ISSN:0976-3031

Available Online at http://www.recentscientific.com

CODEN: IJRSFP (USA)

International Journal of Recent Scientific Research
Vol. 10, Issue, 07(C), pp. 33478-33488, July, 2019

International Journal of Recent Scientific Research

DOI: 10.24327/IJRSR

Research Article

ESTABLISHMENT OF NATIONAL DRL FOR CT IN HYBRID IMAGING STUDIES "THE FIRST NATIONAL NM CT (PET) DOSE AUDIT FOR KW POPULATION"

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DOI: http://dx.doi.org/10.24327/ijrsr.2019.1007.3679

ARTICLE INFO

Article History:
Received 9th July, 2019
Received in revised form 18th July, 2019
Accepted 26th July, 2019
Published online 28thJuly, 2019

Key Words:

PET/CT, NDRL, CTDvol, DLP, Molecular Imaging

ABSTRACT

DRLs for CT used in PET/CT examinations are limited. The study proposes a NDRL for CT part in KW, in support of optimisation and dose reduction. All the PET/CT centers (No:7) participated in the study and only adult oncology patients were collected as the other studies were limited. The CTDIvol, DLP and SL were recorded and the Median, Mean, SD, 75th, 25th percentiles as well as WB effective dose (ED) were calculated. Dose and scan length statistics for HB and WB scans (53% and 47% of total: 197) and the WB+HB presented together with the proposed NDRLs and the Achievable doses. There were variations in proposed and achievable local DRL amongst 7 centers, highlighting the need for NDRL. Third quartile DLP (mGy x cm) and CTDIvol (mGy) values for the HB were (556, 5.5) which were higher than the UK NDRL (400, 4.3) but were lower than the Swiss NDRL (620, 6) and the France NDRL (762, 7.7). Comparatively, the Proposed NDRLs for (WB) were (677, 4.2) which were lower than Swiss National Data (720, 5.0). It is worth noted that, Swiss had about 5000 (HB) & 706 (WB), UK had 370 (HB) and France had 1000 (HB) entries. Calculated ED varied from 4.6 to 13mSv, (mean values=8.4 mSv) for HB and from 4.5 to 8.4 mSv (mean value=5.6 mSv) for WB scans. The study demonstrated the need for national CT DRLs for PET/CT as part of the state of the KW strategy for improving the national health services.

INTRODUCTION

While the clinical applications of CT equipment and their benefits to patients are significant, there is increased global focus on the need to carefully manage radiation exposures from CT imaging, as radiation doses from CT examinations are in general, higher than those from most other medical x-ray imaging examinations.

The development of PET/CT systems has permitted concurrent anatomic and functional imaging of organs and lesions that allows better evaluation of disease [1-3]. The CT components of PET/CT systems are equivalent in power output to their stand-alone versions and may be used for diagnostic purposes under appropriate CT technique. In addition to diagnostics acquisition, the application of CT in hybrid PET/CT scanners may serve other specific purposes, including attenuation correction of the PET image data and tissue localization [4]. The CT dose measurement concept is based on the CT dose index (CTDI), which represents the average absorbed dose from irradiation of contiguous slices. The CTDI for body examinations is measured from 1 full-axial-rotation scan using a 100-mm-long pencil ion chamber placed in the centre and again in the periphery slots of a 32-cm phantom. These 2 measurements are termed $CTDI_{100}^{x}$, where the subscript represents the axial extent of the data collection in millimeters and the superscript represents the ion chamber location in the phantom. The center and periphery measurements are combined into a weighted sum, $CTDI_w = 1/3 \times CTDI_{100}^{centre} + 2/3 \times CTDI_{100}^{periphery}$, meant to represent the average dose across the entire phantom. The $CTDI_w$ is then divided by the pitch factor to accommodate gaps or overlay in contiguous CT projections (i.e., a volume), and the subscript is changed again to indicate this normalization ($CTDI_{vol}$) **[5].** Dose characterization, optimisation, and reference levels based on the CTDI concept have been well studied and understood for diagnostic CT**.** Various organizations in the United States and Europe have established dose reference levels for diagnostic CT based on the 75th percentile of CTDI values recorded from national surveys of different body regions [5-7]. For example, the American College of Radiology has established $CTDI_{vol}$

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dose reference levels for diagnostic head CT ($CTDI_{vol} \leq 75$ mGy) and abdominal CT ($CTDI_{vol} \leq 25$ mGy) [8].

An ^{18}F-FDG PET/CT examination has potential for high patient dose from the combination of the x-rays used to acquire the CT image and the radiotracer administered into the patient to acquire the PET image. The methodology to estimate the radiation exposure of patients receiving ^{18}F-FDG has been well studied and understood [9]. Generally, administered ^{18}F-FDG activities range from 1.25 to 5 MBq/kg, depending on the sensitivity of the PET scanner (2 or 3-dimensional) [10], which equates to a whole-body effective dose of approximately 8.4 mSv for a 70-kg patient who receives an activity concentration of 5 MBq/kg. Including CT as part of a PET/CT examination can raise the total effective dose to as high as approximately 26 mSv [11-14]. However, estimates of PET/CT effective dose are variable and critically depend on an institution's specific CT technique and activity administration protocol [15]. In general, the CT component of a PET/CT examination can contribute more than 50% of the total-examination effective dose.

Unlike diagnostic CT, published dose reference levels for CT used in hybrid PET/CT examinations are limited. There is limited guidance on CT dosimetry metrics in the literature on nuclear medicine practice standards, and many of these reports reference dedicated diagnostic CT practice standards, which may not be appropriate for CT in PET/CT. Of the limited documentation on CT technique for PET oncology, there is general acceptance that CT dose is tailored to its purpose in the reconstruction or the interpretation process [15-16]. For example, acquisition protocols may be designed to achieve high image quality while considering patient dose [11 & 13], compensate for the PET temporal resolution [17-18] or collect ultra-low-dose attenuation correction data [19]. The wide range of $CTDI_{vol}$ values reported in this work likely represents an aggregate summary of these techniques. There are a limited number of studies investigating the optimization of CT technique and image quality for diagnostic and oncologic PET/CT. Most of these studies have focused on lowering estimates of effective dose while maintaining high image quality using the Alderson RANDO anthropomorphic phantom (The Phantom Laboratory) [11-12 & 20].

An internationally recognized approach to radiation protection of patients, recommended by the International Commission on Radiological Protection (ICRP), is the establishment and use of diagnostic reference levels (DRLs) which are dosimetric indicators, established from surveys of imaging practice and provide guidance to help manage dose and promote optimization, so that the applied dose is appropriate for a given clinical need. Furthermore, a widely accepted approach to optimization of medical radiation exposures, recommended by the ICRP [21-22] and the International Atomic Energy Agency (IAEA)[23], is the establishment and use of national, regional and local DRLs.

Diagnostic reference levels (DRL) of the volumetric CT dose index ($CTDI_{vol}$) are levels for Whole-Body/Half -Body CT used in PET/CT examinations are limited [1].

Surveys of dose estimates from imaging modalities highlight the substantial variations in dose between some health care facilities for same examination or procedure and similar patient group (adults or children of defined sizes). Such observations indicate the need for standardization of dose and reduction in variation in dose without compromising the clinical purpose of each examination or procedure. Examination-specific or procedure-specific DRLs for various patient groups can provide the stimulus for monitoring practice to promote improvements in patient protection [24].

DRLs should be set for representative examinations or procedures performed in the local area, country or region where they are applied. National DRLs (NDRLs) should be set on the basis of wide scale surveys of the median doses representing typical practice for a patient group (e.g. adults or children of different sizes) at a range of representative healthcare facilities for a specific type of examination or procedure. NDRLs are commonly set at the third quartile values (the values that splits off the highest 25% of data from the remaining 75%) of these national distributions [25]. As such, NDRLs are not optimum doses, but nevertheless they are helpful in identifying potentially unusual practice (healthcare facilities where median doses are among the highest 25% of the national dose distribution). DRLs can be also established for a region within the country or, in some cases, regions of several countries. They can be also used to set updated values for new imaging technologies that may allow lower dose levels to be achieved. Where no national or regional DRLs are available, DRLs can be set based on local dosimetry or practice data, or can be based on published values that are appropriate for the local circumstances. Clinical protocols for performing a particular examination or procedure should be reviewed if the comparison shows that the facility's typical dose exceeds the DRL, or that the facility's typical dose is substantially below the DRL and it is evident that the exposures are not producing images of diagnostic usefulness or are not yielding the expected medical benefit to the patient. The resulting actions aimed at improving the optimization of protection and safety, which usually, but not necessarily, result in lower typical doses of the facilities for the examinations or the procedures. The examinations or procedures included should represent at least the most frequent examinations performed in the region for which dose assessment is practicable, with priority given to those that result in the highest patient radiation dose.

There is no preferred custodian: what is important is that a patient dose database (for DRLs) is established and maintained, DRL values are set, disseminated through the regulatory processes, and a process for periodic review is established. Fast moving technological developments in medical imaging are providing new opportunities to automatically track and benchmark patient doses. Early evidence in some countries with more advanced electronic systems is very promising.

In this study, DRLs for each center was calculated based on the local practice and then a national DRL (NDRL) for each examination or procedure and patient group was proposed adopting the third quartile value of the volume computed tomography dose index (CTDIvol) and dose length product (DLP) following wide scale national surveys according to the IPEM-UK frame work and the ICRP recommendation for the state of Kuwait.

A comparative study to this project were a national survey conducted by the UK, Swiss and France on PET/CT oncologic

procedures from 47, 16 and 56 centers having PET/CT units [26-28].

METHODOLOGY

The study was a multicentre collaborative research, attempting to collect multiple data from CT of PET/CT hybrid imaging system (that were in current practice in Kuwait hospitals) and to analysis results for setting up a NDRL base line for Kuwait. The data collection was restricted to adult patients as per the Kuwait Ethical Committee recommendation.The Methodology, based on the UK - IPEM, was adopted and was tailored to suit the proposed study involving the Kuwait NM clinical centers. The studies were carried out with participation of 7 PET/CT centers in the state of Kuwait. We managed to collect 197 patient data for CT part of PET/CT centers. The focus was on all PET/CT imaging systems and procedures regardless of their locations and numbers of the systems availability in one center.

To reduce the influence from centers that provided a significantly large number of entries compared to others, the limiting data contribution from each center was set to a maximum of 30 entries. Majority of PET/CT imaging were dedicated to the oncology scan and the collected data were based mostly on this type of imaging and the other isolated studies including heart and brain were excluded. In addition, all topograms (scanograms) and monitoring steps used in contrast-enhanced CT acquisitions (if any) were excluded from the analysis. All proposed CTDI*vol* were approximated to the first decimal place and the DLP to the nearest whole number.

The priority was to estimate typical patient dose quantities for the common present practice on adult patients according to the following steps:

- The record displayed values of radiation dose quantity for maximum samples of 30 typical adult patients per center (i.e. 210 sample data for all the centers), undergoing procedures for common clinical indications. For CT part, the clinical purpose of exposure, attenuation correction (AC), localization or diagnosis for the PET/CT imaging centers were recorded on Whole body, Half Body.
- Calculated, for each type of examination, the median values of dose quantities (e.g. $CTDI_{vol}$ and DLP for CT); which were the typical dose levels (but were not the local DRLs that are set for a group of imaging systems or a group of hospitals).
- Compared the typical dose levels (median values) with published DRLs for a similar practice in the absence of local or national DRLs (e.g. UK or Swiss, France and North America), in order to provide a broad indication of our relative performance and urgency of need for improvement in our imaging technique. A proposed national DRL for Kuwait was then suggested.
- Each center was provided with a guideline summary, a comprehensive "data sheet" and "help sheets" for different scanner types to assist the centres to find various parameters.
- The effective dose for each type of examination using CT part of PET/CT was calculated based on the measured dose values.
- A dedicated software package (i.eImPACT St. George's Healthcare-UK) and CT-Expo software (MedizinischeHochschule) were used to determine CTDIvol and to estimate the ED based on scanner model and the reported CT parameters. The Sante DICOM viewer was used to retrieve all the listed parameters in the data sheets.

Statistical analysis was performed on the data collected for each protocol from the participating centers, in respect of volumetric CT dose index (CTDI*vol*), dose length product (DLP) and scan length (SL), taking into consideration the intended aim (attenuation correction and localization) declared by each nuclear medicine center. For the each of these metrics, the number of entries, median, mean, standard deviation, minimum and maximum values and 75^{th}& 25^{th} percentiles of the combined were calculated. Rounded third quartile values of CTDIvol and DLP were used to produce suggested NDRLs, whereas rounded first quartile values were used to produce achievable doses as a further aid to optimization [29-30].

In order to provide verification, the analyses were performed independently. Once the data were analyzed, NDRLs representing the 75th% percentile of the data distribution, were proposed in addition to achievable dose (defined as the 25th% percentile of the data distribution) for each protocol. The ICRP suggests taking the third quartile of the distribution of individual median values as the DRL. However, in this study, we present both mean and median for DRL to accommodate suggestions by the various groups, including the UK, Swiss and France national surveys.

All PET/CT systems at the 7 centers in KW, except at one center, used Automatic exposure control (AEC) that modulates radiation exposure automatically and is widely used for optimization of radiation dose in CT [31-33]. AEC is a key technology for dose optimization and allows to reduce radiation dose while keeping image quality constant among patients and among locations within a given patient.

We also estimated the effective dose (ED) as a prerequisite for optimization and monitoring of radiation exposure of the CT part of PET/CT facilities. ED is often estimated as a product of the DLP value and a conversion factor selected according to the imaging region [34-36]. CTDIvol is calculated on the basis of radiation dose measured in imaging 16-cm and 32-cm CT dosimetry phantoms for head-mode and body-mode imaging, respectively. When using the same scanner parameters, CTDIvol, and consequently DLP, is larger for a 16-cm phantom than for a 32-cm phantom because of less absorption within a smaller phantom.

The conversion factor from DLP to ED depends on the location, size, and radiosensitivity of organs and tissues exposed to radiation and is lower for the head than for the trunk. For 18F-FDG PET/CT oncology applications, CT images are usually acquired from the head to the proximal thigh sequentially, and a single DLP value, representing half body radiation exposure, is provided on a scanner.

It is also important to note that whereas the fundamental concept of ED has not changed with new ICRP recommendations, important aspects of its calculation have been updated, leading in particular to changes in values of dose per unit exposure since the previous UK CT survey for 2003.

Furthermore, ICRP has now recommended the application of specific reference persons for the calculation of the organ doses necessary for the estimation of ED using Monte Carlo techniques to simulate radiation transport in computational anthropomorphic phantoms. The ICRP adult male (AM) and adult female (AF) voxel phantoms will be adopted in future ICRP publications in place of the physical or mathematical phantoms used previously for the calculation of ED.

To assess the radiation dose from the CT component of the examination, we used dose-length product (DLP) values from the scanner-generated dose reports and a conversion factor—that is, the region-specific normalized effective dose per DLP ($mSv \times mGy^{-1} \times cm^{-1}$) [37]. Effective dose (*ED*) was then estimated as the product of the *DLP* and the corresponding conversion factor (*k*): $ED\ (mSv) \approx k \times DLP$.

For the half body and whole body scan, we used a **k** value of 0.015 $mSv \times mGy^{-1} \times cm^{-1}$ and 0.0093 $mSv \times mGy^{-1} \times cm^{-1}$ respectively [38-39]. The coefficients of ED/DLP for examinations were for adult patients and were calculated as mean values, over a range of CT scanner models operating at medium applied potentials (principally 120 kVp), on the basis of ICRP 103 tissue weighting factors and ICRP 110 voxel phantoms (as an average for AM and AF) [40].

For the calculation of displaying CTDIvol and DLP; GE scanners (GE, Milwaukee, Wisconsin, USA) using 32 cm body CTDI phantom on all systems in this study. Patients were not categorized by age, sex, or weight because the scanning protocol was used with the automatic exposure control (AEC), which accounted for differences in patient size.

All PET/CT centers in this study, except one center, used the Adaptive Statistical Iterative Reconstruction (ASiR) that is the first commercially available reconstruction algorithm that provided significant dose benefit for CT imaging. ASiR has been accepted by numerous sites as the standard-of-care protocol for a variety of applications. As of March 2014, it has been installed on more than 4,200 CT systems, and it is the world's most-used iterative reconstruction (IR) method. ASiR has potential to achieve significant reductions in patient radiation dose in CT exams while achieving image reconstruction speed similar to that of conventional analytical reconstruction using filtered back projection (FBP).

The average CT effective doses presented in this study, have been estimated using the conversion factors stated in the ICRP 102 report and Shrimpton *et al* [41,39].

International Comparison

The mean and median values of dose quantities (e.g. $CTDI_{vol}$ and DLP for CT) of data collected from the Kuwait multiple centers, to establish whether they are above or below the published DRL. Mean values were recommended earlier, but the recent recommendations are favoring median values [42-44].

A similar work has been recently performed and published by the CT working groups in the UK, Swiss and France [26-28].Some of the protocols are common in Kuwait and thus DRL's can be directly compared. For comparison purposes, CTDI*vol* was the most relevant metric, whereas DLP depends directly on the scan length applied at individual centers.

RESULTS AND DISCUSSION

This study has been able to generate data from a truly representative cross section of Kuwait PET/CT practice that is mostly exercised for oncology examination. The data for other studies, including heart and brain were limited to provide a statically acceptable and accurate results and as such were not included in this study. These studies may be considered in the future audit.

The half-body (chest, abdomen and pelvis) fluorine-18-fluorodeoxyglucose (18F-FDG) oncology imaging comprised the majority of PET/CT imaging procedures in PET/CT centers in Kuwait (53% of total collected data, though there was much variation in half body studies in the centers) with the rest of PET/CT studies (47%) performed as the whole body examination (head to toe) using F18-FDG or F18-NAF.

All the participating centers, except one, used AEC and ASiR in acquiring CT part of the PET / CT examination. Minimum and maximum range of mA for setting AEC were very much variable (14-209 mA & 81-400 mA respectively) for both HB and WB oncology PET/CT examinations. One center who did not use AEC, had set the mA low, in the range of 50-83 mA for PET/CT studies, that could be due to intention to use the CT scan for the purpose of attenuation correction at the foremost.

There was not much variation in setting CT tube voltage (i.e. 120kV) for the PET/CT examinations across the 7 centers and in particular all centers adopted the stated value.

Maximum variation in mean value of SL (cm) between 7 PET/CT centers was 22% for HB and 11% for WB PET/CT examination according to the Tables [1-2] data. The mean and median values of SL (cm) for the HB scan were (106, 104) and for the WB were (167, 169) which appeared to be higher than the UK HB (95, 94) and the Swiss HB (94, 101) and WB (119, 128). It is worth noted that the HB was defined to include chest-abdomen-pelvis scan length and the WB scan length was referred to head to toe scan for KW protocols that could be different in setting SL from UK and Swiss protocol point of views. Swiss had only 6 entries for WB scan whereas KW had 93 entries in total. The average male and female lengths for UK and Swiss national were not known.

Summary of dose and scan length statistics for the half body, whole body and the clinical purpose combinations are presented in Tables [1-2], whereas Table [3] presents the same data for the combined half and total body examinations.

In all cases, the CT data were used for AC and localization, but acquisition parameters and patient doses among the 7 PET/CT center systems varied, with a maximum of twofold variation in the dose - length product (DLP) between centers. The third quartile of CTDIvol and DLP values were used to propose the local DRL (LDRL) and the first quartile of CTDIvol and DLP values were calculated to suggest the achievable LDRL for each participating center accordingly [Tables 4-6]. There was a maximum of twofold variation in LDRL for CTDIvol and DLP between seven centers [Tables 4-6]. The proposed national diagnostic reference level (NDRL) and achievable DRL (based on the median and mean values of CTDIvol and DLP) for HB, WB and HB+WB for the proposed examination were calculated and were presented in Tables [7-8].

Table 1 Summary statistics for the distribution of the scanner volume computed tomography dose index and dose-length product for the protocol list (HB) of each centre using PET/CT.

Center	Protocol [Use: AC-L]	$CTDI_{vol}$ [mGy]					DLP [mGy x cm]					Scan Length [cm]				
		Median	Mean	STD	Min	Max	Median	Mean	STD	Min	Max	Median	Mean	STD	Min	Max
1	PET Oncology [HB] : 8N	5.5	5	0.1	5.3	5.7	569	573	26	543	631	97	100	4	97	109
2	PET Oncology [HB]: 21N	4.3	4.5	1.0	3.1	8.7	463	487	125	363	1003	97	101	7	86	109
3	PET Oncology [HB]: 8N	6.0	6.9	1.0	5.0	9.0	803	869	196	616	1210	133	128	15	97	145
4	PET Oncology [HB]: 12N	4.8	4.7	1.6	2.2	8.1	598	544	173	225	825	109	108	9	97	133
5	PET Oncology [HB]: 19N	4.6	5.2	2.0	3.0	5.2	488	554	187	330	975	97	103	9	97	135
6	PET Oncology [HB]: 16N	2.9	2.7	0.4	1.8	3.1	332	324	135	206	332	100	102	10	88	112
7	PET Oncology [HB]: 20N	2.6	2.9	1.3	1.0	2.9	329	341	138	118	582	97	102	8	86	110

*AC- Attenuation Correction, L– Localization, HB – Half Body, N – Number of entries, CTDIvol – CT Dose Volume, DLP – Dose Length Product

Table 2 Summary statistics for the distribution of the scanner volume computed tomography dose index and dose-length product for the protocol list (WB) of each centre using PET/CT.

Center	Protocol [Use: AC-L]	$CTDI_{vol}$ [mGy]					DLP [mGy x cm]					Scan Length [cm]				
		Median	Mean	STD	Min	Max	Median	Mean	STD	Min	Max	Median	Mean	STD	Min	Max
1	PET Oncology [WB] : 20N	3.9	3.9	0.8	2.5	5.7	665	665	111	473	879	168	171	9	156	180
2	PET Oncology [WB]: 6N	2.5	2.8	0.5	2.3	3.5	443	485	90	403	608	168	170	4	168	180
3	PET Oncology [WB]: 21N	4.2	5.0	2.4	2.0	12.9	739	901	445	338	2398	180	174	9	156	192
4	PET Oncology [WB]: 17N	5.0	4.0	0.8	2.9	5.9	659	677	139	468	1005	168	166	9	156	180
5	PET Oncology [WB]: 10N	3.3	3.1	0.6	2.3	3.3	496	492	77	394	598	168	164	13	97	184
6	PET Oncology [WB]: 11N	2.9	2.8	0.1	1.8	3.8	518	483	137	191	709	164	155	20	96	166
7	PET Oncology [WB]: 8N	2.8	2.8	0.6	1.5	3.9	465	480	122	254	721	167	166	11	155	180

*AC- Attenuation Correction, L– Localization, HB – Half Body, N – Number of entries, CTDIvol – CT Dose Volume, DLP – Dose Length Product

Table 3 Summary statistics for the distribution of the scanner volume computed tomography dose index and dose-length product for the protocol list (WB+HB) of each centre using PET/CT.

Center	Protocol [Use: AC&L]	$CTDI_{vol}$ [mGy]					DLP [mGy x cm]					Scan Length [cm]				
		Median	Mean	STD	Min	Max	Median	Mean	STD	Min	Max	Median	Mean	STD	Min	Max
1	PET Oncology [WB+HB]: 28N	4.0	4.3	1.0	2.5	5.7	650	637	103	473	879	168	148	35	97	180
2	PET Oncology [WB+HB]:27N	4.2	4.1	1.2	2.3	8.7	463	487	118	363	1003	109	117	29	86	180
3	PET Oncology [WB+HB]:29N	4.9	5.4	2.2	2.0	12.9	768	892	393	338	2398	168	161	23	97	192
4	PET Oncology [WB+HB]:29N	5.0	4.3	1.2	2.2	8.1	635	616	167	225	1005	156	144	28	97	180
5	PET Oncology [WB+HB]:29N	4.2	4.5	1.9	2.3	4.5	488	533	161	330	975	109	124	31	97	184
6	PET Oncology [WB+HB]:27N	2.9	2.7	0.1	1.8	3.8	339	388	124	191	709	110	124	30	88	166
7	PET Oncology [WB+HB]:28N	2.7	2.9	1.1	1.0	5.1	364	362	154	118	721	109	107	39	86	180

*AC- Attenuation Correction, L– Localization, TB – Total Body, HB – Half Body, N – Number of entry, CTDIvol – CT Dose Volume, DLP – Dose Length Product

Third quartile DLP (mGy x cm) and CTDIvol (mGy) values (556, 5.5) related to the Kuwait HB PET/CT scans (for setting NDRL) were higher than the current UK NDRL (400, 4.3) but lower than the Swiss National NDRL (620, 6) and the France National NDRL (762, 7.7). Comparatively, the Proposed NDRLs for (WB) was (677, 4.2) which was lower than Swiss National Data (720, 5.0).

The Kuwait results were in reasonable agreement with the centers, though, Swiss had about 5000 (HB) & 706 (WB), UK had 370 (HB) and France had 1000 (HB) entries. Calculated ED varied from 4.6 to 13mSv, with a mean value equal to 8.4 mSv for HB and from 4.5 to 8.4 mSv with a mean value equal to 5.6 mSv for WB scans [Tables 9-10].

Table 4 Proposed and achievable LDRL for AC and Localization product for the clinical NM examination protocol (HB) at each centre using PET/CT

Center	Protocol [Use: AC&L]	Proposed LDRL [75th%]		Achievable DRL [25th%]	
		CTDIvol [mGy]	DLP [mGy x cm]	CTDIvol [mGy]	DLP [mGy x cm]
1	PET Oncology [HB] : 8N	5.5	577	5.4	555
2	PET Oncology [HB]: 21N	4.6	486	4.2	432
3	PET Oncology [HB]: 8N	6.9	1036	5.7	734
4	PET Oncology [HB]: 12N	5.6	668	4.0	455
5	PET Oncology [HB]: 19N	5.1	561	4.3	442
6	PET Oncology [HB]: 16N	2.9	339	2.4	302
7	PET Oncology [HB]: 20N	4.3	447	1.9	191

*AC- Attenuation Correction, L– Localization, HB – Half Body, CTDIvol – CT Dose Volume, DLP – Dose Length Product, LDRL – Local Dose reference Level, DLP – Dose Reference Level

Table 5 Proposed and achievable LDRL for AC and Localization product for the clinical NM examination protocol (WB) at each centre using PET/CT

Center	Protocol [Use: AC&L]	Proposed LDRL [75th%]		Achievable DRL [25th%]	
		CTDIvol [mGy]	DLP [mGy x cm]	CTDIvol [mGy]	DLP [mGy x cm]
1	PET Oncology [WB] : 20N	4	719	3.4	613
2	PET Oncology [WB]: 6N	2.4	573	2.3	408
3	PET Oncology [WB]: 21N	5.5	1012	3.9	714
4	PET Oncology [WB]: 17N	4	696	3.5	586
5	PET Oncology [WB]: 10N	3.4	552	2.5	414
6	PET Oncology [WB]: 11N	3.0	546	2.7	462
7	PET Oncology [WB]: 8N	2.9	530	2.7	441

*AC- Attenuation Correction, L– Localization, HB – Half Body, CTDIvol – CT Dose Volume, DLP – Dose Length Product, LDRL – Local Dose reference Level, DLP – Dose Reference Level

Table 6 Proposed and achievable LDRL for AC and Localization product for the clinical NM examination protocol (WB+HB) at each centre using PET/CT

Center	Protocol [Use: AC&L]	Proposed LDRL [75th%]		Achievable DRL [25th%]	
		CTDIvol [mGy]	DLP [mGy xCm]	CTDIvol [mGy]	DLP [mGy xCm]
1	PET Oncology [WB+HB]: 28N	5.3	680	3.8	562
2	PET Oncology [WB+HB]:27N	4.2	496	3.7	429
3	PET Oncology [WB+HB]:29N	6.0	1025	4	714
4	PET Oncology [WB+HB]:29N	5.0	694	3.5	538
5	PET Oncology [WB+HB]:29N	4.8	552	3.4	432
6	PET Oncology [WB+HB]:27N	2.9	510	2.4	302
7	PET Oncology [WB+HB]:28N	3.7	470	1.9	221

*AC- Attenuation Correction, L– Localization, HB – Half Body, TB – Total Body, CTDIvol – CT Dose Volume, DLP – Dose Length Product, LDRL – Local Dose reference Level, DLP – Dose Reference Level

Table 7 Proposed and achievable NDRL for AC and Localization product for the suggested clinical NM protocols using PET/CT: [Based on Mean Value]

Center	Protocol [Use: AC&L]	Proposed NDRL [75th%]		Achievable DRL [25th%]	
		CTDvol [mGy]	DLP [mGy x Cm]	CTDvol [mGy]	DLP [mGy x Cm]
1	PET Oncology [HB]:104N	5.5	556	3.7	414
2	PET Oncology [WB]:93N	4.0	677	2.8	484
3	PET Oncology [WB +HB]:197N	4.4	616	3.5	438

*AC- Attenuation Correction, L– Localization, HB – Half Body, CTDIvol – CT Dose Volume, DLP – Dose Length Product , NDRL – National Diagnostic Reference Level, DLP – Dose Reference Level

Table 8 Proposed and achievable NDRL for AC and Localization product for the suggested clinical NM protocols using PET/CT: [Based on Median Value]

Center	Protocol [Use: AC&L]	Proposed NDRL [75th%]		Achievable DRL [25th%]	
		CTDIvol [mGy]	DLP [mGy x Cm]	CTDIvol [mGy]	DLP [mGy x Cm]
1	PET Oncology [HB]:104N	5.2	568	3.6	398
2	PET Oncology [WB]:93N	4.2	655	2.8	481
3	PET Oncology [WB +HB]:197N	4.6	643	3.5	414

*AC- Attenuation Correction, L– Localization, HB – Half Body, CTDIvol – CT Dose Volume, DLP – Dose Length Product ,NDRL – National Diagnostic Reference Level, DLP – Dose Reference Level

Table 9 Comparison of Proposed NDRL for AC and Localization product for the suggested clinical NM protocols using PET/CT: [Based on Mean Values]

Center	Protocol [Use: AC&L]	UK Proposed NDRL		SWISS Proposed NDRL		FRANCE Proposed NDRL		KUWAIT Proposed NDRL	
		CTDIvol [mGy]	DLP [mGy x Cm]	CTDIvol [mGy]	DLP [mGy x Cm]	CTDIvol [mGy]	DLP [mGy x Cm]	CTDIvol [mGy]	DLP [mGy x Cm]
1	PET Oncology [HB]:104N	4.3	400	6.0	620	6.6	628	5.5	556
2	PET Oncology [WB]:93N			5.0	720	7.7	762	4.2	677
3	PET Oncology [[WB +HB]:197N	X	X	X	X	X	X	4.4	616

*AC- Attenuation Correction, L– Localization, HB – Half Body, CTDvol – CT Dose Volume, DLP – Dose Length Product, NDRL – National Diagnostic Reference Level, DLP – Dose Reference Level

Table 10 Comparison of Proposed NDRL for AC and Localization product for the suggested clinical NM protocol using PET/CT: [Based on Median Values: KW only]

Center	Protocol [Use: AC&L]	UK Proposed NDRL		SWISS Proposed NDRL		FRANCE Proposed NDRL		KKUWAIT Proposed NDRL	
		CTDIvol [mGy]	DLP [mGy x Cm]	CTDIvol [mGy]	DLP [mGy x Cm]	CTDIvol [mGy]	DLP [mGy x Cm]	CTDIvol [mGy]	DLP [mGy x Cm]
1	PET Oncology [HB]:104N	4.3	400	6.0	620	6.6	628	5.2	568
2	PET Oncology [WB]:93N			5.0	720	7.7	762	4.2	655
3	PET Oncology WB +HB]:197N	X	X	x	x	X	X	4.6	638

*AC- Attenuation Correction, L– Localization, HB – Half Body, CTDIvol – CT Dose Volume, DLP – Dose Length Product, NDRL – National Diagnostic Reference Level, DLP – Dose Reference Level

Table 11 Comparison of CT effective dose as a result of AC and Localization product for the suggested clinical NM protocol using PET/CT: Using the recommended published conversion factors; K=0.015 (mSv/mGy/cm) and K=0.0093 (mSv/mGy/cm)

Center	Protocol [Use: AC-L]	ED [mSv] Half Body [HB] K= 0.015 mSv/mGy/cm		ED [mSv] Whole Body [WB] K= 0.0093 mSv/mGy/cm			ED [mSv] Scan Length [WB+HB]	
		Median	Mean		Median	Mean	Median	Mean
1	PET Oncology [HB] : 8N	8.5	8.6	PET Oncology [WB] : 20N	6.2	6.2	PET Oncology [WB+HB]: 28N	7.4	7.4
2	PET Oncology [HB]: 21N	6.9	7.3	PET Oncology [WB]: 6N	4.1	4.5	PET Oncology [WB+HB]:27N	5.5	5.9
3	PET Oncology [HB]: 8N	12	13	PET Oncology [WB]: 21N	6.9	8.4	PET Oncology [WB+HB]:29N	9.5	10.7
4	PET Oncology [HB]: 12N	9	6.8	PET Oncology [WB]: 17N	6.1	6.3	PET Oncology [WB+HB]:29N	7.6	6.6
5	PET Oncology [HB]: 19N	7.3	8.3	PET Oncology [WB]: 10N	4.6	4.6	PET Oncology [WB+HB]:29N	6.0	6.5
6	PET Oncology [HB]: 16N	5	4.9	PET Oncology [WB]: 11N	4.8	4.5	PET Oncology [WB+HB]:27N	4.9	4.7
7	PET Oncology [HB]: 20N	4.3	4.6	PET Oncology [WB]: 8N	4.3	4.5	PET Oncology [WB+HB]:28N	4.3	4.6

*AC- Attenuation Correction, L– Localization, HB – Half Body, N – Number of entry, CTDIvol – CT Dose Volume, DLP – Dose Length Product
NDRL – National Diagnostic Reference Level, DLP – Dose Reference Level, K= Conversion Factor

The calculated ED varied from 4.6 to 13mSv (with a mean value equal to 8.4 mSv) for HB and from 4.5 to 8.4 mSv (with a mean value equal to 5.6 mSv) for WB scans respectively [Table 11].

Six out of seven centers had accommodated Discovery™ GE PET/CT with Optima™, 64 slices CT part, including one digital GE PET/CT. The remaining scanner was a Fillips Gemini PET/CT. Six out of seven sites were reported using automatic current modulation (AEC) which goal is to automate the adjustment of tube current (mA) along the way based on patient thickness and the radiation attenuation of tissues, patient length and the asymmetry along the patient's body.

Data presented in Figures [1,3 & 5] show the range of doses (75th percentile CTDIvol) for the proposed HB, WB and HB+WB oncology examinations related to AC & Localization clinical purposes. Similarly, Figures [2,4 & 6] are presenting variations of DLP (75th percentile) for each NM center for HB, WB and WB+HB in relation to the proposed DLP for each NM PET/CT center. The dose results (CTDIvol) for 2 centers appear to be 47% and 51% less than the proposed NDRL for HB and about 49% less for the WB oncology examinations. The deviation could be justified as one of the centers has accommodated a state of art digital PET/CT which has elevated technology other than the rest of PET/CT respectively. The other center has accommodated a Philips PET/CT of an older model, setting a low mA for the purpose of attenuation correction primarily, and with no use of AEC or ASiR. The ratio of maximum to minimum mean doses for HB and WB scans between different centers for the same clinical studies varied from 1.1 - 3.7 for the HB and 1.5 -6.5 for the WB. There were variations of proposed and achievable local DRL in practice between 7 centers, highlighting the need for national DRL.

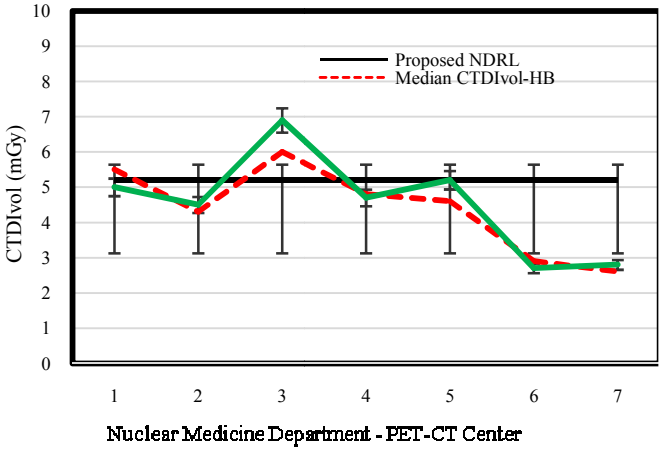

Figure 1 CTDIvol (75th percentile) for each PET-CT unit, compared to the proposed NDRL for HB data.

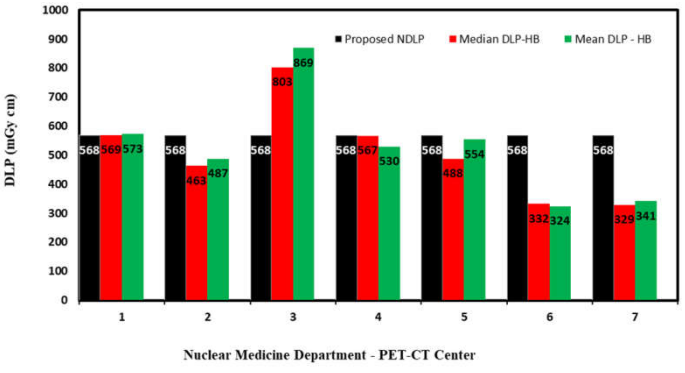

Figure 2 DLP (75th percentile) for each PET-CT unit, compared to the proposed NDLP for HB data.

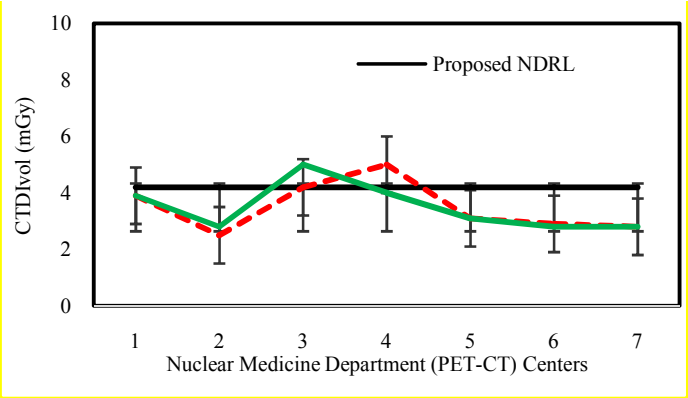

Figure 3 CTDIvol (75th percentile) for each PET-CT unit, compared to the proposed NDRL for WB data.

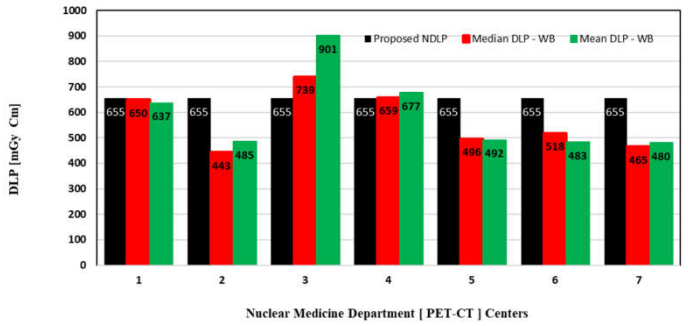

Figure 4 DLP (75th percentile) for each PET-CT unit, compared to the proposed NDRL for WB data.

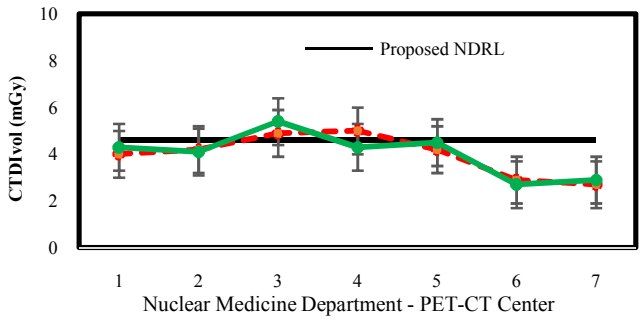

Figure 5 CTDIvol (75th percentile) for each PET-CT unit, compared to the proposed NDRL for WB+HB data.

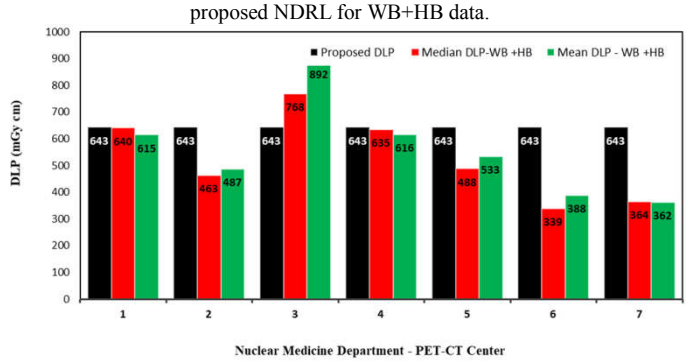

Figure 6DLP (75th percentile) for each PET-CT unit, compared to the proposed NDRL for WB +HB data.

CONCLUSIONS

It is anticipated that with the establishment of NDRLs and achievable dose, it will be possible to optimize practice across the Kuwait and reduce this variation in future surveys, and to promote improvements in patient protection and quality care in state of Kuwait. The outcome has further paved the way for setting a NDRL CT part of the PET / CT examination for Kuwait populations which based on the current facilities and practice that is more realistic than external sites, and it will facilitate and assist to create a data bank (i.e. National Archive) for the future years to sever as a monitoring tool to elevate quality care for KW populations.

DISCLOUSURE

This study was supported by the Kuwait Foundation for theAdvancement of Sciences (KFAS) research grant (PR1813MN01)that facilitated the initial phase of this investigationusing state of art technology, technique and advanced science.

Acknowledgements

We appreciate and thank the following NM PET/CT centers in Kuwait for their effective participation in provision of patient CT data (arranged alphabetically): Adan Hospital; Chest Diseases Hospital; Cancer Control Center; Farwaniya Hospital; Jahra Hospital; Jaber Al Ahmed Molecular Imaging Center and Mubarak Al Kabeer Hospital. We also thank IPEM -UK for their input.

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How to cite this article:

Michael Masoomi *et al*., 2019, Establishment of National DRL for CT in Hybrid Imaging Studies"the First National NM CT (PET) dose Audit for KW Population". *Int J Recent Sci Res.* 10(07), pp.33478-33488.
DOI: http://dx.doi.org/10.24327/ijrsr.2019.1007.3679

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