

Establishment of national diagnostic dose reference levels (DRLs) for routine computed tomography examinations in Jordan

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Abstract

Background: Dose reference levels (DRLs) are used as indicators as well as guidance for dose optimization and to ensure justification of appropriate dose for a given clinical indication. The main aims of this study were to establish local DRLs for each CT imaging protocol as a reference point to evaluate the radiation dose indices and to compare our DRLs with those established in other countries and against the internationally reported guidelines.

Materials and methods: 2000 CT dose reports of different adult imaging protocols from January 2021 until April 2022 were collected retrospectively at different hospitals in Jordan. Data were collected from CT scans that were performed using different types and models of CT scanners and included four adult non-enhanced, helical CT imaging protocols; Head, Chest, Abdomen-Pelvis, and Chest-Abdomen-Pelvis.

Results: The average doses of CTDI_{vol}, DLP, and effective dose were (65.11 mGy, 1232.71 mGy·cm, 2.83 mSv) for the head scan, (16.6 mGy, 586.6 mGy·cm, 8.21 mSv) for the chest scan, (17.91 mGy, 929.9 mGy·cm, 13.9 mSv) for the abdomen-pelvis scan, and (19.3 mGy, 1152 mGy·cm, 17.25 mSv) for the chest-abdomen-pelvis scan. In comparison with results from different international studies, DLP values measured in the present study were lower for the chest-abdomen-pelvis and abdomen-pelvis CT scans, and higher for the head CT and chest CT scans.

Conclusions: It is very important that each country establishes its own DRLs and compares them with those reported by other countries, especially the developed ones. It is also important that these levels are regularly updated.

Keywords: computed tomography; dose reference levels (DRLs); dose length product; CT dose index-volume; effective dose.

Introduction

Computed tomography (CT) is one of the most important X-ray based imaging modalities in diagnostic radiology used worldwide. The development of the radiation dose reference levels (DRLs) for CT scans should take into account the differences in CT scanner designs and models between the manufacturers. DRL value was defined by the International Commission on Radiological Protection (ICRP) as an arbitrary theoretical value set at the 75th percentile of the distribution of the medians of distributions of the DRL quantity obtained from surveys or from the settings.¹ The purpose of a DRL is to recognize facilities where protection is not optimized i.e. the local median value of the DRL quantity is greater than the national DRL value; therefore further investigation of practices is advisable.¹

These differences increase with the variability in CT imaging protocols, and, as a result, the differences in the absorbed dose by patients increase. The latter necessitates choosing appropriate CT imaging protocols to reduce the absorbed dose by patients and minimize the variability among institutions and scanners.²

It was reported that the radiation dose contribution of CT scanning to the population worldwide was the highest among other ionizing radiation-based imaging modalities.³⁻⁵ Furthermore, it was reported that CT dose may be responsible for about 0.6-3.2% of malignant tumors in different countries.⁶ As a result, there is a great global interest in minimizing the radiation doses resulting from CT scanning.⁷ For these reasons, optimization of CT scan parameters is highly recommended by the International Atomic Energy Agency (IAEA), the International Commission on Radiation Protection (ICRP), and

the European Commission (EC). These agencies recommended that CT doses must be continuously assessed, monitored, and compared against the established guidelines.^{8,9} It is also recommended that each country must establish its own local DRLs for use as indicators and provide guidelines for dose optimization and ensure that the appropriate dose is justified for any given clinical CT scanning.¹⁰ The annual monitoring of DRLs is highly recommended.^{1,11} However, the DRL process is not sufficient alone. Other concerns are the image quality, more specifically, the diagnostic information provided by the examination, at the same time, seeking to reduce patient exposures to radiation to a level as low as reasonably achievable. The ICRP Commission recommended using the median value (the 50th percentile) of the national distribution of values of dose-related quantities to provide additional guidance for further optimization efforts. If local median values of the DRL quantity are below the national median value, image quality, rather than the amount of radiation used, should be considered as a greater priority in this additional optimisation process.¹²⁻¹⁵ If the median values of DRL quantities are higher than the established local (national) DRLs, the investigation should start with an evaluation of the equipment, then an evaluation of procedure protocols, factors causing increased radiation doses must be re-adjusted or re-calibrated, and finally evaluation of operator technique.^{1,16}

Volume CT dose index (CTDI_{vol}) is derived from the weighted or average CTDI (CTDI_w) given across the field of view (**Equation 1**). It is used to calculate the CT dose in helical scanning, where the CTDI_w is normalized by the pitch factor:^{9,17}

$$CTDI_{vol} = \frac{CTDI_w}{pitch} \quad \text{Eq. 1}$$

Dose-Length Product (DLP) is another CT dose index that is used to better represent the total energy delivered during the protocol used along a specific length of scanned anatomy, where:⁹

$$DLP (mGy.cm) = CTDI_{vol}(mGy) \times Scan Length (cm) \quad \text{Eq. 2}$$

The effective dose (E) was predicted from the DLP values and then was used in more rigorous calculations methods. So DLP is used to estimate the imparted energy to develop conversion coefficients by which the effective dose can be estimated:^{9,17-19}

$$Effective dose (mSv) \approx k \times DLP \quad \text{Eq. 3}$$

where the k is k -factor ($mSv \cdot mGy^{-1} \cdot cm^{-1}$). To calculate more reliable effective dose for clinical use, k factors were developed to incorporate the effect of patient body size into effective dose calculations. k factors used were as follows: 0.0023 for the head, 0.014 for the chest, 0.015 for the abdomen–pelvis, and the chest–abdomen–pelvis.^{9,17-19}

The main aims of this study were i) to establish local DRLs for each CT imaging protocol as a reference point to evaluate the radiation dose indices, ii) to compare our DRLs with those established in other countries and against the international reported guidelines, and iii) to compare the measured CTDI_{vol}, DLP and effective dose with the international reported guidelines. This is the first study that included most of the local hospitals in Jordan along with four different routine non-enhanced CT procedures to establish DRL for each of the four routine CT imaging protocols in the present study.

Material and methods

Study's collection form

The current study used a previous collection form used in a CT dose survey performed in Egypt in 2017 in collaboration with IAEA and was kindly shared by the corresponding author of that work.²⁰ The data collected included information related to the scanner, routine CT protocols, patient weight, examination data, and dose indices (CTDI and DLP).

Study design and Data Collection

This is a large-scale retrospective study. It was carried out at twenty-eight hospitals that covered about 90% of government and private hospitals in Jordan. Four research assistants reviewed about 2000-CT dose reports of different adult imaging protocols given in the last year (January 2021 until April 2022). This study focused on four adult non-enhanced, helical CT imaging protocols; i) Head, ii) Chest, iii) Abdomen-Pelvis (AP), and iv) Chest-Abdomen-Pelvis (CAP). All CT dose reports were obtained by different types and models of CT scanners, namely: General Electric (GE), Philips, Toshiba, Neusoft, Siemens, and Hitachi. Nearly a similar number of dose reports were collected for each imaging protocol, with more than 20 dose reports collected for each protocol from each type and model of CT scanner.

However, this study was divided into two phases; to help assess the effect of sample size on the DRL values. During phase one, approximately 50% of hospitals were visited, and about 1000 dose reports were extracted and collected to determine the CT dose radiation levels (CTDI_{vol}, DLP, and effective dose). This phase was referred to as '*Present Study_Phase I*'. During phase two, the other hospitals were visited, and the remaining CT dose reports were collected to calculate the DRLs such that the total number of reports from the two phases was 2000. The second phase was referred to as '*Present Study_Phase II*'. By calculating the CTDI_{vol} and DLP, we can suggest DRL values for CT examinations.

Table 1. Descriptions of different CT protocols for different types of scanners used in all regional hospitals involved in the study.

Protocol	Scanner Type (# of slices / raw)	kV	mAs (mean)
Chest, abdomen and pelvis K value: 0.015 ^{9,17-19}	Philips (16)	120	269
	GE (64)	120	287
	Toshiba (16)	100	131
	Hitachi (16)	120	165
Abdomen and pelvis K value: 0.015 ^{9,17-19}	Philips (16)	120	216
	Siemens (16)	100	231
	Neusoft (16)	120	250
	Toshiba (16)	120	148
	Hitachi (16)	120	165
	Philips (16)	140	190
	Siemens (16)	140	350
Head CT scan K value: 0.0023 ^{9,17-19}	Philips (16)	120	200
	Siemens (16)	100	443
	Neusoft (16)	120	490
	Toshiba (16)	120	200
	Hitachi (16)	120	225
	Philips (16)	120	432
Chest CT scan K value: 0.014 ^{9,17-19}	Siemens (16)	140	396
	Philips (16)	120	180
	Siemens (16)	120	146
	Neusoft (16)	120	250
	Toshiba (16)	120	124
	Hitachi (16)	120	150
	Philips (16)	140	177
	Siemens (16)	120	270

Number of series: 1; rotation time range: 0.28 – 1.00; pitch range: 0.6713-1.500.

CT scanners and imaging protocols

Seven CT scanners of different models were included in the survey. Information on the scanner's name and model, number of detectors, kV, mAs, rotation time, and number of series are summarized in **Table 1**. All CT scanners were manufactured between 2000 and 2014 and installed from 2002 through 2017. All CT scanners were calibrated by the manufacturer's services prior to data collection to ensure that dose parameters (CTDI_w, CTDI_{vol}, DLP, kV, and mAs) were accurately measured. Only dose parameters from routine non-enhanced, helical CT scans were extracted. A total of 2000 CT exams were used to extract the dose reports. 559 head scans, 559 chest scans, 559 abdomen-pelvis scans, and 323 chest-abdomen-pelvis scans.

Patient weights included in the present study ranged from 48.0 to 111.0 kg, with medians distribution for different scanners ranging from 72.0 and 78.0 kg. Because the patient's weight was used as a parameter to adjust the patient's dose; the median distribution of weight in the study was confirmed to be within the range for different scanners. Based on ICRP 2017, a median weight of 70 ±10 kg may be appropriate for some countries.¹

Statistics analysis

Data were tabulated and organized into different Microsoft Excel sheets. Data for CTDI_{vol}, DLP and ED (effective dose) were analyzed for each exam (Head, Chest, abdomen-pelvis,

Chest-abdomen- pelvis scans) for all scan reports collected from all hospitals with respect to the first quartile (25th percentile), mean, second quartile (median, 50th percentile), and third quartile (75th percentile) values. The achievable dose was proposed based on the median value of CTDI_{vol} and DLP per scan. The data used to establish DRLs at the hospitals were based on the rounded third quartile and were compared with the published international reports.^{1,19}

Results

The 3rd quartile for CTDI_{vol}, as well as the effective dose values, was (65.1 mGy, 2.83 mSv) for the head scan, (16.6 mGy, 8.21 mSv) for the chest scan, (17.9 mGy, 13.9 mSv) for the abdomen and pelvis scan, and (19.3 mGy, 17.25 mSv) for the chest-abdomen-pelvis scan, respectively. The median values of the radiation dose indices in terms of CTDI_{vol} and effective dose are shown in **Table 2**. All the mean values were remarkably consistent, with a maximum deviation from the mean of approximately 10% to 15%.

Tables 3-6 show the 3rd quartile for CTDI_{vol}, DLP, as well as the effective dose values of the present study. The values are shown in comparison with other similar international studies for the same CT imaging protocols.

Table 2. Analysis by examination type of average CTDI_{vol} per sequence, total DLP per examination and ED per examination, for distribution of values per CT scanner.

CT examinations	Values of CTDI _{vol} per sequence (mGy)				Values of DLP per examination (mGy·cm)				Values of ED per examination (mSv)			
	1 st quartile (25%)	Median (50%)	Mean	3 rd quartile (75%)	1 st quartile (25%)	Median (50%)	Mean	3 rd quartile (75%)	1 st quartile (25%)	Median (50%)	Mean	3 rd quartile (75%)
CAP CT scan	9.9	13.9	14.3	19.3	670	913	1140	1150	10	13.6	13.4	17.2
AP CT scan	9.7	13.2	14.6	17.8	480	686	724	923	7.2	10.2	10.8	13.8
Head CT scan	50.1	51.9	55.8	64.3	973	1114	1115	1223	2.23	2.5	2.56	2.8
Chest CT scan	8.1	12.86	12.7	16.6	328	453	466	582	4.4	6.37	6.44	8.1

CAP: chest abdomen pelvis, AP: abdomen pelvis; ED: effective dose

Table 3. Comparison between the current study with international studies for chest-abdomen-pelvis CT scan (3rd quartile).

The country	CTDI _{vol} (mGy)	DLP (mGy·cm)	Effective dose (mSv)
JORDAN (Current Study)	19.3	1152.87	17.25
GREECE 2015 ³⁶	17	1020	15.3
IRSN FRANCE 2013 ²⁶	20	1000	15
SWITZERLAND 2013 ²⁹	15	1000	15
CANADA 2016 ³⁴	17	1269	19.035
EGYPT 2017 ²⁰	33	1320	19.8
AUSTRALIA 2020 ⁵⁰	11	940	14.1
IRELAND 2012 ³⁷	12	850	12.75
MALAYSIA 2019 ²⁴	11	695	10.425

Effective dose coefficient or conversion coefficient $k=0.015^{9,17-19}$

Table 4. Comparison between the current study with international studies for abdomen pelvis (3rd quartile).

The country	CTDI _{vol} (mGy)	DLP (mGy·cm)	Effective dose (mSv)
JORDAN (current study)	17.9	929	13.90
UAE 2020 ²⁸	14.0	810	12.15
EU COMMISSION 2004 ¹⁹	15.0	724	10.86
SWITZERLAND 2013 ²⁹	15.0	650	9.75
IRSN FRANCE 2013 ²⁶	17.0	800	12.00
ICRP 2010 ¹⁵	35.0	780	11.70
AUSTRALIA 2020 ⁵⁰	13.0	600	9.00
US 2017 ³²	16.0	781	11.72
CANADA 2016 ³⁴	18.0	874	13.11
JAPAN 2016 ³⁵	20.0	1000	15.00
GREECE 2011 ²³	35.0	780	11.70
GREECE 2015 ³⁶	16.0	760	11.40
EGYPT 2017 ²⁰	31.0	1325	19.88
UK 2011 ¹⁰	15.0	745	11.18
IRELAND 2012 ³⁷	12.0	600	9.00
IRAN 2019 ³⁸	12.0	524	7.86
TURKEY 2015 ³⁹	13.0	204	3.06
TURKEY 2021 ⁴⁰	8.6.0	457	6.86
SYRIA 2010 ⁴¹	24.1	721	10.82
MALAYSIA 2016 ⁵¹	12.8	450	6.75
MALAYSIA 2019 ²⁴	7.0	309	4.64

Effective dose coefficient or conversion coefficient $k=0.015^{9,17-19}$

Table 5. Comparison between the current study with international studies for brain CT (3rd quartile).

The country	CTDI _{vol} (mGy)	DLP (mGy·cm)	Effective dose (mSv)
JORDAN (current study)	65.1	1232	2.83
UAE 2020 ²⁸	40.0	695	1.60
EU COMMISSION 2004 ¹⁹	72.0	945	2.17
SWITZERLAND 2013 ²⁹	65.0	1000	2.30
IRSN FRANCE 2013 ²⁶	65.0	1050	2.42
AUSTRALIA 2020 ⁵⁰	52.0	770	1.77
US 2017 ³²	56.0	962	2.21
CANADA 2016 ³⁴	82.0	1302	3.00
JAPAN 2016 ³⁵	85.0	1350	3.11
GREECE 2011 ²³	60.0	1050	2.42
GREECE 2015 ³⁶	67.0	1055	2.43
EGYPT 2017 ²⁰	30.0	1360	3.13
UK 2011 ¹⁰	60.0	970	2.23
IRELAND 2012 ³⁷	66.0	940	2.16
IRAN 2019 ³⁸	46.0	723	1.66
TURKEY 2015 ³⁹	66.4	810	1.86
TURKEY 2021 ⁴⁰	53.0	988	2.27
SYRIA 2010 ⁴¹	60.7	793	1.82
MALAYSIA 2016 ⁵¹	46.8	1050	2.42

Effective dose coefficient or conversion coefficient $k=0.0023^{9,17-19}$

Table 6. Comparison between the current study with international studies for chest CT (3rd quartile).

The country	CTDI _{vol} (mGy)	DLP (mGy·cm)	Effective dose (mSv)
JORDAN (current study)	16.6	586	8.21
UAE 2020 ²⁸	10.0	276	3.85
EU COMMISSION 2004 ¹⁹	12.0	421	5.89
SWITZERLAND 2013 ²⁹	10.0	400	5.60
IRSN FRANCE 2013 ²⁶	15.0	475	6.65
ICRP 2010 ¹⁵	35.0	650	9.10
AUSTRALIA 2020 ⁵⁰	10.0	390	5.46
US 2017 ³²	16.0	443	6.20
CANADA 2016 ³⁴	14.0	521	7.29
JAPAN 2016 ³⁵	20.0	550	7.70
GREECE 2011 ²³	30.0	650	9.10
GREECE 2015 ³⁶	14.0	480	6.72
EGYPT 2017 ²⁰	22.0	420	5.88
UK 2011 ¹⁰	15.0	350	4.90
IRELAND 2012 ³⁷	11.0	390	5.46
IRAN 2019 ³⁸	12.0	377	5.27
TURKEY 2015 ³⁹	11.6	289	4.05
TURKEY 2021 ⁴⁰	8.3	314	4.40
SYRIA 2010 ⁴¹	22.0	520	7.28
MALAYSIA 2016 ⁵¹	19.9	600	8.40

Effective dose coefficient or conversion coefficient $k=0.014^{9,17-19}$

Discussion

This is a large-scale study that was carried out to establish national DRLs and effective doses for each patient undergoing CT examination, which covers a wide geographical area in Jordan. It includes a description of the approaches and instruments, patient characteristics, dose indices, routine CT examinations, and a comparison with those of other countries. To the best of our knowledge, this is the first study that included most of the local hospitals in Jordan along with four different routines, non-enhanced, helical CT procedures to establish DRL for each of the four routine CT imaging protocols in the present study.

Many countries in the Middle East or Western countries had estimated their dose reports, which were considered regional references^{4,5,10,20,21,23-25}. Many other studies focused on how to reduce the CT radiation doses during diagnostic imaging without affecting the quality of the diagnostic images^{8,12}. CT radiation dose indicators were clearly determined and implemented in France²⁶, European Union (UN)²⁷, UAE²⁸, Switzerland^{29,30}, Australia³¹, USA^{32,33}, Canada³⁴, Japan³⁵, Greece^{23,36}, Egypt²⁰, UK¹⁰, Ireland³⁷, Iran³⁸, Turkey^{39,40}, Syria⁴¹, and Malaysia^{24,42} but with limited information from other neighboring countries. Some other studies, on the other hand, are now outdated and compared their results with old studies^{41,43}, suffer from missing some important information⁴³⁻⁴⁵, have a limited number of patients and sites^{46,47}, or are almost limited to a specific imaging protocol²¹.

Nowadays, many CT manufacturers are trying to develop new CT models that are able to deliver radiation doses during any clinical imaging protocol within acceptable ranges by incorporating different modifications to their products. In addition, improved CT imaging protocols were also implemented by those manufacturers to produce high-quality images with reduced patient radiation doses.⁴⁸ In comparison with results from different international studies, DLP values measured in the present study were lower for the chest abdomen-pelvis and abdomen-pelvis CT scans and higher for the head CT and chest CT scans.

In a previous study by Taylor S. et al., CTDI_{vol} and DLP data were measured, and the effect of the sample size was evaluated.⁴⁹ It was obvious that as the number of derived dose indices for all CT imaging protocols increases, the changes in the average level of radiation doses decrease. In our study, the number of dose reports was higher than the numbers recommended by their study.

The 3rd quartile for CTDI_{vol} and the effective dose values (**Table 3**) for the head imaging protocol (65.1 mGy, 2.83 mSv, respectively) were lower than the 3rd quartile measured in some previous studies^{19,34,35,37,39}, and higher than the 3rd quartile measured in other studies^{10,20,26,28,32,36,38,40,41,50,52}. Similarly, the 3rd quartile for CTDI_{vol} and the effective dose values (**Table 4**) for the chest imaging protocol (16.6 mGy, 8.21 mSv,

respectively) were lower than the 3rd quartile measured in some previous studies^{20,23,35,50}, and higher than the 3rd quartile measured in other studies^{10,18,26,28-29,32,34,37-40,52}. Moreover, the 3rd quartile for CTDI_{vol} and the effective dose values (**Table 5**) for the abdomen-pelvis imaging protocol (17.9 mGy, 13.9 mSv, respectively) were lower than the 3rd quartile measured in some previous studies^{20,23,34,35,41}, and higher than the 3rd quartile measured in other studies^{10,18,26,28-29,31,32,36-40,50,51}. Finally, the 3rd quartile for CTDI_{vol} and the effective dose values (**Table 6**) for the chest-abdomen-pelvis imaging protocol (19.3 mGy and 17.25 mSv, respectively) was lower than the 3rd quartile measured in some previous studies^{20,26} and higher than the 3rd quartile measured in other studies^{24,31,34,36,37}.

It was found that the Middle East countries recorded higher doses as compared with the Western World countries. The latter could be attributed to the fact that these developed countries have more advanced scanners and protocols as well as an up to date radiation dose guidelines and regulations. Furthermore, the difference in the awareness of the radiation protection guidelines and policies between these countries can also contribute to these dose level variations. From all previous results, it is very critical that each country establishes its own DRLs and compares them with those reported by other countries, especially the developed ones.

It is also important that these DRLs are regularly updated, as it is obvious that the updated dose levels of the same country are always lower than the old ones. This can be seen in Turkey, for example, where the old CTDI_{vol} and effective dose levels were higher (66.4 mGy, 1.9 mSv, respectively)³⁹ than the recent ones (53 mGy, 2.3 mSv, respectively)⁴⁰. Furthermore, Greece recorded lower updated dose levels where the recent CTDI_{vol} and effective dose levels were lower (16 mGy, 11.4 mSv, respectively)³⁶ than the old ones (35 mGy, 11.7 mSv, respectively)²³. This could be attributed to the recent advances in CT scanners and the increased attention toward the radiation doses received during any CT imaging protocol.

Sample size has been shown to affect the average dose level, where the increased number of reports in phase two of this study changed the average dose level (**Figures 1-3**). These findings are in line with other studies' reports.⁴⁹ However, we have considered the results of the larger sample size.

The main limitation of this study is the limited number of anatomical regions that were used to establish the DRLs. Future studies should include more anatomical regions to generate more comprehensive and representative DRLs that can be used thoroughly.

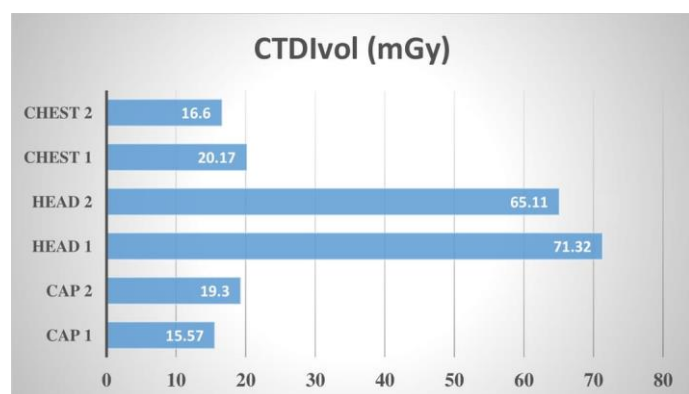


Figure 1. The CTDI_{vol} values for the current study as compared with sample size (1: refer to the first 1000 reports, 2: refer to 2000 reports).

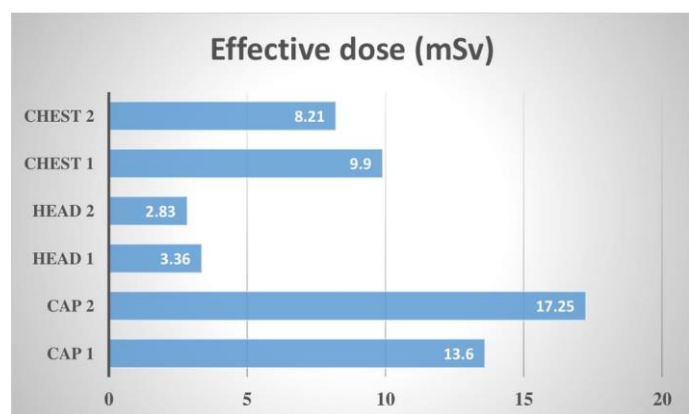


Figure 2. The effective dose values for the current study as compared with sample size (1: refer to the first 1000 reports, 2: refer to 2000 reports).

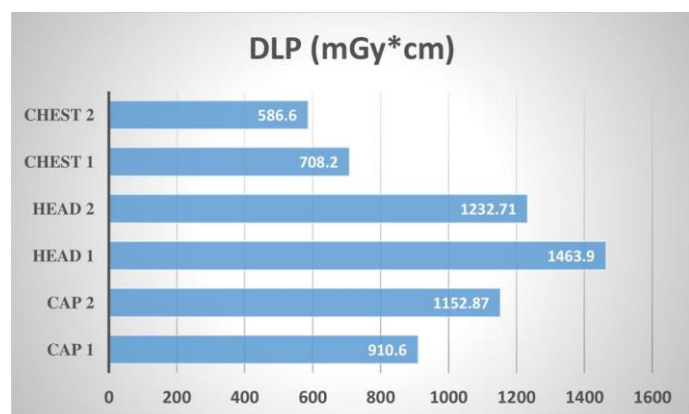


Figure 3. The DLP values for the current study as compared with sample size (1: refer to the first 1000 reports, 2: refer to 2000 reports).

Conclusion

It is very important that each country establishes its own DRLs and compares them with those reported by other countries, especially the developed ones. It is also important that these levels are regularly updated. Dividing the present study into two distinct phases helps assess the effect of sample size on the DRL values, where the increased number of reports in phase two of this study decreased the average dose level. Furthermore, newly designed CT scanners are implemented with updated imaging protocols and techniques that create high-quality images with the lowest possible radiation doses.

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