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Poor practice and governance in Lebanese national diagnostic reference levels of adult head and body computed tomography: A nationwide study

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ABSTRACT

Lebanon has one of the highest number of computed tomography (CT) scanners per capita in the world which could likely be one of the causative factors of its high cancer incidence. In this study, we aimed to establish a national diagnostic reference level (NDRL) in adult CT examinations of the head and body in Lebanon. Dose Length Product (DLP) (n = 2730) were recorded in 91 hospitals/centers in Lebanon for head, chest, and abdomen-pelvis CT. Data was obtained from adult patients (≥18 years) with a weight range of 75–80 kg, from January 2018 until December 2019. Then, the median, mean and 75th percentile of the DLP was calculated for each anatomical region. NDRL was reported as the 75th percentile. Then, the established NDRL was benchmarked with international countries as the USA, UK, and Australia. In our study, data were collected from imaging departments (n = 91), with a response rate of 65% of the national total. All CT scanners ranged from 1 to 256 slices. The 75th percentile for the DLP of the head, chest, and abdomen-pelvis CT scan in Lebanon was 1426, 646, and 967 mGy cm respectively. A significant difference in mean DLP of the chest and abdomen-pelvis CT in different governorates was noted with north Lebanon having the highest levels (604 and 882 mGy cm respectively) ($p < 0.05$). When benchmarked with 18 different countries, Lebanon ranked 2nd, 3rd, and 4th highest in 75th percentile DLP for head, chest, and abdomen-pelvis CT scans respectively. In conclusion, the established Lebanese NDRL for adult routine CT scans of head, chest, and abdomen-pelvis were significantly higher than the reported international radiation dose thresholds. This demonstrates a great scope for radiation dose reduction and the need for urgent intervention of DRL to optimize CT scanning procedures and protocols in Lebanon.

1. Introduction

The use of Computed tomography (CT) imaging continues to rise day by day due to its important role in understanding, diagnosing, screening, and managing various pathologies in medicine (Appel et al., 2018; Parakh et al., 2016). This increase could have contributed to increased radiation exposure to patients with the potential rising lifetime risk of cancer (Shao et al., 2020). Radiologists, radiographers, medical physicists, manufacturers, and researchers have implemented a series of improvements in examination protocol development, software, and hardware as well as artificial intelligence with the aim to reduce radiation dose (Mayo-Smith et al., 2014; Schindera et al., 2013; Willemink and Noël, 2019). Currently, in the United States, over 80 million CT scans were performed each year, compared with just three million in 1980 (Wildman-Tobriner et al., 2018). In Lebanon, the high CT scans application can be due to the rapidly aging Lebanese population in conjunction with very high rates of environmental pollution (Shamseddine et al., 2014) which has placed Lebanon as one of the highest

Abbreviations: CT, Computed Tomography; DRL, Diagnostic Reference Level; ALARA, As Low AS Reasonably Achievable; DLP, Dose Length Product.

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cancer rates in the world (Schlemmer et al., 2018). This high cancer incidence in Lebanon could potentially be coupled with one of the top ten largest per capita number of CT scanners in the world at 37.28 per million population (Schlemmer et al., 2018).

Diagnostic reference level (DRL) was introduced by the International Commission on Radiological Protection (ICRP) in 1996 (Brink and Miller, 2015; Fawzi et al., 2020). It aimed to act as an advisory measurement to improve optimization by identifying dangerous radiation doses exposed to patients from medical imaging (Brink and Miller, 2015; Connor et al., 2016; Järvinen et al., 2015). ICRP highlighted the need for justification and optimization of radiological examinations, focusing on the idea that patients' benefit is always above any other detriments and radiation exposure should be optimized according to clinical indications (Kanal et al., 2017). DRL can serve as a template to compare and benchmark radiation doses on local, regional, national, and international levels. It indicates the usual practice in an institution, region, and nation which can be used to detect levels above the established threshold which prompts further investigation, protection optimization, and protocol audit to achieve radiation reduction (Brink and Miller, 2015; Connor et al., 2016; Gray et al., 2005; Vassileva and Rehani, 2015). DRL embraces a multitude of imaging modalities starting from conventional radiography to CT, mammography and ending up in interventional radiologic procedures. The Dose Length Product (DLP) is the result of the product of the volumetric CT dose index and the length of CT performed in milliGray.cm (Tsapaki et al., 2006). The standard for DRL is typically set at approximately the 75th percentile of the distribution of collectively measured doses whether the source was a patient or a phantom (Erskine et al., 2014; Kanal et al., 2017; Mafalanka et al., 2014; Moorin et al., 2014; Santos et al., 2014; Saravanakumar et al., 2014; Schafer et al., 2014; Simantirakis et al., 2014; Strauss, 2014; Suliman and Mohammedzein, 2014; Vassileva and Rehani, 2015). Establishing a National DRL (NDRL) is of great importance and mandates a positive intricate communication between authorities and professional societies in a country.

Employing an NDRL is a crucial tool in radiation dose optimization, as it is endorsed by many professional and regulatory organizations in the world. To our knowledge, no organization has established an NDRL for adult computed tomography in Lebanon. Our study aimed to establish an NDRL in commonly performed adult CT examinations of the head and body in Lebanon and benchmark it with international levels.

2. Materials and methods

2.1. Study design and population

This retrospective study was approved by the Institutional Review Board (IRB) and was exempted for the patient's informed consent by the ethics committee. A snapshot of hospitals and medical centers all over Lebanon was taken. Of 140 institutions invited to participate in the study, 91 accepted voluntarily. Written administrative approval was obtained from medical directors and the IRB office of institutions prior to data collection.

Data were retrospectively collected from public (n = 16), private (n = 63) hospitals and medical centers (n = 12) all over Lebanon (total n = 91). The acceptance rate of hospitals and centers to participate in the study was approximately 65%. DLP (mGy.cm) values of the head, chest and abdomen-pelvis CT scans were collected from the Radiology Information System (RIS) and Picture Archiving and Communication System (PACS). These included data from routine CT scans performed on adult patients (>18 years of age) with a weight range of 70–80 kg, between January 2018 until August 2019. The estimated weight range selected was based on eye observations for an average body habitus that corresponds to protocols selected for an average weighted body. Specific weights were not taken as not all scans contained data on patient weight.

The radiation dose recorded provides a snapshot of practices during this period reflecting the working load and patient volume. Pediatric patients below the age of 18 years were excluded from the study. Quality control and assurance documents for each CT scanner were reviewed to ensure the manufacturer's daily, monthly, and yearly calibration tests have been carried out. This was conducted for each institution prior to collecting information to record the radiation dose levels which could be potentially affected the results if they were not calibrated correctly.

2.2. Data collected

Data were collected by 6 radiographers across 5 administrative divisions of Lebanon (governorates); Beirut, Mount Lebanon, South, North, and Beqaa. All radiographers were trained prior to field trip data collection by an expert in calculating CT radiation dose using DRL data collection criteria recommended by the ICRP. The total DLP, CT scan type, and detector number were recorded using a paper-based model from each hospital and center. The form was adapted from the one employed in the Australia NDRL survey (Hayton et al., 2013). For each hospital and center, DLP from three anatomical regions, Head, chest, and abdomen-pelvis were recorded. Then from these anatomical areas, the DLP of ten patients was recorded.

2.3. Effective dose calculation

For each of the CT scans, individual effective dose [mSv] was calculated from DLP [mGy.cm]), which were recorded for each patient. The Effective dose was calculated by using the DLP measurements and appropriate coefficients of body region (k coefficients: 0.0023 mSv.$mGy^{-1}.cm^{-1}$ for head CT, 0.017 $mSv.mGy^{-1}.cm^{-1}$ for chest CT, and 0.015 $mSv\ mGy^{-1}.cm^{-1}$ for abdominal CT) (Brady et al., 2015):

$$E = k \times DLP$$

2.4. Statistical analysis

Data sets were analyzed using IBM SPSS Statistics v22.0 (IBM Corp. Armonk, NY). The CT data were analyzed using descriptive statistics. The mean DLP for CT scans of the head, chest, and abdomen-pelvis examinations were calculated and compared between Lebanese Governorate, hospital type, and CT manufacturer by ANOVA, and quantitative variables were expressed as mean and standard deviation. Results with a $p \leq 0.05$, were considered significant. NDRLs were reported as the 75th percentile of DLP for CT of head, chest, and abdomen-pelvis and were benchmarked with international levels in the US, UK, Europe, and Australia.

3. Results

3.1. Hospitals and CT scanner

Ninety-one hospitals and centers were included in the study, where 69.2% were private hospitals, 17.5% public hospitals and 13.1% were medical centers. They represented 65% of all CT scanners available in Lebanon. All CT scanners surveyed had multislice scanners which ranged from 1-256 slices. Five different manufacturing brands of CT were found in the hospitals and centers visited (Toshiba/Canon Medical, Phillips, Siemens, Neusoft, and General Electric).

3.2. Dose results

NDRL were derived for each of the Head, chest, and abdomen pelvis routine CT scans for adult patients. The DRL was in terms of DLP and effective dose. The Lebanese NDRL was defined as the 75th percentile of the spread of mean doses from practices. The employment of the 75th percentile of DLP is better than the use of the mean since it compensates

for the possible outliers that result from different patient weights and sizes. A total of 2730 total DLP values for adult patients who underwent routine head (910 DLP), chest (910 DLP), and abdomen-pelvis (910 DLP) CT were recorded (Table 1). For routine head, chest, and abdomen-pelvis CT the mean DLP (1165.89, 503.4, and 793 mGy.cm respectively), 75th percentile DLP (1426, 646, and 967 mGy.cm respectively), and effective dose (3.28, 10.9,8 and 14.51 Sv respectively) were calculated.

Further stratification of data was performed according to the location and type of the visited intuitions (Table 2). The 75th percentile for head CT was the highest in Mount Lebanon (1480.50 mGy.cm) and lowest in North Lebanon governorates (1363.14 mGy.cm), whereas, for chest CT the highest was in North Lebanon (752.70 mGy.cm) and the lowest in Mount Lebanon (565.57 mGy.cm). In addition, for abdomen-pelvis, the 75th percentile was the highest in the north of Lebanon (1099 mGy.cm) and lowest in Beirut (822.79 mGy.cm). No statistical significance was demonstrated when comparing the mean DLP of head CT in different Lebanese governorates ($p > 0.05$). Whereas a significant difference was demonstrated for chest and abdomen-pelvis CT ($p < 0.05$).

When comparing the 75th percentile according to the type of institution for head and chest CT the lowest DLP was recorded in Private hospitals (1421 and 630.36 mGy.cm respectively) and the highest for the head was in public hospitals (1443 mGy.cm) and for chest CT in public hospitals and medical centers (697–698.5 mGy.cm). The 75th percentile for abdomen-pelvis CT scan was the lowest in public hospitals (931.30 mGy.cm) and highest at medical centers (992 mGy.cm). In addition, no statistical significance was demonstrated when comparing different *mean* DLP of the head, chest, and abdomen pelvis CT in different types of hospitals ($p > 0.05$).

When comparing the 75th percentile for the DLP in head CT scanner, GE (1386 mGy.cm) had the lowest dose and Toshiba/Cannon had the highest dose (1599.18 mGy.cm) (Table 3). Whereas for chest and abdomen-pelvis CT scanner Neusoft had the lowest value (614 and 943 mGy.cm respectively) and Philips had the highest value (698.76 and 1024.30 mGy.cm respectively).

The established Lebanese DRLs were compared with internationals doses in Table 4 and Fig. 1. Lebanese doses for head, chest and abdomen-pelvis CT scan are higher than in most international countries. In respect to all 19 countries, Lebanon occupies the 2nd, 3rd, and 4th place of highest 75th percentile DLP of the head, chest, and abdomen-pelvis CT respectively.

4. Discussion

In this study, a nationwide survey of radiation exposure during adult CT examination of head, chest, and abdomen-pelvis was employed aiming to establish the first NDRL in Lebanon. The survey revealed information on the radiation dose exposure to adult patients from CT, such as the effective dose and the mean and 75th percentile for the DLP of CT of head, chest, and abdomen-pelvis. These values are an accurate representation of the status of CT activities in Lebanon. The radiation doses were analyzed according to different parameters, the type of institution, its geographic location, type of CT scan manufacturer, and the number of CT detectors. Then, the doses were benchmarked with international values. Unfortunately, when benchmarked with 18 international countries, Lebanon demonstrated extremely high radiation levels. It ranked the 2nd, 3rd, and 4th order of country with the highest 75th percentile of DLP value for head, chest, and abdomen-pelvis CT scan respectively. These extremely dangerous Lebanese doses should raise great concern and attention from health professionals and organizations to investigate its causes and establish methods for protection optimization to achieve radiation reduction.

When taking into consideration the manufacturer of CT scanner, Siemens, General Electric, and Neusoft provided the lowest 75th percentile of DLP for head, chest, and abdomen-pelvis CT. On the other hand, our study demonstrated that Philips and Toshiba/Cannon provided the highest 75th percentile DLP. This was consistent with a study by Sohrabi et al. that stated that Siemens and GE CT scanners deliver lower radiation doses to patients and Philips generally deliver higher doses (Sohrabi et al., 2017). In addition, this study stated that Neusoft CT scanners also deliver higher radiation doses compared with other manufactures, which contradicts our findings (Sohrabi et al., 2017). This variability in doses can be explained by the differences in beam collimation and detector arrays of CT scanners. Another reason for this variability can be the adherence of radiographers to the CT parameters (Tube potential current and scan time) set by the manufacturers for chest and abdomen-pelvis CT scans without optimizing according to clinical indication. Some radiographers demonstrated limited knowledge regarding the functions of AC modulation while other institutions lacked its use during scanning. AC modulation plays an important role in dose optimization and it contributes to the reduction of delivered dose while maintaining adequate image quality Scan length, tube potential, and current are directly proportionate to the radiation dose exposed to patients (Livingstone et al., 2010). Thus, dose optimization is always essential. Significant variability in DRL of the chest and abdomen-pelvis CT scan in different Lebanese governorates with no specific trend was noticed. The 75th percentile for chest CT was the lowest in Mount Lebanon and the highest in the North. On the other hand, the 75th percentile for abdomen-pelvis CT was the lowest in Beirut and the highest in the North. Interestingly, the type of institution didn't significantly affect the 75th percentile for the DLP. Differences in CT technology, scanning protocols, and a load of hospitals are great contributors to these variations (Ekpo et al., 2018).

When comparing the established NDRL with other countries, Lebanon demonstrated to have a significantly higher dose for the head, chest, and abdomen-pelvis CT scan. Only Kenya demonstrated 13%, 38%, and 90% higher doses of the head, chest, and abdomen-pelvis CT scan respectively than Lebanon (Ekpo et al., 2018). In addition, Nigeria had 14% and 53% higher doses in the chest and abdomen-pelvis CT scan respectively, and Japan 3% higher abdomen-pelvis CT dose compared to Lebanon (Ekpo et al., 2018). The high radiation dose was extremely notable for head CT, where the 75th percentile for DLP was 47%, 48%, and 62% higher than UK, USA, and Australia respectively. In addition, chest CT had a 6%, 46%, and 65% higher dose, and for abdomen-pelvis CT a 30%, 25%, and 61% higher dose than UK, USA, and Australia respectively (Butler and Kanal, 2018; Roch et al., 2018). This further confirms the urgent need to optimize CT examinations and protocols in Lebanon and establish radiation dose monitoring guidelines. Significant radiation dose variations within and between Lebanon can be attributed to differences in CT technology, protocols used, and most importantly the levels of medical physicists and radiographers' training background. One of the great influences of the high radiation dose levels in Lebanon may be due to the educational and training background of radiographers. In Lebanon, the minority of working radiographers have a university bachelor's degree in radiography with the majority having training certificates that vary from a few months to a 2-year college diploma. This gap of training can prompt to lack of or inadequate protocol optimization and radiation protection.

Our recommendations are to establish patient dose management programs at the level of medical facilities, governmental organizations, and radiographers. Medical facilities should provide radiographers

Table 1
Descriptive statistic for DLP and Effective dose in Lebanon.

	Lebanon		
	Mean DLP	75th Percentile	Effective Dose
Head CT Without contrast	1165.89	1426	3.28
Chest CT without Contrast	503.4	646.03	10.98
Abdomen Pelvis with Contrast	793.25	967.6	14.51

Note – Data are the DLP and effective dose in milliGray-cm (mGray -cm) and Sievert (Sv), respectively.

Table 2
Descriptive statistics for the DLP and effective dose in different governorates of Lebanon and different types of hospitals and centers.

	CT Head no Contrast			CT Chest no Contrast			CT Abdomen Pelvis with Contrast		
	Mean DLP	75 Percentile	Effective dose	Mean DLP	75 Percentile	Effective dose	Mean DLP	75 Percentile	Effective dose
Governorates									
Beirut	1169.10	1422.81	3.27	474.16	660.20	11.22	723.68	822.79	12.34
Beqaa	1181.55	1409.11	3.24	499.55	627.30	10.66	736.90	948.00	14.22
South Lebanon	1173.62	1450.32	3.34	485.76	642.55	10.92	738.79	950.00	14.25
Mount Lebanon	1253.85	1480.40	3.40	443.76	565.57	9.61	816.73	998.47	14.97
North	1041.53	1363.14	3.14	604.36	752.70	12.80	882.83	1099.00	16.48
Type of Hospital/Center									
Private Hospital	1162.77	1421.10	3.27	493.23	630.36	10.72	785.75	963.40	14.45
Public Hospital	1196.81	1443.00	3.32	517.14	697.00	11.85	779.71	931.30	13.96
Medical Center	1140.48	1423.00	3.27	536.61	698.50	11.87	847.97	992.00	14.88

Note – Data are the DLP and effective dose in milliGray-cm (mGray.cm).

Table 3
Established DRL for each anatomical area according to CT scanner manufacturer.

	Philips		General Electric		Neusoft		Toshiba/Cannon		Siemens	
	Mean	75th DLP	Mean	75th DLP	Mean	75th DLP	Mean	75th DLP	Mean	75th DLP
Head	1218	1457	1088	1386	1192	1443	1272	1599	1235	1387
Chest	537	698	537	635	500	614	506	679	573	644
Abdomen/Pelvis	906	1024	890	989	844	943	897	1099	873	973

Note – Data are in mean and 75th percentile of DLP in milliGray-cm (mGray. cm).

Table 4
Benchmarking of the established Lebanese DRL in terms of DLP (mGray.cm) with international values.

		75th Percentile					
		CT Head	Δ Lebanon-Country	CT Chest	Δ Lebanon-Country	CT Abdomen Pelvis	Δ Lebanon-Country
Lebanon Switzerland (Ekpo et al., 2018)	2019	1426	0	646	0	967	0
	2010	1000	+426	350	+296	700	+267
Australia (ARPANSA, 2018)	2018	880	+546	390	+256	600	+367
UK (Roch et al., 2018)	2014	970	+456	610	+36	745	+222
Greece (Ekpo et al., 2018)	2015	1053	+373	481	+165	758	+209
Japan (Ekpo et al., 2018)	2015	1350	+76	550	+96	1000	−33
Germany (Roch et al., 2018)	2016	850	+576	350	+296	700	+267
Belgium (Roch et al., 2018)	2016	950	+476	290	+356	–	–
USA (Butler and Kanal, 2018)	2017	962	+464	443	+203	775	+192
France (Roch et al., 2018)	2017	850	+576	350	+296	650	+317
Syria (Ekpo et al., 2018)	2009	793	+633	520	+126	721	+246
Turkey (Ekpo et al., 2018)	2015	810	+616	289	+357	204	+763
Italy (Ekpo et al., 2018)	2014	1312	+114	509	+137	555	+412
Ireland (Ekpo et al., 2018)	2012	940	+486	390	+256	600	+367
Canada (Ekpo et al., 2018)	2017	1098	+328	483	+163	806	+161
Nigeria (Ekpo et al., 2018)	2017	1310	+116	735	−89	1486	−519
Kenya (Ekpo et al., 2018)	2016	1612	−186	895	−249	1842	−875
India (Ekpo et al., 2018)	2014	925	+501	456	+190	482	+485
Portugal (Ekpo et al., 2018)	2014	1010	+416	470	+176	800	+167

Note – Data is the DLP of different countries in milliGray-cm (mGray.cm).

continuous training to fortify their knowledge about radiation protection, protocol justification, and optimization, and methods to maintain a balance between a suitable image quality needed for diagnosis and radiation dose. Additionally, they are responsible to manage and monitor their radiation dose level accurately regularly and compare with the established NDRL in Lebanon. It is also an added value to the acquisition of upgraded CT technology and reconstruction algorithms. Governmental organizations should establish a compulsory audit of radiation doses from medical facilities. In addition, they should follow up on regional and NDRL in Lebanon on yearly basis taking into consideration all medical imaging procedures. Furthermore, physicians should always establish a risk-benefit when referring patients for imaging and radiographers should adherence to the ALARA principles, methods of protocol optimization and justification, and radiation protection. Lastly, we recommend re-evaluating the NDRLs for Lebanon after two years.

There are shortcomings in our study. Firstly, CTDI volumes were not recorded, and they are also good measurements to establish DRL. Second, different established protocols for each anatomical area, which may vary from one institution to another, were not recorded. Third, no control for the patient's height was established and weight was estimated based on eye observations for an average body habitus which influence the DLP values selected. Fourth, the different reconstructions algorithms employed in different institutions, which potentially affect radiation levels, were not taken into consideration. Finally, image quality, which was beyond the scope of our survey and may hinder the possibility to achieve optimization of CT examination, was not assessed.

5. Conclusion

This paper defines the first Lebanese established NDRL for adult CT scans. The established Lebanese DRLs for CT scan of head, chest, and abdomen pelvis was higher than most of the international publications.

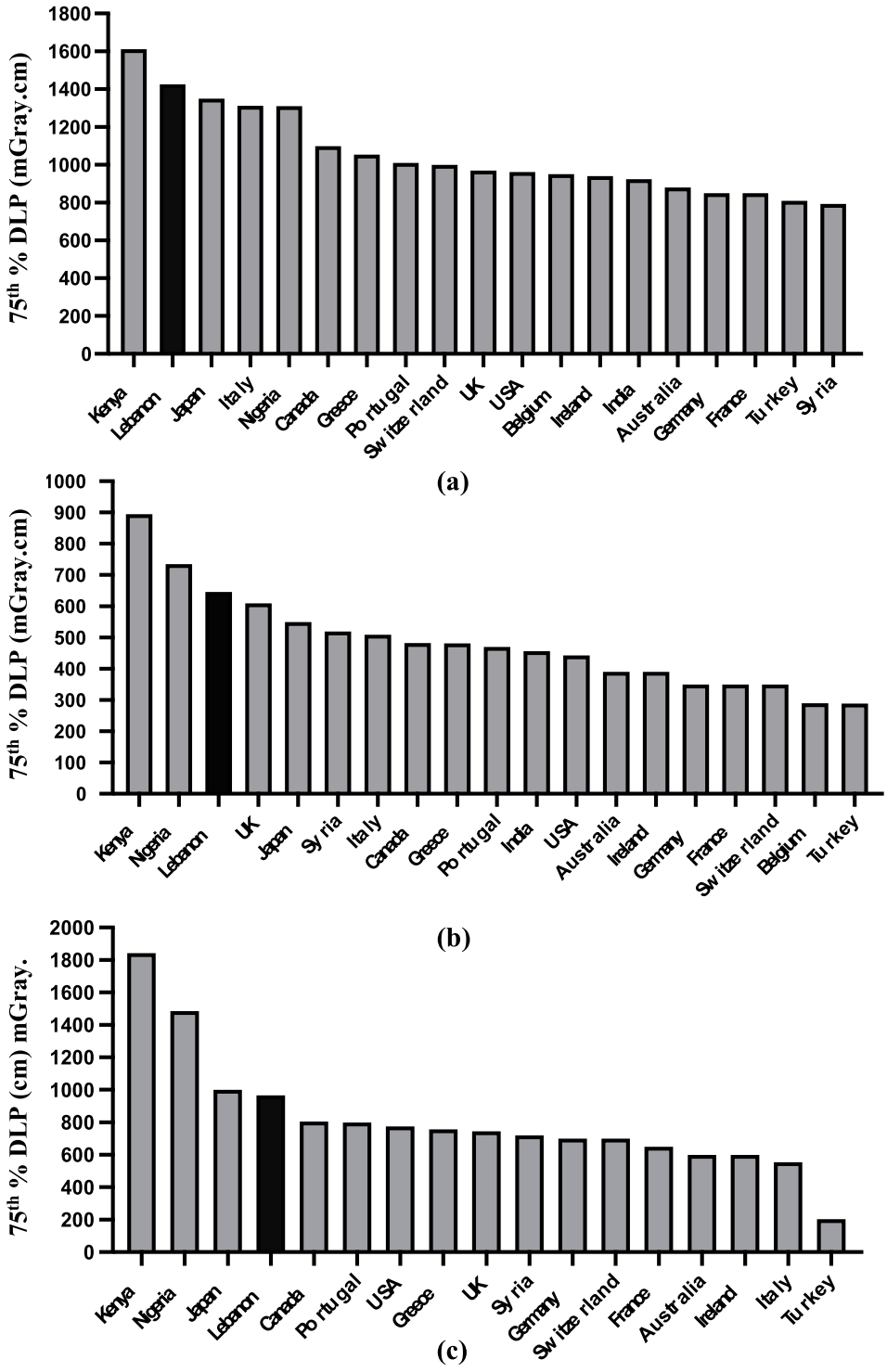

Fig. 1. Comparison of DRL established at the 75th percentile in Lebanon with international values (a) for head CT scan (b) for chest CT scan and (c) for abdomen pelvis CT scan.

This demonstrates a great scope for radiation dose reduction and the urgent need for a policy of DRL to optimize CT scanning procedures and protocols in Lebanon as well as an national educational program to educate radiographers and radiologists on parameter modification techniques in conjunction with optimal image quality assesment. This could be achieved by the employment of patient dose management programs and systems at the level of medical facilities and governmental organizations. These programs will aim to fortify both radiographers' and radiologists knowledge about radiation protection, protocol justification, and optimization combined with rigorous radiation audits at hospitals at the national level.

CRediT authorship contribution statement

Lina Karout: Conceptualization, Data curation, Project administration, Manuscript Drafting, Review. **Sarah Khalife:** Conceptualization, Data curation, Project administration, Manuscript Drafting, Review. **Mohamad Fawzi Awad:** Data curation, Formal analysis, Project

administration, Review. **Ghida Arnous:** Data curation, Formal analysis, Project administration, Review. **Mohamad Roumie:** Data curation, Formal analysis, Project administration, Project administration, Review. **Mohammad Ahmmad Rawashdeh:** Data curation, Formal analysis, Project administration, Project administration, Review. **Charbel Saade:** Conceptualization, Project administration, Manuscript Drafting, Review.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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