Internal Medicine*, **10**, 83-89. https://doi.org/10.4236/ojim.2020.101008

[29] Sulieman, A., Elzaki, M. and Khalil, M. (2011) Occupational Exposure to Staff during Endoscopic Retrograde Cholangiopancreatography in Sudan. *Radiation Protection Dosimetry*, **144**, 530-533. https://doi.org/10.1093/rpd/ncq353

[30] Sulieman, A., Alzimami, K., Gafar, R., Babikir, E., Alsafi, K. and Suliman, I. (2014) Occupational and Patient Exposure in Coronary Angiography Procedures. *Radiation Physics and Chemistry*, **104**, 68-71. https://doi.org/10.1016/j.radphyschem.2013.12.028