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National Diagnostic Reference Levels for Nuclear Medicine in Qatar

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Short running title: NDRL for NM in Qatar

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Abstract:

Nuclear medicine (NM) started in Qatar in mid 1980s with a one head gamma camera in Hamad General Hospital (HGH). However, Qatar is expanding and now Hamad Medical Corporation (HMC) has two NM departments and one Positron Emission Tomography (PET)/CT Center for Diagnosis and Research with several hybrid single photon emission computed tomography (SPECT)/CT and PET/CT. Furthermore, two new NM departments will be established in Qatar in the coming three years. Therefore, there is a need for optimizing radiation protection in NM imaging and establishing 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 computed tomography (CT) part especially in hybrid SPECT/CT and PET/CT.

Methods: Data was collected for adult patients from the 3 SPECT/CT machines in the two NM facilities and from the 2 PET/CT machines in the PET/CT Center. The 75th percentile values (also known as the third quartile Q3) were considered as preliminary DRL values and they were consistent with the most commonly administered activities. DRL results for NM imaging in Qatar adults are described including various general NM protocols especially Technetium-99m (^{99m}TC) based radiopharmaceuticals and PET/CT protocols including mainly oncology applications.

Results: First DRLs for NM imaging in Qatar adults were established; values are in agreement with other published DRLs as it is the case for example for PET Oncology using ^{18}F-fluorodeoxyglucose (FDG) with DRLs of 258, 230, 370, 400 and 461–710 MBq for Qatar, Kuwait, Korea, UK and USA, respectively. Similarly, for NM Cardiac Stress or Rest Myocardial Perfusion imaging using^{99m}Tc Methoxy Isobutyl Isonitrile (MIBI), DRLs were 926, 976, 1110, 800 and 945-1402 MBq for Qatar, Kuwait, Korea, UK and USA, respectively.

Conclusions: This study will enable administrated activity optimization for NM procedures in Qatar and this will be of great value especially for the new departments that will adhere to these DRLs.

Keywords: DRLs, nuclear medicine, Qatar, PET/CT, SPECT/CT

Introduction:

There is no doubt that the use of ionizing radiation and radioactive substances in diagnostic and therapeutic procedures is beneficial and, nowadays, around 50 million NM procedures is done worldwide as per the World Nuclear Association. As such. the levels of medical radiation exposure have been continuously increasing during the past decade to reach numbers which are comparable to or even larger than the exposure of the population due to natural sources (*1*). One of the main constraints is that the capacity of ionizing radiation to penetrate and then transform and/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 three 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 risk and therefore optimizing clinical protocols and minimizing their potentially harmful effects.

Three general categories of medical practices involve such ionizing radiation including diagnostic radiology, nuclear medicine (NM), and radiation therapy. This paper will focus on diagnostic nuclear medicine 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/therapy benefit. As such, it is not appropriate to apply administrated activity limits or administrated activity constraints and the remaining rule is that the given radioactive administrated activity should cause more benefits than harm. As a result, medical radiation systems use diagnostic reference levels (DRLs) as reference values without having administrated activity limits (*3*).

DRLs are an important tool that help to reduce patient exposure while optimizing NM clinical protocols. This optimization is really important especially in multi-modality imaging such as in NM where exposure is caused by the injected radiopharmaceutical but also with the associated CT in a hybrid PET/CT or SPECT/CT imaging.

Given that Qatar is expanding and at least two new NM departments will be inaugurated in the upcoming three years, creating specific DRLs for Qatar NM is a must. The results presented in this paper will be the first national DRLs for nuclear medicine procedures in Qatar as a start for future updates in the upcoming years.

Materials and Methods

Data collection and DRL calculation

HMC is the only institute in Qatar offering NM diagnostic services for adults distributed into three main sites: HGH, National Center for Cancer Care and Research and the PET/CT Center for Diagnosis and Research. Data was collected from the 3 SPECT/CT machines in the two NM facilities and from the two PET/CT machines in the PET/CT Center. The institutional review board at HMC approved this retrospective study. The DRLs are determined by the following methodology:

First step, protocols for each type of NM examination performed at each site are identified. Note that this survey was conducted for adults only.

Second step, for radiopharmaceuticals, a database was created per NM examination of the actual administered activity of radioisotope for all patients acquired for a two-year period from the beginning of 2020 till the end of 2021.

Third step, for each NM examination, the median and the 75^{th} percentile (the third quartile Q3) of the injected administrated activity are calculated. The DRLs are established based on Q3 (*4*) as recommended by the International Commission on Radiological Protection (ICRP). The obtained results are then compared to other countries including Kuwait, Korea, Japan, Australia, UK, USA and Europe.

Fourth step, a second database was created containing the $CTDI_{vol}$ (Volume CT dose index) and DLP (Dose Length Product) values for each nuclear medicine examination having a CT scan coming from SPECT/CT or PET/CT study. The median and 75^{th} percentile values (Q3) were calculated for each $CTDI_{vol}$ and DLP values. CT in PET/CT and SPECT/CT DRLs were based on the scanned area going from whole body 1 (WB 1, Base of the Skull to Mid-Thigh), whole body 2 (WB 2, Vertex to knees) and Total body (TB, Vertex to Toes) in PET/CT and cardiac (corresponding to a Myocardial Perfusion Study) or whole body SPECT/CT regions.

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 the PET/CT WB 1 and 2 and SPECT/CT WB; 0.0093 was used for the PET/CT TB and 0.015 was used for SPECT/CT Cardiac as above (*5*,*6*).

Statistical Analysis

The median values (50 percentile), the mean ± standard deviation and the 75^{th} percentile were estimated using Microsoft excel.

Results

Figure 1 shows two examples for distribution histograms showing the number of patients compared to the administrated activity for PET ^{18}F – FDG patient (Figure 1.A) and NM Bone ^{99m}Tc – Diphosphonate (Figure 1.B). The corresponding mean administrated activities were 231.12 ± 44.82 MBq and 721.97 ± 78.67 MBq, respectively.

Table 1 shows the results obtained for different procedures and radiopharmaceuticals for both PET and SPECT and including the median injected administrated activities and the DRLs. For ^{18}F based tracers DRL values were between 187 MBq for sodium fluoride (NaF) and 260 MBq for prostate-specific membrane antigen (PSMA). For ^{99m}Tc, DRLs were between 19 MBq for Nanocolloid and Phytate tand 926 MBq for MIBI NM Cardiac stress or Rest.

Comparisons of obtained DRLs with those of other countries for protocols that associated DRL exists, are shown in Table 2. PET Oncology using ^{18}F- FDG indicated DRLs of 258, 230, 370, 400 and 461–710 MBq for Qatar, Kuwait, Korea, UK and USA, respectively. Similarly, for NM Cardiac Stress or Rest using ^{99m}Tc – MIBI, DRLs were 926, 976, 1110, 800 and 945 - 1402 MBq, respectively. Regarding ^{99m}Tc-Diphosphonate, DRLs were 740, 944, 925, 600 and 848 -1185 MBq, respectively.

Moreover, Qatar CT achievable dose and DRLs (from both PET/CT and SPECT/CT) for both $CTDI_{vol}$ and DLP are shown in Table 3. Regarding CT from PET/CT, DRL for $CTDI_{vol}$ ranges form 4.42 mGy to 5.3 mGy for PET/CT TB and PET/CT WB1, respectively. DRLs for DLP, ranges from 521.75 mGy*cm to 831.5 mGy*cm for PET/CT WB2 and PET/CT TB, respectively. For CT from SPECT/CT, DRLs for DLP ranges from 103.58 mGy*cm for SPECT/CT Myocardial Perfusion Study and 211.48 mGy*cm for SPECT/CT WB.

Finally, obtained ED are shown in Table 4. For CT from PET/CT, ED ranges from 5.01 mSv for PET/CT WB2 to 7.73 mSv for PET/CT TB. For CT from SPECT/CT, ED ranges from 1.59 mSv for SPECT/CT Myocardial Perfusion Study to 3.17 mSv for SPECT/CT WB.

Discussion

The first NM DRLs for adults in Qatar was established based on local data assessment. Application of Q3, which is the same standard as in other studies to establish the DRLs of nuclear medicine imaging, was confirmed as appropriate for domestic nuclear medicine imaging studies. In case the value of any DRL value is 'consistently exceeded' at a facility which means that the median value of the DRL quantity at the facility for a representative sample of patients within an agreed weight range is greater than the DRL value (ICRP 135), possible reasons should be investigated and if corrective action is required, a plan should be implemented (and documented) without undue delay (*7*).

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 in adult patients undergoing nuclear medicine imaging. The calculated CT effective dose, although based on K-factors helped to obtain a clear idea on the radiation impact of including CT in different PET/CT and SPECT/CT based scans with different filed of views.

DRL is not a patient by patient radiation dose monitoring and is not an indicator for good or bad practice but it is an additional data to verify that the department is operating in an optimal condition. In case DRL is exceeded, action should be taken to verify the reason. In some cases, like the use of some old machines, some higher DRLs can be acceptable. The highest priority for any diagnostic examination is to achieve sufficient image quality (*8*).

Qatar DRLs results were in good agreement with other countries / regions and therefore are adequate with the required optimization. Comparing our study results with those of other countries in the Gulf region, the DRL for Qatar is lower than that for Kuwait by 20% for NM thyroid uptake, 57 % in NM parathyroid, 50 % NM lung, 49 % in NM renogram and 50% for NM renal scintigraphy. The PET oncology and PET brain DRLs are in line with that for Kuwait and lower by 20-30 % than those of other counties such as Korea, Australia, UK and EU as presented in Table 2. In only three protocol Qatar DRLs were noticed to be lower than all other countries which may be advantageous given that physicians agreed with the quality of the obtained images. These protocols are the NM Parathyroid using ^{99m}TC – MIBI, the NM Lymphoscintigraphy using ^{99m}TC – Phytate and the NM Renogram using ^{99m}TC – diethylene-triamine-pentaacetate (DTPA).

Regarding CT in hybrid PET/CT studies for whole body 1, Qatar DRLs compared to French and Japan DRLs were lower (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, Qatar DRLs compared to Japan DRLs was lower (4.86 vs 5.03 for $CTDI_{vol}$ and 211.48 vs 384.1 for DLP, respectively).

The present study has some limitations. One of them is specific to our study and other limitations can be found in other equivalent studies. First, in Qatar, for adult patients, 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 clinical physicians demand images of sufficient quality to achieve a diagnosis image quality, including image quality as a factor during DRLs calculation (regarding radiopharmaceutical administrated activity or CT dose) is not achieved neither in our study nor in other published DRLs studies given that it is not easy to assess NM or CT images objectively. Third, pediatric DRLs were not established and it was an adult only study. This is normal in our case given that the European Association of Nuclear Medicine pediatric dosage card (*9*) is used and therefore dose is fixed for all pediatric patients based on their weight.

Conclusion

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

Disclosure

This study was supported by the Qatar National Research Fund (a member of Qatar Foundation) under grant NPRP10-0126-170263.

The authors declare no conflicts of interest.

Key Points

Key point questions: Establish diagnostic reference levels (DRLs) for the first time in Qatar in order to optimize radiation protection in NM imaging

Pertinent findings: DRL in Qatar for NM administrated activity as well as associated CT dose in hybrid system were established and obtained values are consistent with other published DRLs in Europe, Japan, Korea, Australia and US.

Implication for patient care: This study will enable administrated activity optimization for NM procedure in Qatar and especially for new opening of departments that will adhere to these DRLs. This may spare ionizing radiation exposure for patients as well as for staff.

References

1. Radiation Protection and Safety in Medical Uses of Ionizing Radiation. Vienna: INTERNATIONAL ATOMIC ENERGY AGENCY; 2018.

2. Do K-H. General Principles of Radiation Protection in Fields of Diagnostic Medical Exposure. *Journal of Korean Medical Science*. 2016;31:S6.

3. ICRP Publication 105. Radiation protection in medicine. *Ann ICRP*. 2007;37:1-63.

4. Vassileva J, Rehani M. Diagnostic Reference Levels. *American Journal of Roentgenology*. 2015;204:W1-W3.

5. Diagnostic reference levels in medical imaging: review and additional advice. *Ann ICRP*. 2001;31:33-52.

6. Shrimpton PC, Jansen JTM, Harrison JD. Updated estimates of typical effective doses for common CT examinations in the UK following the 2011 national review. *Br J Radiol*. 2016;89:20150346.

7. Vañó E, Miller DL, Martin CJ, et al. ICRP Publication 135: Diagnostic Reference Levels in Medical Imaging. *Ann ICRP*. 2017;46:1-144.

8. Cho S-G, Kim J, Song H-C. Radiation Safety in Nuclear Medicine Procedures. *Nucl Med Mol Imaging*. 2017;51:11-16.

9. Lassmann M, Treves ST. Paediatric radiopharmaceutical administration: harmonization of the 2007 EANM paediatric dosage card (version 1.5.2008) and the 2010 North American consensus guidelines. *Eur J Nucl Med Mol Imaging*. 2014;41:1036-1041.

10. Alnaaimi MA, Alduaij MA, Shenawy FA, et al. National Diagnostic Reference Levels for Nuclear Medicine in Kuwait. *J Nucl Med Technol*. 2022;50:54-59.

11. Song H-C, Na MH, Kim J, Cho S-G, Park JK, Kang K-W. Diagnostic Reference Levels for Adult Nuclear Medicine Imaging Established from the National Survey in Korea. *Nucl Med Mol Imaging*. 2019;53:64-70.

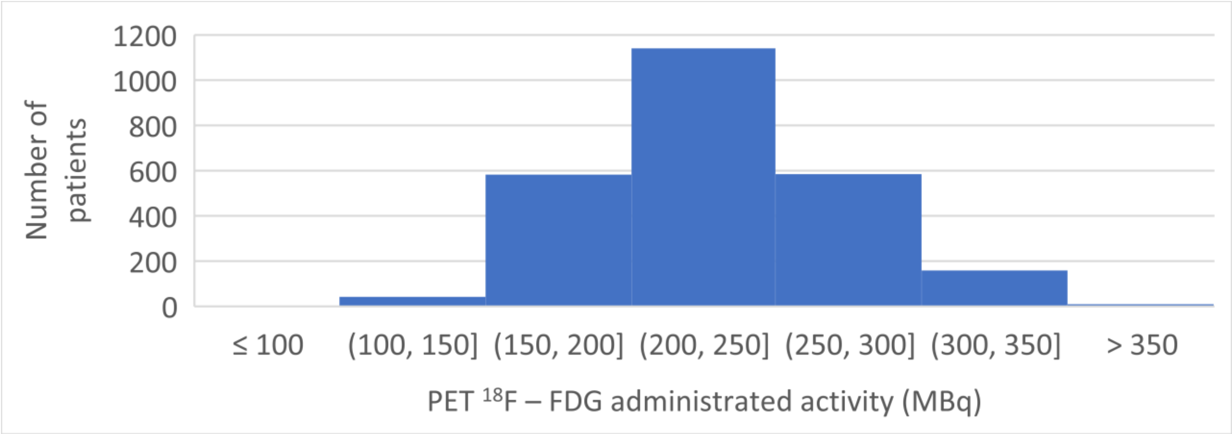
12. Abe K, Hosono M, Igarashi T, et al. The 2020 national diagnostic reference levels for nuclear medicine in Japan. *Ann Nucl Med*. 2020;34:799-806.

13. e5605c6d2607f5b521c46cdf7a23082c. Current Australian diagnostic reference levels for nuclear medicine. ARPANSA. https://www.arpansa.gov.au/research-and-expertise/surveys/national-diagnostic-reference-level-service/current-australian-drls/nm.

14. Hart D, Wall B. UK nuclear medicine survey 2003–2004. *Nuclear medicine communications*. 2005.

15. Report No. 172 – Reference Levels and Achievable Doses in Medical and Dental Imaging: Recommendations for the United States (2012) - NCRP | Bethesda, MD. https://ncrponline.org/shop/reports/report-no-172-reference-levels-and-achievable-doses-in-medical-and-dental-imaging-recommendations-for-the-united-states-2012/.

16. European Commission (EC) (2014) Diagnostic Reference Levels in Thirsty-Six European Countries Part 2/2. Radiation Protection n180. - References - Scientific Research Publishing. https://www.scirp.org/(S(lz5mqp453ed%20snp55rrgjct55))/reference/referencespapers.aspx?referenceid=3023821.



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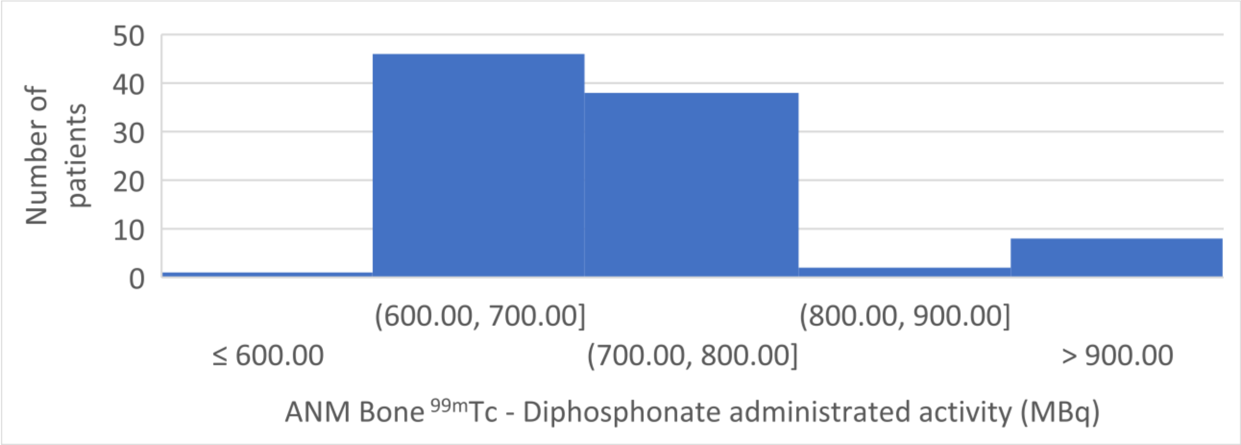

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Figure 1: Distribution histogram showing the number of patients compared to the administrated activities for: A. PET ^{18}F – FDG patients, and B. NM Bone ^{99m}Tc – Diphosphonate patients

Table 1: PET/CT and general NM procedures number of included studies, median activities (50th percentile) and DRLs (75th percentile).

Procedure	Radiopharmaceutical	Number of studies	Median activity (MBq) 50th percentile	DRL (MBq) 75th percentile
PET Oncology	**^{18}F - FDG**	2523	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 - Oncology**	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 Whole body	**^{131}I - NaI**	32	185	190
NM Parathyroid	**^{99m}Tc - MIBI**	118	374	384
NM Cardiac Stress or Rest	**^{99m}Tc - MIBI**	2556	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 - PYP**	22	722	740
NM Lung Ventilation	**^{99m}Tc - Technegas**	23	74	99

Table 2: Qatar DRLs for PET/CT and general NM procedures in comparison to other countries.

Procedure	Radiopharmaceutical	Qatar This study	Kuwait (*10*)	Korea (*11*)	Japan (*12*)	Australia (*13*)	UK (*14*)	USA (*15*)	EU (*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	848–1185	500–1110
NM Thyroid Uptake	**^{99m}Tc - Pertechnetate**	195	185	217	300	215	80		75–222
NM Whole body	**^{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	1110	1200	1520	800	945-1402	
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

Table 3: Achievable dose (50th percentile) and DRLs (75th percentile) for both the $CTDI_{vol}$ (Volume CT dose index) and DLP (Dose Length Product) for different scan regions including CT imaging in PET/CT and SPECT/CT based scans.

Protocol	Scan Region	$CTDI_{vol}$ (mGy)		DLP (mGy × cm)	
		Achievable dose - 50th percentile	DRL - 75th percentile	Achievable dose - 50th percentile	DRL - 75th percentile
PET/CT WB1	Base of the 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 imaging	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

Table 4: Median activity (50th percentile) and DRLs (75th percentile) for the effective dose calculated using the K factor for different scan regions including CT imaging in PET/CT and SPECT/CT based scans.

Protocol	Scan Region	K factor $mSv \times mGy^{-1} \times cm^{-1}$	Effective Dose (mSv) Median 50th percentile	Effective Dose (mSv) DRL 75th percentile
PET/CT WB1	Base of the 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 Study	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

Graphical abstract: