National Diagnostic Reference Levels for Nuclear Medicine in Qatar

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Nuclear medicine (NM) started in Qatar in the mid-1980s with a 1-head γ-camera in Hamad General Hospital. However, Qatar is expanding, and now Hamad Medical Corp. has 2 NM departments and 1 PET/CT Center for Diagnosis and Research, with several hybrid SPECT/CT and PET/CT cameras. Furthermore, 2 new NM departments will be established in Qatar in the coming 3 y. Therefore, there is a need to optimize radiation protection in NM imaging and establish diagnostic reference levels (DRLs) for the first time in Qatar. This need is not only for the NM part of the examination but also for the CT part, especially in hybrid SPECT/CT and PET/CT. **Methods:** Data for adult patients were collected from the 3 SPECT/CT machines in the 2 NM facilities and from the 2 PET/CT machines in the PET/CT center. The 75th percentile values (also known as the third quartile) were considered preliminary DRLs and were consistent with the most commonly administered activities. The results for various general NM protocols were described, especially ^{99m}Tc-based radiopharmaceuticals and PET/CT protocols including mainly oncologic applications. **Results:** The first DRLs for NM imaging in Qatar adults were established. The values agreed with other published DRLs, as was the case, for example, for PET oncology using ^{18}F-FDG, with DRLs of 258, 230, 370, 400, and 461–710 MBq for Qatar, Kuwait, Korea, the United Kingdom, and the United States, respectively. Similarly, for cardiac stress or rest myocardial perfusion imaging using ^{99m}Tc-methoxyisobutylisonitrile, the DRLs were 926, 976, 1,110, 800, and 945–1,402 MBq for Qatar, Kuwait, Korea, the United Kingdom, and the United States, respectively. **Conclusion:** The optimization of administered activity that this study will enable for NM procedures in Qatar will be of great value, especially for new departments that adhere to these DRLs.

Key Words: DRLs; nuclear medicine; Qatar; PET/CT; SPECT/CT

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There is no doubt that the use of ionizing radiation and radioactive substances in diagnostic and therapeutic procedures is beneficial. According to the World Nuclear Association, today around 50 million nuclear medicine (NM) procedures are done worldwide every year. As such, medical radiation exposure has been continuously increasing during the past decade, reaching levels that are comparable to or even greater than exposure of the population to natural sources of radiation (*1*). One of the main constraints of nuclear medicine procedures is that the capacity of ionizing radiation to penetrate and then transform or kill tissue cells can make it potentially dangerous to health. General principles of radiation protection from the hazard of ionizing radiation are summarized as 3 key words: justification, optimization, and dose limits (*2*). The main idea is therefore to make the radiation as low as reasonably achievable by balancing the benefits to the risks and therefore optimizing clinical protocols and minimizing their potentially harmful effects.

Three general categories of medical practice involve such ionizing radiation: diagnostic radiology, NM, and radiation therapy. This paper will focus on diagnostic NM imaging.

Medical exposure differs from occupational and public exposure in that patients are directly, and in a known way, exposed to radiation for their diagnostic or therapeutic benefit. It is therefore not appropriate to apply administered activity limits or administered activity constraints, the remaining rule being that the given activity should cause more benefit than harm. As a result, medical radiation systems use diagnostic reference levels (DRLs) as reference values and do not have administered activity limits (*3*).

DRLs are an important tool that helps to reduce patient exposure while optimizing NM clinical protocols. This optimization is especially important in multimodality imaging, such as imaging that includes an NM component (for which exposure is caused by the injected radiopharmaceutical) along with a CT component in a hybrid PET/CT or SPECT/CT imaging system.

Given that Qatar is expanding and that at least 2 new NM departments will be inaugurated in the upcoming 3 y, creating specific DRLs for Qatar NM is a must. The results presented in this paper will be the first national DRLs for NM procedures in Qatar and can serve as a starting point for future updates.

MATERIALS AND METHODS

Data Collection and DRL Calculation

Hamad Medical Corp. is the only institute in Qatar offering NM diagnostic services for adults. The services are distributed into 3 main sites: Hamad General Hospital, the National Center for Cancer Care and Research, and the PET/CT Center for Diagnosis and

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Research. Data were collected from the 3 SPECT/CT machines in the 2 NM facilities and from the 2 PET/CT machines in the PET/CT center. The institutional review board at Hamad Medical Corp. approved this retrospective study; all patients were adults.

The DRLs were determined using 5 steps. In the first step, protocols for each type of NM examination performed at each site were identified. The second step was creation of a radiopharmaceutical database of the administered activity for each NM examination performed from the beginning of 2020 till the end of 2021. Third, the median (50 percentile) and the third quartile (75th percentile) of the administered activity were calculated. The DRLs were established on the basis of the third quartile (*4*) as recommended by the International Commission on Radiological Protection. The results were then compared with those of other countries, including Kuwait, Korea, Japan, Australia, the United Kingdom, the United States, and Europe.

In the fourth step, a second database was created containing the volume CT dose index ($CTDI_{vol}$) and the dose–length product (DLP) for each NM examination that had an associated CT scan obtained through SPECT/CT or PET/CT. The median and 75th percentile were calculated for each $CTDI_{vol}$ and DLP. The DRLs for the CT portion of PET/CT and SPECT/CT were based on the scanned region. For PET/CT, these regions were whole-body 1 (WB1, base of skull to mid-thigh), whole-body 2 (WB2, vertex to knees), and total body (TB, vertex to toes); for SPECT/CT, these regions were heart (corresponding to a myocardial perfusion study) or whole body (WB).

Finally, to assess the radiation dose from the CT component of the examination, the effective dose (ED) was calculated using the DLP and a conversion factor k (where ED [mSv] $\approx$ k $\times$ DLP). A factor of 0.0096 was used for PET/CT WB1 and WB2 and SPECT/CT WB; 0.0093 was used for PET/CT TB and 0.015 was used for SPECT/CT cardiac studies (*5,6*).

Statistical Analysis

The median, mean $\pm$ SD, and 75th percentile were estimated using Microsoft Excel.

RESULTS

Figure 1 presents 2 examples of distribution histograms showing the number of patients compared with the administered activity for an ^{18}F-FDG PET scan (Fig. 1A) and a ^{99m}Tc-diphosphonate NM bone scan (Fig. 1B). The respective mean administered activities were 231.12 $\pm$ 44.82 MBq and 721.97 $\pm$ 78.67 MBq.

Table 1 shows the results for different procedures and radiopharmaceuticals for both PET and SPECT and including the median injected administered activities and the DRLs. For ^{18}F-based tracers, DRLs were between 187 MBq for NaF and 260 MBq for prostate-specific membrane antigen. For ^{99m}Tc, DRLs were between 19 MBq for nanocolloid and phytate and 926 MBq for methoxyisobutylisonitrile NM cardiac stress or rest studies.

Table 2 compares the obtained DRLs with those of other countries for protocols for which an associated DRL exists. Oncologic PET studies using ^{18}F-FDG had DRLs of 258, 230, 370, 400, and 461–710 MBq for Qatar, Kuwait, Korea, the United Kingdom, and the United States, respectively. Similarly, for cardiac stress or rest NM studies using ^{99m}Tc-methoxyisobutylisonitrile, the DRLs were 926, 976, 1,110, 800, and 945–1,402 MBq, respectively. Regarding ^{99m}Tc-diphosphonate, the DRLs were 740, 944, 925, 600, and 848−1,185 MBq, respectively.

Moreover, achievable CT doses and DRLs (from both PET/CT and SPECT/CT) in Qatar for both $CTDI_{vol}$ and DLP are shown in Table 3. Regarding CT from PET/CT, the DRLs for $CTDI_{vol}$ ranged from 4.42 to 5.3 mGy for PET/CT TB and PET/CT WB1, respectively. The DRLs for DLP ranged from 521.75 to 831.5 mGy·cm for PET/CT WB2 and PET/CT TB, respectively. For CT from SPECT/CT, the DRLs for DLP ranged from 103.58 mGy·cm for SPECT/CT myocardial perfusion to 211.48 mGy·cm for SPECT/CT WB.

Finally, the obtained EDs are shown in Table 4. For CT from PET/CT, EDs ranged from 5.01 mSv for PET/CT WB2 to 7.73 mSv for PET/CT TB. For CT from SPECT/CT, EDs ranged from 1.59 mSv for SPECT/CT myocardial perfusion to 3.17 mSv for SPECT/CT WB.

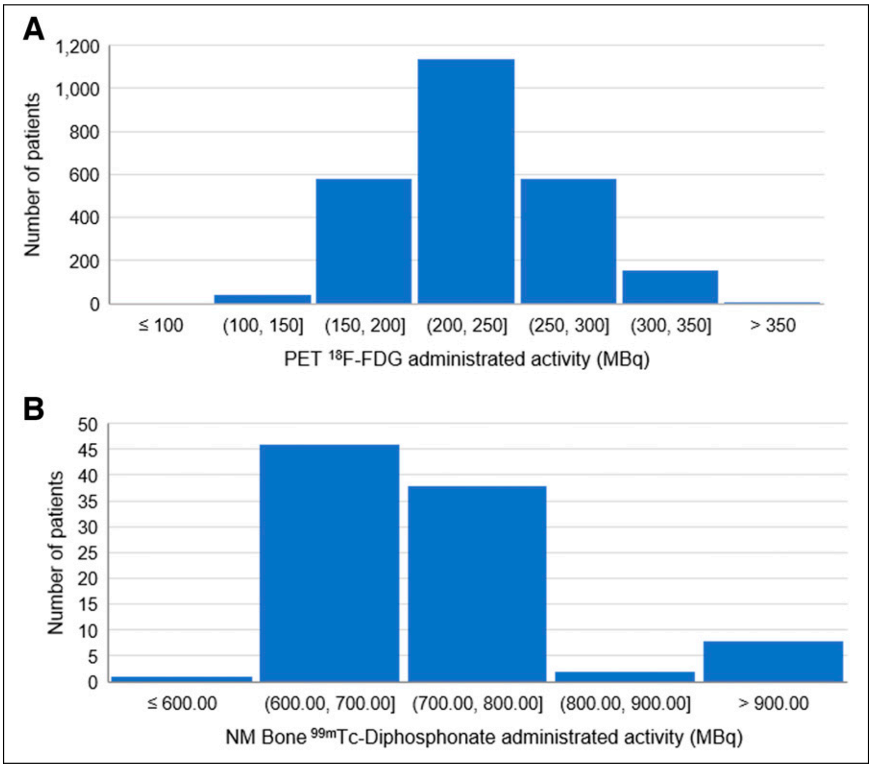

FIGURE 1. Distribution histogram showing number of patients compared with administered activities for PET ^{18}F-FDG patients (A) and NM bone ^{99m}Tc-diphosphonate patients (B). NM = nuclear medicine.

TABLE 1
PET/CT and General NM Procedures: Number of Included Studies, Median Activities (50th Percentile), and DRLs (75th Percentile)

Procedure	Agent	Studies (*n*)	Median activity, 50th percentile (MBq)	DRL, 75th percentile (MBq)
PET oncology	^{18}F-FDG	2,523	228	258
PET brain	^{18}F-FDG	10	200	202
PET oncology	^{18}F- or ^{68}Ga-PSMA	94	234	260
PET oncology	^{18}F-NaF	449	158	187
PET oncology	^{68}Ga-DOTATATE	107	135	140
NM bone	^{99m}Tc-diphosphonate	95	703	740
NM thyroid uptake	^{99m}Tc-pertechnetate	457	189	195
NM WB	^{131}I-NaI	32	185	190
NM parathyroid	^{99m}Tc-MIBI	118	374	384
NM cardiac stress or rest	^{99m}Tc-MIBI	2,556	925	926
NM lung	^{99m}Tc-MAA	82	74	103
NM lymphoscintigraphy	^{99m}Tc-phytate	8	19	19
NM hepatobiliary	^{99m}Tc-HIDA	19	185	188
NM gastric emptying	^{99m}Tc-phyton	52	19	36
NM renogram	^{99m}Tc-DTPA	13	186	189
NM renogram	^{99m}Tc-MAG3	356	185	189
NM renal scintigraphy	^{99m}Tc-DMSA	71	75	101
NM sentinel node localization in breast	^{99m}Tc-nanocolloid	211	19	19
NM cardiac	^{99m}Tc-pyrophosphate	22	722	740
NM lung ventilation	^{99m}Tc-Technegas*	23	74	99

*Cyclomedica.
PSMA = prostate-specific membrane antigen; MAA = macroaggregated albumin; HIDA = hepatobiliary iminodiacetic acid; DTPA = diethylenetriaminepentaacetate; MAG3 = mercaptoacetyltriglycine; DMSA = dimercaptosuccinic acid.

DISCUSSION

The first NM DRLs for adults in Qatar were established on the basis of local data assessment. Application of the third quartile, which is the same standard as in other studies to establish the DRLs of NM imaging, was confirmed as appropriate for domestic NM imaging studies. When any DRL is consistently exceeded at a facility (i.e., the median value of the DRL for a representative sample of patients within a certain weight range is greater than the DRL in International Commission on Radiological Protection publication 135), possible reasons should be investigated and a plan should be implemented and documented without delay if corrective action is required (*7*).

TABLE 2
Qatar DRLs for PET/CT and General NM Procedures in Comparison to Other Countries

Procedure	Agent	Qatar (this study)	Kuwait (*10*)	Korea (*11*)	Japan (*12*)	Australia (*13*)	U.K. (*14*)	U.S. (*15*)	European Union (*16*)
PET oncology	^{18}F-FDG	258	230	370	240	310	400	461–710	200–400
PET brain	^{18}F-FDG	202	231	370	240	250	250		
NM bone	^{99m}Tc-diphosphonate	740	944	925	950	920	600	848–1,185	500–1,110
NM thyroid uptake	^{99m}Tc-pertechnetate	195	185	217	300	215	80		75–222
NM WB	^{131}I-NaI	190	200	185		185	400		90–400
NM parathyroid	^{99m}Tc-MIBI	384	900	740	800	900	900		400–900
NM cardiac stress or rest	^{99m}Tc-MIBI	926	976	1,110	1,200	1,520	800	945–1,402	
NM lung	^{99m}Tc-MAA	103	217.5	222	260	240	100	147–226	100–296
NM lymphoscintigraphy	^{99m}Tc-phytate	19	40	148		52	40		74–150
NM gastric emptying	^{99m}Tc-phyton	36	37	111		44	12	31–50	150–540
NM renogram	^{99m}Tc-DTPA	189	90	555	400	500	300	407–587	
NM renogram	^{99m}Tc-MAG3	189	370	500	400	305	100	283–379	100–370
NM renal scintigraphy	^{99m}Tc-DMSA	101	200	185	210	200	80	189–289	70–183

MIBI = methoxyisobutylisonitrile; MAA = macroaggregated albumin; DTPA = diethylenetriaminepentaacetate; MAG3 = mercaptoacetyltriglycine.

TABLE 3
Achievable Dose (50th Percentile) and DRLs (75th Percentile) for Both $CTDI_{vol}$ and DLP for Different Scan Regions Including CT Imaging in PET/CT- and SPECT/CT-Based Scans

		$CTDI_{vol}$ (mGy)		DLP (mGy·cm)	
Protocol	Scan region	Achievable dose, 50th percentile	DRL, 75th percentile	Achievable dose, 50th percentile	DRL, 75th percentile
PET/CT WB1	Base of skull to mid-thigh	4.08	5.3	378.1	547.93
PET/CT WB2	Vertex to knees	3.68	4.49	453.6	521.75
PET/CT TB	Vertex to toes	3.08	4.42	540.4	831.5
SPECT/CT myocardial perfusion	Mid chest to lower neck	3.72	4.26	89.62	103.58
SPECT/CT WB*	Thorax and abdomen	4.86	4.86	211.48	211.48

*Fixed region size.

DRLs can be used to optimize radiation protection by setting the appropriate level of administered activity and its associated CT parameters (affecting CT dose) in hybrid systems for adults undergoing NM imaging. The calculated CT ED, although based on k factors, helped to obtain a clear idea of the radiation impact of including CT in different PET/CT- and SPECT/CT-based scans having different fields of views.

DRLs are not a method of patient-by-patient radiation dose monitoring and are not an indicator of good or bad practice but, rather, provide additional data to verify that the department is operating optimally. When DRLs are exceeded, the reason should be verified. In some cases, such as when certain old machines are used, some higher DRLs can be acceptable. The highest priority for any diagnostic examination is to achieve sufficient image quality (*8*).

The DRLs for Qatar agreed well with those for other countries and regions and therefore are adequate with the required optimization. Comparing our study results with those of other countries in the Gulf region, the DRLs for Qatar were lower than those for Kuwait by 20% for NM thyroid uptake studies, 57% for NM parathyroid studies, 50% for NM lung studies, 49% for NM renography, and 50% for NM renal scintigraphy. The PET oncology and PET brain DRLs were in line with that for Kuwait and lower by 20%–30% than those for other counties, such as Korea, Australia, the United Kingdom, and the European Union, as presented in Table 2. In only 3 protocols were Qatar DRLs lower than in any other country—a finding that may be advantageous, given that physicians agreed that the obtained images were of sufficient quality. These protocols were NM parathyroid studies using ^{99m}Tc-methoxyisobutylisonitrile, NM lymphoscintigraphy using ^{99m}Tc-phytate, and NM renography using ^{99m}Tc-diethylenetriaminepentaacetate.

Regarding the CT in hybrid PET/CT WB1 studies, the Qatar DRLs were lower than French and Japanese DRLs (5.3 vs. 6.6 and 5.5 for $CTDI_{vol}$ and 547.93 vs. 628 and 550 for DLP, respectively). Similarly, for CT in hybrid SPECT/CT WB studies, the Qatar DRLs were lower than Japanese DRLs (4.86 vs. 5.03 for $CTDI_{vol}$ and 211.48 vs. 384.1 for DLP, respectively).

The present study had some limitations. One is specific to our study, and the others exist for equivalent studies. First, for adults in Qatar, only 2 NM facilities and 1 PET/CT facility are available. As a result, the obtained values should be updated whenever new facilities are established. Second, although clinicians demand images of diagnostic quality, including image quality as a factor during DRL calculation (regarding radiopharmaceutical administered activity or CT dose) is not achievable in either our study or other published DRL studies, given

TABLE 4
Median Activity (50th Percentile) and DRLs (75th Percentile) for ED Calculated Using k Factor for Different Scan Regions Including CT Imaging in PET/CT- and SPECT/CT-Based Scans

			Effective dose (mSv)	
Protocol	Scan region	k factor ($mSv \cdot mGy^{-1} \cdot cm^{-1}$)	Median, 50th percentile	DRL, 75th percentile
PET/CT WB1	Base of skull to mid-thigh	0.0096	3.63	5.26
PET/CT WB2	Vertex to knees	0.0096	4.35	5.01
PET/CT TB	Vertex to toes	0.0093	5.03	7.73
SPECT/CT myocardial perfusion	Mid chest to lower neck	0.015	1.34	1.59
SPECT/CT WB*	Thorax and abdomen	0.015	3.17	3.17

*Fixed region size.

that it is not easy to assess NM or CT images objectively. Third, because the study was of adults only, pediatric DRLs were not established. However, Qatar uses the European Association of Nuclear Medicine pediatric dosage card (*9*), and dose for pediatric patients is therefore fixed and based on their weight.

CONCLUSION

Radiation protection is an essential part of NM, especially in growing countries such as Qatar. DRLs can help to optimize such radiation protection to establish the safest NM practice. DRLs for Qatar should be reviewed 5 y after this study.

DISCLOSURE

This study was supported by the Qatar National Research Fund (a member of the Qatar Foundation) under grant NPRP10-0126-170263. No other potential conflict of interest relevant to this article was reported.

KEY POINTS

QUESTION: Can DRLs be established for the first time in Qatar to optimize radiation protection in NM imaging?

PERTINENT FINDINGS: DRLs for administered activity in Qatar, as well as the associated CT dose in hybrid systems, were successfully established and were consistent with published DRLs for Europe, Japan, Korea, Australia, and the United States.

IMPLICATIONS FOR PATIENT CARE: Optimization of administered activity for NM procedures in Qatar, especially when new departments are opened, may spare patients and staff from exposure to ionizing radiation.

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