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Original Research Article

Effective radiation dose evaluation in nuclear medicine examination

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Radiopharmaceuticals are used in nuclear medicine to obtain diagnostic findings based on justified clinical indications according to patient age, weight, and body mass index (BMI) to approve a reasonable low amount of attainable radiation dose without affecting the quality of the image. This study intended to assess patient effective dose in the cardiac, bone, thyroid and renal scan procedures. The current study was conducted at two nuclear medicine departments in Sudan (Al-Neeleen Diagnostic Centre (NDC) and Radiation Isotope Centre Khartoum (RICK)). A total of 193 procedures were performed at the two nuclear medicine departments using technetium ^{99m}Tc isotope. Effective doses were estimated using computer software based on administered activity. The mean patients weight in cardiac, bone, thyroid and renal scans were 73.8±13, 64.8±19.6, 63.8±15.1, and 67.3±28.1 kg, respectively. The mean administered activity and effective dose per procedure were 810±246 and 7.1±2 for cardiac scan, 796.8±58.2 and 4.6±0.31 for bone scan, 195.1±21.2 and 2.6±0.27 for thyroid scan, and 198.6±32.9 MBq and 0.97±0.16 mSv for renal scan, respectively. Because administered activity depends on the procedure type and patient weight, it was 3 times higher in cardiac scan compared to thyroid scan. The results of this study revealed that patient's doses were lower compared to previous published studies.

Key words: Radionuclide dosimetry, radiation exposure, ^{99m}Tc, radiation risk.

INTRODUCTION

Radiopharmaceuticals have been used in nuclear medicine for diagnostic and therapeutic studies since its emergence in 1960 (Cherry et al., 2012). New procedures introduced and new radioactive substances are developed continually to diagnose different clinical conditions. Patients are exposed to ionizing radiation resulting from radioisotopes administration. The patients' doses in nuclear medicine procedures ranged between 740 -1110 MBq for bone scan, 296 – 1110 MBq for cardiac scan, 111 – 740 MBq for renal scan, and 74 – 370 MBq for thyroid scan (Shackett et al., 2009). The radiation risks resulting from radiopharmaceuticals administration must be balanced against the projected benefit from the examination to prevent patients from avoidable detriment (ICRP 106, 2007). On the other hand, the radiation exposure from the patient to the member of staff and public including patient's family members, especially radiosensitive groups such as children, is of great concern and the related risk needs precise evaluation. Nowadays, many gamma emitter radioisotopes are used in diagnostic investigations, for instance ^{99m}Tc, ^{111}In, ^{123}I, ^{131}I, ^{201}Tl, ^{18}F, etc. (Lassman el al., 2004) . To improve radiation dose optimisation in nuclear medicine, the International Commission on Radiological Protection (ICRP) recommendation (ICRP 73, 1990), the International Atomic Energy Agency (IAEA), and the European Commission (EC, 1997) recommended the use of administrated activity and effective dose as radiation quantities for evaluating patients' doses nuclear medicine investigation and reporting diagnostic reference level. Although, the radiation risks associated with nuclear medicine exposure is below the documented radiation risks (100 mSv), practitioners are encouraged to reduce the dose to its minimal value because radiation induced cancer risk has no threshold. The main sources of occupational exposure in nuclear medicine are during preparation and administration of the radiopharmaceuticals to the patients ($^{99m}Tc/^{99}Mo$) (ICRP, 2012; Edam et al., 2019).

There are limited available data regarding patient's doses and related radiation risks in Sudan. Recent survey showed that there are five nuclear medicine (NM) centers equipped with six nuclear medicine imaging equipment including γ-camera and single photon emission computed tomography (SPECT). This implies a high workload compared with the population in Sudan which is approximately 40 million (Mettler et al., 2008). To our knowledge, no national diagnostic reference level (DRL) was adopted in the country. Thus, the scientific community has to establish local dose reference level to evaluate the current practice leading to dose optimization in clinical environment. Thus this study aims to assess patient effective radiation dose during cardiac, bone, thyroid, and renal scan.

MATERIALS AND METHODS

All data were collected from two nuclear medicine departments: Al-Neeleen Medical Diagnostic Center ((NDC) Private Center) and Radiation Isotope center (RICK- public center) in Khartoum Sudan.

A total of 130 procedures were performed in NDC (40 cardiac scan, 46 thyroid scan and 40 bone scan) and investigated using a gamma camera (single-head) (Orbiter – Scintron 37) manufactured by Siemens, Medical Imaging Electronics (MiE), Erlangen, Germany). The gamma camera unit has a 387 mm field of view (FOV) and 37 photo multiplier tubes (PMTs). ^{99m}Tc is the radionuclide of choice for many nuclear medicine examinations due to is suitable photon energy (0.140 MeV) and reasonable half-life (6.0 hrs) (Figure 1). A total of 63 procedures were performed in RICK (22 bone scan, 21 thyroid scan, and 20 renal scan) using the Nucline Spirit, Mediso γ camera with dual head and low energy collimator, a NaI (Tl) crystal, a light guide and an array of photomultiplier tubes (PMTs) . The NaI (Tl) scintillating crystal has 9.5 mm thickness and dimensions of 59 x 47 cm (Figure 2). The data of this study were collected from the patients' administrated activities (AAs) (MBq) and patients' demographic data (age, weight and BMI) and used to evaluate the imaging protocol to ensure optimum image quality.

The administered activity to each patient was calculated using the following equation:

$$Patient\ dose = \frac{(standard\ dose\ \times patient\ weight\ (kg)}{Standard\ weight\ (70\ kg)}$$

Bone Scan examination

The Radiopharmaceutical used for the bone scan procedure was ^{99m}Tc Methylene Diphosphonate (MDP) with gamma-ray energy 140keV and the administered activity (^{9m}Tc – MDP) ranging from 15 mCi (555MBq) to 20 mCi (740 MBq) which was administered intravenously with an uptake time for imaging of about at least 150 min post injection. In order to obtain proper image, patients prepared for the nuclear medicine imaging procedure by drinking 1 liter of water after administration of radiopharmaceutical. Urination is necessary prior image acquisitions stage to improve image quality (Christian et al., 2012).

Scan of urinary system

^{99m}Tc-DTPA is a radiopharmaceutical used for renal scan to assess the kidney function with gamma ray spectrum of about 140 keV and the administered activity of around 5-10 mCi (185-370MBq). The patient should be injected with 10 mCi of DTPA to focus on the urinary system in a portable study. In cases of kidney failure, the aorta is used as a reference point. The image is taken immediately after administrated activity. Patient is placed in a supine position with the camera at the posterior. The patient is allowed to drink water 30 minutes prior the study (Christian et al., 2012).

Endocrine System scan

The radionuclide ^{99m}Tc Pertechnetate is used to assess the function of the endocrine system. The maximum administrated activity is about 370 MBq for adult. The time of imaging is about 20 minutes post injection (Shackett et al., 2009).

Cardiac scan examination:

To evaluate the function of myocardial perfusion, the Radiopharmaceutical used is 99m Tc-MIBI and the administrated dose is about 900 MBq. The patient is positioned supine on a SPECT imaging couch (Shackett et al., 2009).

RESULT AND DISCUSSION

A total of 193 nuclear medicine procedures were

Figure 1: Siemens Orbiter 37 Gamma camera single head

Figure 2: Mediso gamma camera dual head

performed in the present work to establish the Administrated Activity (AA) and the effective dose in Sudan. The mean AAs and effective dose correlated with the results of scientific papers published in international literature.

In this study, for cardiac patients with an average range of 73.8±13 Kg, the Administrated Activity (AA) in Mega Becquerel (MBq) was about (810±246 MBq) and the effective dose in milli Sievert (mSv) was about (7.1±2 mSv).While for bone scan patients with size range of 64.8±19.6 Kg, the AA was about (796.8±58.2 MBq) and the effective dose was about (4.6±0.31 mSv). Although for

Table 1. Mean, ±Sd and range of patient demographic data, administered activity and effective dose in cardiac, thyroid and bone scans

Exam	No.	Age (y)	weight (kg)	Activity (MBq)	effective dose(mSv)
Cardiac	40	(57.8±9)	(73.8±13)	(810.0±246)	(7.1±2)
		(30-82)	(46-111)	(740-1665)	(6.7-13.2)
Thyroid	46	(43.8±14)	(64.1±17)	(177.4±16)	(2.3±0.2)
		(19-70)	(14-93)	(114.7-192)	(1.5-2.5)
Bone	44	(57.3±10)	(63.7±12)	(751.2±34)	(4.3±0.2)
		(36-75)	(42-75)	(740-925)	(4.2-5.3)

Table 2. Mean, ±Sd and range of patient demographic data, administered activity and effective dose in Bone, thyroid and kidney in Isotope center

Exam	No.	Age (y)	weight (kg)	Activity (MBq)	effective dose (mSv)
Bone	22	(51.9±15.5)	(65.8±27.2)	(842.4±73.3)	(4.8±0.42)
		(82-24)	(160-30)	(933.1-703)	(5.7-4)
Thyroid	21	(37±7.7)	(63.55±13.2)	(212.8±26.3)	(2.8±0.34)
		(50-25)	(98-50)	(254.56-152.1)	(3.3-1.97)
Kidney	20	(40.4±14.1)	(67.3±28.1)	(198.6±32.9)	(.97±0.16)
		(68-17)	(68-17)	(251.60-155.4)	(1.23-0.76)

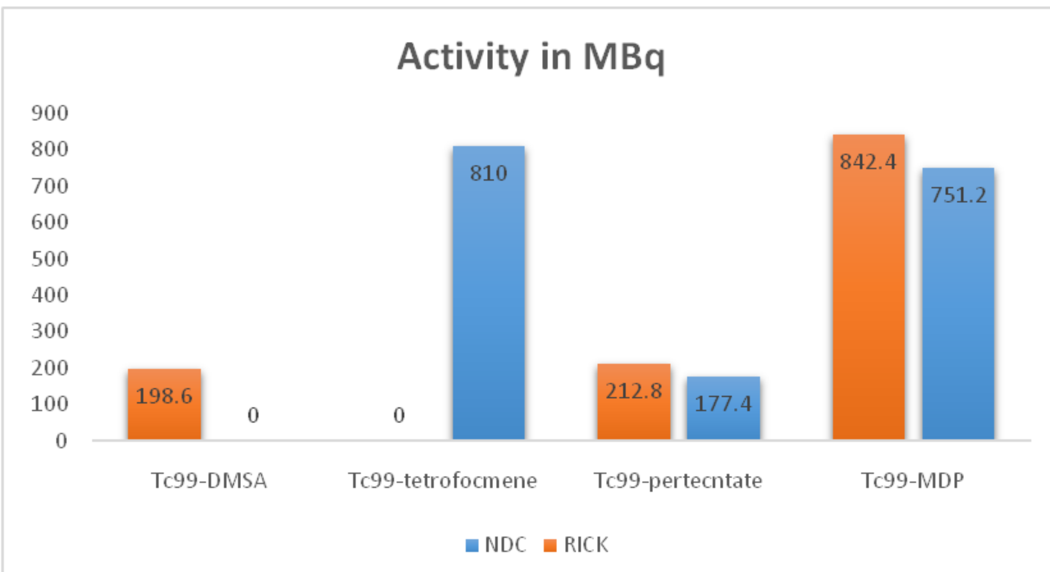

Figure 3: the activity comparisons in two medical center in Sudan

thyroid scan with mean patient size of 63.8±15.1kg, the AA was (195.1±21.2 MBq) and the effective dose was about (2.6±0.27 mSv). Finally for renal study with average patient weight of about 67.3±28.1 kg, the AA was about (198.6±32.9 MBq) and the effective dose was (0.97±0.16 mSv) (Tables 1 and 2) and (Figure 3 and 4). As shown in Table 3, there is quite a distinction between Administrated Activities given by countries except in Brazil which has higher dose in bone and thyroid scan compared with other countries. The results of Administrated Activities in our studies in (Table 3) and (Figure 5) regarding the average AA in (MBq) of different types of diagnostic examinations was compared with a survey from other countries (Vogiatzi, et al., 2011; Bomben et al., 2004; Khoury etal, 1994; Flores et al., 2006; Papadopoulos et al., 1990; Lai et al., 1995; Mettler et-al., 1986; DRL Japan, 2015).Table 4 and Figure 6 shows the range of radioisotope administrated activities and the administrated activity for Sudanese. It is mentioned that the Sudanese AAs is within the values of (IAEA, 1996; ARSAC, 2006; EC, 1999; SSK, 2000) except for (RSNA, 2008) ^{99m}Tc-DMSA for renal scan, ^{99m}Tc-MDP/HDP for bone scan,^{99m}Tc- Tetrofosmin for Cardiac scan and TcO_4

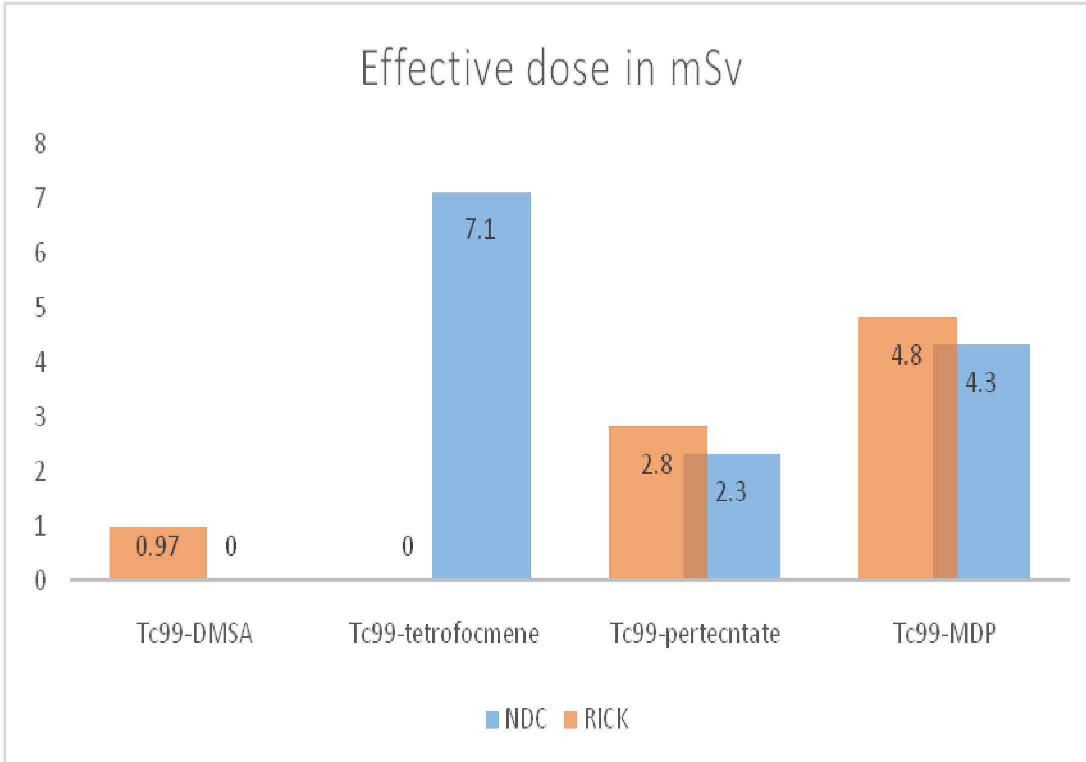

Figure 4: the effective dose comparisons in two medical center in Sudan

Table 3: Comparison of average administered activity (MBq) of different types of diagnostic examinations with survey from other countries (Adults ≥ 16 years old).

Diagnostic Exam.	**Radiopharma ceutical**	**Average Administered Activity (MBq)**								
		NDC	RICK	Bomben etal, 2004 (Argantina)	Khoury et al, 2000 (Brazil)	Flores etal, 2006(Cuba)	Vogiatzet al, 2011 (Greece)	Lai etal, 1995 (Tiwan)	Mettler, 1986 (USA)	DRL Japan, 2015
Bone	Tc-99m MDP/HDP	(751.2±34) (740-925)	(842.4±73.3) (933.1-703)	860	1016	740	735	560	740	950
Cardiac	Tc-99m Tetrofosmin	(810.0±246) (740-1665)	N/A	700	N/A	N/A	N/A	540	N/A	900
Thyroid	TcO4	(177.4±16) (114.7-192)	(212.8±26.3) (254.56-152.1)	210	426	222	183	80	185	300
Kidney	Tc-99m DMSA	N/A	(198.6±32.9) (251.60-155.4)	230	234	222	183	150	N/A	210

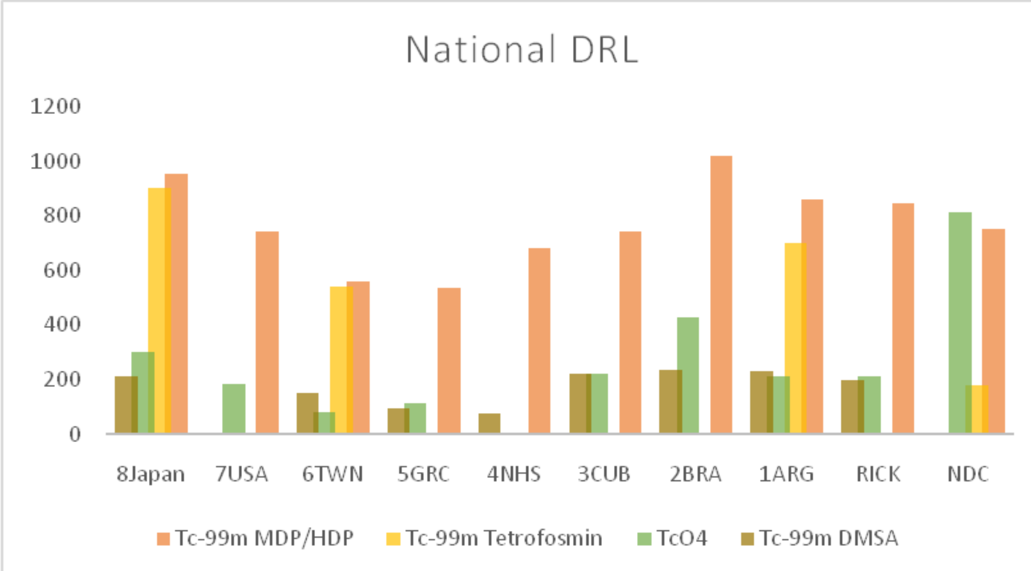

Figure 5: the activity comparisons between the local and National DRL

Table 4. Comparison of average administered activity (MBq) of different types of diagnostic examination with difference recommended DRLs (Adults ≥ 16 years old).

Diagnostic Exam.	Radiopharmaceutical	Average Administered Activity (MBq)						
		NDC	RICK	IAEA 1996	ARSAC 2006	RSNA 2008	EC 1999a	SSK 2000
Bone	Tc-99m MDP/HDP	(751.2±34) (740-925)	(842.4±73.3) (933.1-703)	800	800	1110	600	750
Cardiac	Tc-99m Tetrofosmin	(810.0±246) (740-1665)	N/A	800	800	1500	N/A	N/A
Thyroid	TcO4	(177.4±16) (114.7-192)	(212.8±26.3) (254.56-152.1)	200	80	370	N/A	N/A
Kidney	Tc-99m DMSA	N/A	(198.6±32.9) (251.60-155.4)	160	80	370	80	70

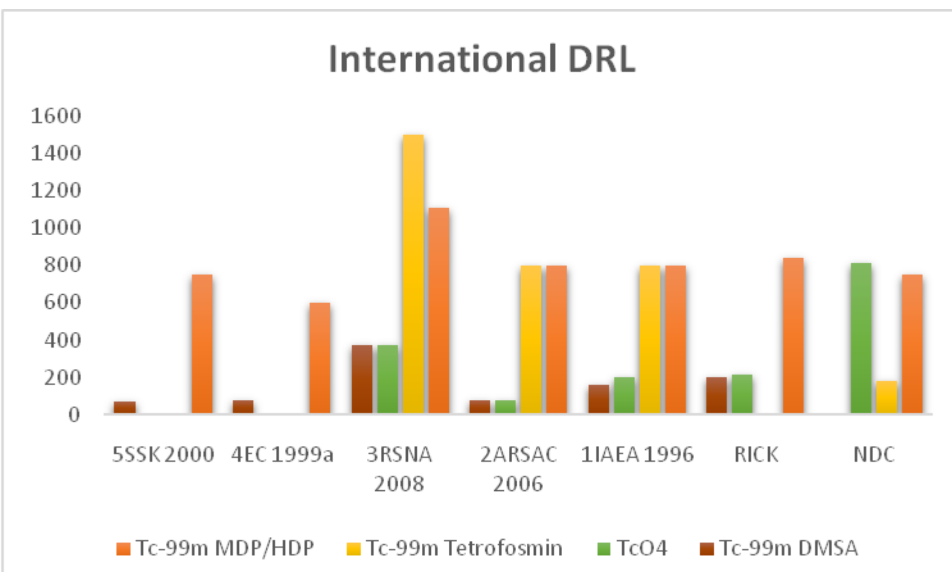

Figure 6: the activity comparisons between the local and international DRL

for thyroid scan when the administrated activities value was increased. That means the Sudanese administrated activity is within the tolerance value of international literature. In (RSNA, 2008), the AAs is increased to approximately one and half the AAs used in Sudan for cardiac scan. When compared with (EC, 1999; SSK, 2000), there was observed increase in mean dose in Sudanese Administrated Activities.

One of the main objectives of this study was to progress a national database of patient dose in diagnostic imaging in view of establishing the Administrated Activities in Sudan. Also the study was conducted under the real clinical settings and did not consider the potential factors that might affect the dose measured namely exposure parameters and performance of the machine. This survey was narrowed to adult patients with age greater than 16 years in nuclear medicine. For nuclear medicine, it is recommended that the medical facilities in the country adopt these administrated activities and effective dose as guidance in order to compare with their local practices. If doses exceed these a review is considered to guarantee effective protection of the adjusted patients while maintaining diagnosable image. Nonetheless, if the administrated activities and effective dose are exceeded, this does not essentially mean that the investigation has been unsuitably conducted. Exposures beyond the level might be beneficial in order, for example, to reach image quality which is improved. On the other hand, helpful action should be taken as required if the radiation dose do not afford beneficial diagnostic findings.

CONCLUSIONS

The outcomes of this survey correlate with the outcome of published studies from other international surveys. Administrated activities and effective dose will be valuable in providing regulation to the professional and regulatory bodies on dose levels for numerous examinations and procedures including ionizing radiation. To develop the administration of patient's doses involving ionizing radiation, radiation exposure data must be documented and scientifically compared with the international literature. Patients are exposed to three times higher radiation dose from cardiac and bone scans based on the administered activity.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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