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REVIEW

A systematic review on the current status of adult diagnostic reference levels in head, chest and abdominopelvic Computed Tomography

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Abstract

Computed tomography (CT) is a routinely employed diagnostic tool for the detection and diagnosis of disease processes. Despite the primary focus of radiation dose reduction and improvements in CT scanners, radiation dose exposure remains an ever-increasing concern. Scanning protocol optimisation relative to body weight and scanner manufacturer still lags behind the diagnostic reference levels (DRLs) that are set on an international scale. The aim of this systematic review is to evaluate the current status of adult DRLs in head, chest and abdominopelvic CT over time on a global scale. A search was carried out in early 2019 using the Medline, PubMed, EMBASE, SCOPUS and manual databases. The reference lists of published articles were also assessed to identify further articles. The preferred reporting items for systematic reviews and meta-analyses (PRISMA) methodology was employed to evaluate articles for relevance. Articles were included if they assessed the DRL in head, chest

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and abdominopelvic scans. The search resulted in 6079 articles, of which 67 were included after a thorough screening process. The literature demonstrates a wide dose variation in reported head, chest and abdominopelvic dose length product (DLP) DRL, ranging from 700–1359, 330–707 and 550–1486 mGy·cm, respectively. Where reported, the volumed CT dose index ($CTDI_{vol}$) DRL in the head, chest and abdominopelvic studies ranged from 30.4–85.5, 9–15 and 12.3–31 mGy·cm, respectively. The global means were shown to be slightly lower and significantly lower than the reported values of DLP and $CTDI_{vol}$ values for the American College of Radiology and European Commission, respectively. This review emphasises the need for an international standardisation for head and body DRL establishment methods, to provide a more comparable global measurement of dose variations across CT sites as well as regular monitoring of delivered radiation dose to patients.

Keywords: dose length product (DLP),
volumed computed tomography dose index ($CTDI_{vol}$),
diagnostic reference level (DRL), computed tomography (CT), radiation protection and radiation dose

(Some figures may appear in colour only in the online journal)

1. Introduction

The number of computed tomography (CT) scanners and examinations performed have grown considerably in the last decade, with an estimated growth of 10% every year for both scanner installation and examinations [1]. The probability of inducing harmful stochastic effects increases with the increased utilisation of CT, the most hazardous effect potentially being cancer [2]. Even with the as low as reasonably achievable (ALARA) principle and the intention of reducing radiation dose exposure and maintaining optimal quality, the radiation dose delivered is still ever-increasing [1]. The question remains: how much have we reduced the radiation dose with the employment of diagnostic reference levels (DRLs)?

The DRL is a concept that was first introduced in 1996 by the International Commission of Radiation Protection (ICRP) in their 73rd publication [3]. In their 135th issue, it was defined as 'a form of investigation level used to identify situations where optimisation of protection may be required in the medical exposure of patients' [3]. This concept is seen as an indicator for optimal imaging techniques and to tailor the examination according to the patient's body habitus and clinical information [4]. In order to combat the risk of developing radiation-induced biological effects (mainly cancer), the DRL should be regularly monitored [3].

There are several methods to quantify the radiation dose delivered in CT. CT dose index (CTDI) is one measure of radiation output. It represents the average absorbed dose in the z-axis from a series of scans. In particular, $CTDI_{vol}$ (volume) is the common measurement taken and utilised by The American College of Radiology (ACR) for accreditation purposes [5]. $CTDI_{vol}$ calculates the dose using specialised, ionisation-chamber dosimeters, the ratio of slices and the pitch factor [3]. Although easily accessible to radiologists, it provides information on the intensity of the radiation rather than the dose quantity. $CTDI_{vol}$ is calculated using the following formula:

$$CTDI_{vol} = CTDI_w/\text{pitch},$$

where pitch is the ratio of the table increment per gantry rotation to the total nominal beam width [3].

Dose length product (DLP) is another common measurement that calculates the total dose given from a scan acquisition by multiplying the $CTDI_{vol}$ with scan length:

$$\mathrm{DLP\ (mGy{\cdot}cm)} = \mathrm{CTDI_{vol}\ (mGy)} \cdot \mathrm{scan\ length\ (cm)}.$$

DLP provides more accuracy in reflecting the potential biological effect from radiation exposure [3].

DLP and $CTDI_{vol}$ are found in post-scan dose reports most of the time and are accessible to radiologists. They are often embedded in articles for the purpose of comparing and calculating dose averages in different countries or areas and reflect the total amount of radiation absorbed, and thus estimate probable risks to the body [3].

The aim of this systematic review is to gather all the available data to date and determine the current status of adult DRL in head, chest, and abdominopelvic CT. The 75th percentile of the proposed DRL will be used because it allows the detection of outliers due to potential extreme high or low doses [6]. The rationale is to lay out the current information on DRL, given by each country's practices, and address certain gaps that are underlying today's practices in CT scanning, including the variation and reporting of data. The aim of this study is to ascertain whether or not improvement in the global DRL, the inter-variation of nations, and the advancements in CT scans and technology have produced a reduction in global DRL.

2. Methodology

2.1. Search strategy

We conducted this review using the preferred reporting items for systematic reviews and meta-analyses (PRISMA) methodology, recommended for conducting systematic reviews in accordance with the PRISMA checklist for including all items that applied to this review [7, 8]. A search for relevant studies was conducted on the following databases: MEDLINE (OVID SP) (Ovid MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations and Daily 1946 to 5 February 2019); Embase.com; PubMed; and Scopus. The search strategies are reported in full in the appendix.

The search strategy combined the controlled vocabulary 'Medical Subject Headings' (MeSHs) in Medline (OVID), Pubmed, and Emtree in Embase.com, with keywords of the three different concepts in our topic: DRL, CT and reference levels. Limitations in terms of publication years, gender, publication types, or age were not applied to keep the search as broad and highly sensitive as possible. We did not perform grey literature searches or refer to unpublished documents because of time constraints and a lack of resources.

Results from Medline (OVID) (4219 results), Embase (5869 results), Pubmed (2822 results) and Scopus (4388 results) were exported to the citation manager tool Endnote Client for the screening process. We focussed on articles that covered national studies; for multiple studies in the same nation, we collected data from the most recent article for up-to-date information and directly preceding studies for comparison purposes. All studies were original papers conducted to assess national DRL (NDRL). Two reviewers reviewed and agreed upon all papers individually based on the inclusion and exclusion criteria mentioned below; a third reviewer reviewed any paper disagreed upon by the first two reviewers. The screening process started

Radiation	Reference levels	CT	DRL (Only keywords)
Radiometry	Reference values	Tomography	DRL
Radiation dosage	Reference standards	X-ray tomography	NDRL
Radiation monitoring		X-ray computed	DLP
Radiation exposure		Tomography, spiral computed	Diagnostic reference level[a]
Radiation absorption		Imaging, three-dimensional	
Radiation protection		Tomography scanners	
Radiation scatter		Multidetector CT	
Radiodiagnosis		Computed assisted tomography	

[a]((MeSH terms used in the combined search strategy along with the keywords for DRL))

in early 2019 and took a period of two months to complete. The two reviewers performed calibration exercises after title and abstract screening, and then 177 articles were eligible/identified for full-text screening.

2.2. Inclusion criteria

A preliminary screening of titles was performed to identify and include studies that discuss the radiation doses in routine CT examinations of the brain, chest, abdomen and pelvis. The screening initially included abstracts that discussed DLP and $CTDI_{vol}$ in the previously listed CT examinations performed on adults (>18 years old) with average weight. For the full-text review, the reviewers collected data from articles that established only NDRLs in original studies. The data collected included third quartile and mean DLP, $CTDI_{vol}$ and $CTDI_w$.

2.3. Exclusion criteria

Studies that have been excluded are examinations with specialised protocols, such as colonography, angiographies and urography, as well as cardiac and extremities examinations. Studies that focussed on population exposure, trauma, pediatrics, obese patients, or those performed with low or high resolution protocols were eliminated. Contrast studies were not included. Non-English-language studies were also excluded.

3. Results

Figure 1 shows the methodology for the study selection process demonstrated via the PRISMA flowchart. The combined search strategy identified 6075 articles (4148 from Medline, 2822 from Pubmed, 5869 from Embase and 4388 from Scopus) after removing duplicates. An additional four articles were identified through a manual search, 177 articles were eligible for full-text review after screening titles and abstracts, and 67 articles were included for data extraction. We assessed the Cohen's kappa coefficient to be 99.8% agreement and a coefficient of 0.996.

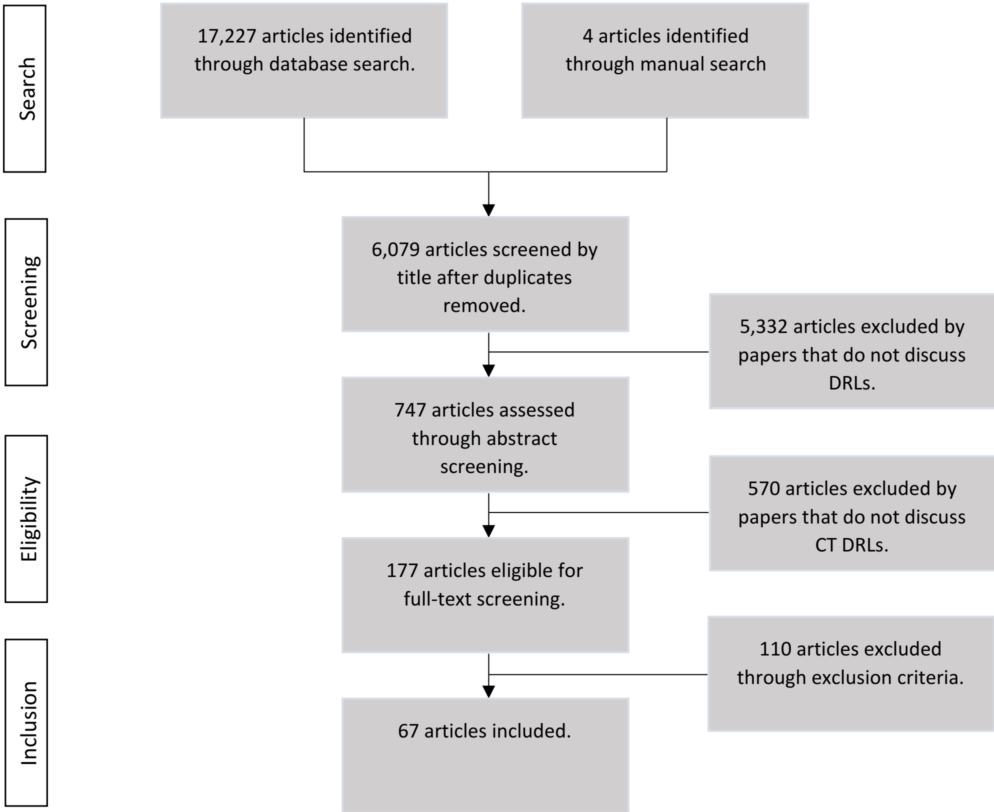

Figure 1. PRISMA flowchart for the selection of studies. The outcomes of the systematic review of the literature through record identification, screening and analysis in the PRISMA statement flow diagram.

A summary of the demographic information for the most recently published NDRL articles is demonstrated in table 1. The variation in the availability of data showed a lack of consistency in the presentation of information between countries. While some countries had missing demographic information, others lacked demographics completely. There were varying acceptance rates ranging from 10% to 100%. Greece [9], Egypt [10], Serbia [11] and Luxembourg [12] had a 100% acceptance rate. Moreover, the number of scanners spanned from as few as three scanners [13] to as many as 880 scanners [14]. Other countries did not provide independent demographics but this information was delivered as a collective by international projects [15, 16].

The DRL published in each nation's most recent study is summarised in table 2. The data listed are third quartile and mean DLP, $CTDI_{vol}$ and $CTDI_w$ values. NDRLs in some nations were established via multinational projects [15, 16]. On the other hand, some nations established more recent DRLs on a local or provincial level, such as Canada [44] and India [4]. However, we only included previous studies that provided national data for the purpose of this review. Some countries, such as Brazil [45], have only provincial DRL without a national study and so were excluded.

The DRLs collected in this review showed a wide range of dose values. The following values were taken from the 75th percentile values. The DRL values for head DLP ranged from

Table 1. Demographic information for recently published NDRL articles.

Country	Year of study	Year of collection	No. of centres	Acceptance rate	No. of CT scanners	No. of CT exams
Australia [17]	2018	2017	—	—	—	1708
Bulgaria [18]	2018	—	91	—	—	1793
Canada [19]	2016	2012–2013	—	75%	381	13 648
Egypt [10]	2017	2014–2016	50	100%	50	2286
Finland [20]	2015	2012	—	57%	57	3600
France [14]	2018	2015	—	80%	880	1014
Germany [21]	2019	2016–2018	—	—	—	—
Greece [9]	2015	2009–2013	—	100%	91	6003
Iran [22]	2015	2014	19	79%	19	708
Ireland [23]	2012	2009–2010	30	75%	34	21 197
Italy [24]	2014	2011	65	85%	70	3224
Japan [25]	2019	2017	—	16.6%	—	1585
Kenya [26]	2016	2010	10	33%	—	2063
Korea [27]	2015	2013	32	—	73	4380
Luxembourg [12]	2014	2010	8	100%	8	—
Malaysia [28]	2013	2007–2009	—	—	—	—
Malta [29]	2012	2009	3	60%	5	276
Netherlands [30]	2013	2010	14	67%	19	247
Nigeria [31]	2018	2016–2017	36	20.50%	36	1440
Norway [32]	2015	2008	104	69%	—	—
Poland [33]	2017	2013	64	15%		267 700
Portugal [34]	2013	2011–2012	31	21%	48	36 467
Republic of Belarus [35]	2010	2007–2008	7	—	8	—
Saudi Arabia [36]	2018	—	3	—	4	60
Serbia [11]	2014	—	4	100%	6	—
Switzerland [37]	2010	2007–2009	—	—	179	982
Sri Lanka [13]	2012	2006–2011	3	—	3	—
Syria [38]	2010	2009	30	—	30	109

Table 1. continued

Country	Year of study	Year of collection	No. of centres	Acceptance rate	No. of CT scanners	No. of CT exams
Taiwan [39]	2016	2013–2014	30	—	30	2536
Turkey [40]	2015	2013	167	10%	167	—
UAE [41]	2011	2005–2011	4	—	5	—
UK [42]	2016	2011	—	30%	182	—
US [43]	2017	2014	583	—	—	585 571
A* [16]	2009	2005–2008	73	—	—	—
B* [15]	2010	—	—	—	—	—

A*Bosnia and Herzegovina, Czech Republic, Estonia, Republic of Srspska, Ghana, Kuwait, Morocco, Thailand, Algeria, Tunisia, and Former Yugoslav Republic of Macedonia.
B*Croatia, Denmark, Lithuania, Slovenia, Moldova, Austria, Belgium.

Table 2. The DRL published in each country's most recent study. DLP: dose length product; $CTDI_{vol}$: volumed CT dose index; $CTDI_w$: weighted CT dose index.

Country	Year of publication	Body region	DLP		$CTDI_w$		$CTDI_{vol}$	
			75th	Mean	75th	Mean	75th	Mean
Portugal [34]	2013	Head	1010	802	—	—	75	70
		Chest	470	390	—	—	14	12.4
		Abdomen	800	563	—	—	18	14
		Pelvis	—	—	—	—	18	17.2
Algeria [16]	2009	Chest	—	347	—	9.2	—	—
		Abdomen	—	554	—	15.4	—	—
		Pelvis	—	604	—	19.1	—	—
Australia [17]	2018	Head	880	—	—	—	52	—
		Chest	390	—	—	—	10	—
		A–P	600	—	—	—	13	—
Greece [9]	2015	Head	1053	909	—	—	66.70	60.7
		Chest	481	395	—	—	14.4	12.1
		A–P	758	628	—	—	16.3	13.9
Italy [24]	2014	Head	1312	1086	—	—	69	64
		Chest	569	453	—	—	15	12
		A–P	920	733	—	—	18	15
Switzerland [37]	2010	Head	1083	—	—	—	69	—
		Chest	424	—	—	—	13	—
		A–P	633	—	—	—	14	—
Nigeria [31]	2018	Head	1310	—	—	—	61	—
		Chest	735	—	—	—	17	—
		A–P	1486	—	—	—	20	—
Germany [21]	2019	Head	890	—	—	—	60	—
		Chest	340	—	—	—	12	—
		A–P	820	—	—	—	15	—

Table 2. continued

Country	Year of publication	Body region	DLP		$CTDI_w$		$CTDI_{vol}$	
Japan [25]	2019	Head	1359	706	—	—	85.5	74.9
		Chest	543.4	454	—	—	14	12
		A–P	870.9	433	—	—	18.2	15.1
Bulgaria [18]	2018	Head	1000	—	80	—	60	—
		Chest	500	—	18	—	16	—
		Abdomen	470	—	17	—	18	—
Egypt [10]	2017	Head	1359	1001	—	—	30.4	28.8
		A–P	1323	976	—	—	31	28.6
Korea [27]	2015	Head	904	748	—	—	52.8	50
		Chest	707	583	—	—	13.2	10.4
		Abdomen	1028	835	—	—	13.3	11.7
Ireland [23]	2012	Head	940	857	—	—	58.4	51.4
		Chest	393	354	—	—	9.3	8.6
		A–P	598	547	—	—	12.3	11.1
Iran [22]	2015	Head	700	589	—	—	43	32.11
		Chest	330	270	—	—	10	9.1
		A–P	550	430	—	—	10	8.85
Kenya [26]	2016	Head	—	1274	—	—	—	55
		Chest	—	709	—	—	—	14
		Abdomen	—	1340	—	—	—	14
		Pelvis	—	1257	—	—	—	18
Malta [29]	2012	Head	736	531	—	—	41	38.3
		Chest	492	455	—	—	13.1	11.9
		Abdomen	539	513	—	—	12.1	11.3
Turkey [40]	2015	Head	810	660	—	—	66.4	—
		Chest	289	247	—	—	11.6	—
		Abdomen	204	176	—	—	13.3	—
		Pelvis	421	—	—	—	19.4	—

Table 2. continued

Country	Year of publication	Body region	DLP		$CTDI_w$		$CTDI_{vol}$	
France [14]	2018	Head	834	—	—	—	46.3	—
		Chest	344	—	—	—	9.2	—
		A–P	641	—	—	—	12.8	—
Finland [20]	2015	Head	800	—	—	—	55	—
		Chest	290	—	—	—	9	—
		Abdomen	560	—	—	—	12	—
United Arab Emirates [41]	2011	Head	1000	—	—	—	—	—
		Chest	500	—	—	—	—	—
		A–P	1000	—	—	—	—	—
Taiwan [39]	2016	Head	—	930	—	—	—	—
		Chest	—	404	—	—	—	—
		A–P	—	738	—	—	—	—
Republic of Belarus [35]	2010	Head	730	597	—	50	60	50.2
		Chest	500	408	—	19	20	16.4
		Abdomen	600	470	—	24	25	21
		Pelvis	490	—	—	—	25	—
Poland [33]	2017	Head	—	889	—	—	—	—
		Chest	—	376.3	—	—	—	—
		Abdomen	—	474.4	—	—	—	—
		Pelvis		456.9	—	—	—	—
Syria [38]	2010	Head	793	668	60.7	53.5	—	—
		Chest	520	396	22	16.9	—	—
		Abdomen	721	567	24.1	20.2	—	—
		Pelvis	542	465	27.5	23.4	—	—
Ghana [16]	2009	Chest	—	396	—	17.1	—	—
		Abdomen	—	496	—	20.4	—	—
		Pelvis	—	415	—	20.4	—	—

Table 2. continued

Country	Year of publication	Body region	DLP		$CTDI_w$		$CTDI_{vol}$	
Serbia [11]	2014	Head	—	953.4	—	—	—	65
		Chest	—	590.8	—	—	—	18.2
		Abdomen	—	1706	—	—	—	58.7
Former Yugoslav Republic of Macedonia [16]	2009	Chest	—	342	—	11.4	—	—
		Abdomen	—	526	—	13	—	—
		Pelvis	—	416	—	11.4	—	—
Kuwait [16]	2009	Chest	—	223	—	12	—	—
		Abdomen	—	552	—	11.7	—	—
Republic of Srpska [16]	2009	Chest	—	246	—	6.9	—	—
		Abdomen	—	448	—	10.2	—	—
		Pelvis	—	231	—	8.3	—	—
Estonia [16]	2009	Chest	—	833	—	15.7	—	—
		Abdomen	—	910	—	19	—	—
		Pelvis	—	698	—	14.5	—	—
Morocco [16]	2009	Chest	—	256	—	10	—	—
		Abdomen	—	341	—	11.9	—	—
		Pelvis	—	271	—	10.6	—	—
Tunisia [16]	2009	Chest	—	874	—	24.3	—	—
		Pelvis	—	599	—	25.4	—	—
Bosnia and Herz. [16]	2009	Chest	—	437	—	13.5	—	—
		Abdomen	—	460	—	—	—	—
		Pelvis	—	323	—	—	—	—
Czech Republic [16]	2009	Chest	—	341	—	21.3	—	—
		Abdomen	—	444	—	18.4	—	—
		Pelvis	—	466	—	20.3	—	—
Thailand [16]	2009	Chest	—	301	—	15.3	—	—
		Abdomen	—	574	—	18.5	—	—
		Pelvis	—	390	—	16.8	—	—

Table 2. continued

Country	Year of publication	Body region	DLP		$CTDI_w$		$CTDI_{vol}$	
Luxembourg [12]	2014	Head	—	813	—	—	—	52.2
		Chest	—	233	—	—	—	6.8
		Abdomen	—	431	—	—	—	9.6
Saudi Arabia [36]	2018	Head	—	912	—	—	—	50.5
		Chest	—	428	—	—	—	9.4
UK [42]	2016	Head	973	890	—	—	61	58
		Chest	614	500	—	—	12	11
		A–P	745	645	—	—	14	13
Malaysia [28]	2013	Head	1050	—	46.8	—	—	—
Norway [32]	2015	Chest	600	—	19.9	—	—	—
		abdomen	450	—	12.8	—	—	—
India [46]	2006	Pelvis	730	—	39.1	—	—	—
		Head	1002	866	—	—	73	64
		Chest	402	325	—	—	13	10
		Abdomen	703	590	—	—	15	13
		Pelvis	—	403	—	—	—	11
		Chest	—	355	—	—	—	12.3
		Abdomen	—	459	—	—	—	12.6
Canada [19]	2016	Head	1302	—	—	—	79.1	—
		Chest	521	—	—	—	14.1	—
		A–P	874	—	—	—	18.1	—
USA [43]	2017	Head	1011	—	—	—	57	—
		Chest	545	—	—	—	15	—
		A–P	1004	—	—	—	20	—
Croatia [15]	2010	Head	—	—	—	—	50	—
		Abdomen	—	—	—	—	25	—
Denmark [15]	2010	Head	1100	—	—	—	—	—
		Chest	700	—	—	—	—	—
		Abdomen	800	—	—	—	—	—
		Pelvis	600	—	—	—	—	—

Table 2. continued

Country	Year of publication	Body region	DLP		$CTDI_w$		$CTDI_{vol}$	
Lithuania [15]	2010	Head	950	—	—	—	—	—
		Chest	650	—	—	—	—	—
		Abdomen	1200	—	—	—	—	—
		Pelvis	550	—	—	—	—	—
Slovenia [15]	2010	Head	1040	—	—	—	—	—
		Chest	475	—	—	—	—	—
		Abdomen	555	—	—	—	—	—
Sri Lanka [13]	2012	Chest	—	417	—	9.7	—	—
		Abdomen	—	590	—	13	—	—
		Pelvis	—	590	—	13	—	—
Moldova [15]	2010	Head	—	—	—	—	50	—
		Abdomen	—	—	—	—	25	—
Austria [15]	2010	Head	1300	—	—	—	—	—
		Chest	550	—	—	—	—	—
		Abdomen	1200	—	—	—	—	—
		Pelvis	650	—	—	—	—	—
Netherlands [30]	2013	Head	935.6	813.7	—	—	—	—
		Chest	346.5	320	—	—	—	—
		Abdomen	618	567	—	—	—	—
		Pelvis	382.1	332	—	—	—	—
Belgium [15]	2010	Head	1020	—	—	—	—	—
		Chest	400	—	—	—	—	—
		Abdomen	830	—	—	—	—	—

700–1359 mGycm, with the lowest from Iran and the highest from Japan and Egypt. The DRL values for $CTDI_{vol}$ ranged from 30.4–85.5 mGycm with the lowest being Egypt and the highest being Japan.

The DRL values for chest DLP ranged from 289–707 mGy·cm, with the lowest being Turkey and the highest being Korea. The DRL values for $CTDI_{vol}$ ranged from 9–20, with the lowest being Finland and the highest being Republic of Belarus.

Last but not least, the DRL values for abdominopelvic DLP ranged from 470–1486 mGy·cm with the lowest being Bulgaria and the highest Nigeria. Taking into consideration the variation in reported abdominopelvic values, some countries reported abdominal and pelvic values separately. Turkey reported the lowest DLP for the abdomen, 204, and pelvis, 421. The DRL values for $CTDI_{vol}$ ranged from 10–31 mGy·cm with the lowest being Iran and the highest Egypt.

We compared the changes in DLP and $CTDI_{vol}$ between the most recent and preceding studies for countries that have established an NDRL in more than one survey, for the purpose of analysing the difference in dose values over the years. We were able to compare a total of 14 countries due to the availability of values adequate for reliable comparisons in older studies, shown in table 3. A negative difference implies that the DLP or $CTDI_{vol}$ has decreased over the years while a positive difference indicates an increase. Australia, France, Kenya, Korea, Ireland and Finland have shown a complete reduction in their DRL. We were able to compare only head values for the United States, which showed a reduction in the DRL. Poland, Switzerland and Taiwan have shown an increase in their head DRL, and a reduction in the other values. Bulgaria, Serbia and the UK have shown an increase in their DRL compared to previous years. Japan has shown an increase in the head $CTDI_{vol}$ value but a reduction in all the other values. The availability of comparative data in only 14 countries calls attention to the need for constant updating of the NDRL in every country.

Finally, we conceptualised a global means value where all available mean DRLs were averaged. This was used to compare the value to the ACR guidelines [57]. The results of the global means for DLP and $CTDI_{vol}$ are shown in table 4. When comparing the global means to the ACR 2016 DRL guidelines [57], we found that the global means of both DLP and $CTDI_{vol}$ were below or almost similar to the ACR DRL with a DLP decrease of 11%, 1% and 18%, for the head, chest and abdomen/pelvis, respectively. A minimal reduction in $CTDI_{vol}$ was observed with a decrease of 3.5% and 1% for the head and abdomen/pelvis, respectively, and no change in chest $CTDI_{vol}$. In addition, the global mean of the DLP and $CTDI_{vol}$ for the head, chest, abdomen and pelvis were lower than the European Commission (EC) 2004 guideline [6] with a DLP decrease of 18%, 31%, 15% and 8%, respectively, and a $CTDI_{vol}$ decrease of 10%, 60%, 48.5% and 60%, respectively.

4. Discussion

This study is aimed at collecting all available data on NDRLs for routine head, chest and abdominopelvic studies of adult patients. For a reliable systematic review, we included all the most recent national studies or those considered representative through a small sample of institutions or scanners. Having a larger sample size gives the study more credibility for measurements, while having a small sample can result in many uncertainties [3]. Apart from having an optimal number of CT scanners for representation, other factors such as selecting several model types and the number of patients are important for higher precision and accuracy [3, 58]. Several countries in this study failed to report scanner demographics, which brings the reliability of their studies into question.

Table 3. Difference in the mean and tirrd quartiles DLP and CTDI values between the two most recent studies for countries that have had an established NDRL for two years or more.

Country	Years of comparison	Diff. in mean DLP			Diff. in mean CTDI			Diff. in 3rd Q DLP			Diff in 3rd Q CTDI		
		Head	Chest	A–P	Head	Chest	A–P	Head	Chest	A–P	Head	Chest	A–P
Australia	2018 [17]–2013 [47]	—	—	—	—	—	—	–120	–60	–100	–8	–5	—
Bulgaria	2018 [18]–2010 [48]	—	—	—	—	—	—	+202	+77	+95*	—	—	
France	2018 [14]–2017 [49]	—	—	—	—	—	—	–116	–136	–49	—	—	—
Japan	2019 [25]–2018 [50]	–464.7	–267.5	—	+6	–4.3	—	+67	–145.6	—	+7.5	–1	—
Kenya	2016 [26]–2012 [51]	–301	–241	–362*	–6	–1.1	–2.1*	—	—	—	—	—	—
Korea	2015 [27]–2010 [52]	–70.7	–263.7	–428.3*	—	—	—	–56	–415	–648*	—	—	—
Serbia	2014 [11]–2009 [16]	—	+442.8	+1194*	—	—	—	—	—	—	—	—	—
Switzerland	2010 [37]–2004 [53]	—	—	—	—	—	—	+283	–56	—	—	—	—
Taiwan	2016 [39]–2007 [54]	+275	–51	—	—	—	—	—	—	—	—	—	—
UK	2016 [42]–2006 [55]	+130	+70	+155	—	—	—	—	—	—	—	—	—
US	2017 [43]–2008 [56]	—	—	—	—	—	—	—	—	—	–19	—	—
Finland	2015 [20]–2010 [15]	—	—	—	—	—	—	–200	–210	–40	–10	–21	–3*
Ireland	2012 [23]–2010 [15]	—	—	—	—	—	—	–10	–67	–42	—	—	—
Poland	2017 [33]–2006 [46]	+362	–70.7	–75.6*	—	—	—	—	—	—	—	—	—

* Abdomen only. (−)Decrease. (+) Increase.

Table 4. Averaged global means of all recent studies. SD: standard deviation.

	Head	Chest	Abdomen	Pelvis	A-P
Global mean DLP (SD)	854 (198)	449 (170)	665 (326)	525 (222)	641 (180.5)
Global mean $CTDI_{vol}$ (SD)	54 (13)	12 (3.1)	18 (13)	14 (4)	15 (7)
ACR 2016 DLP ($CTDI_{vol}$) [57]	962 (56)	443 (12)	—	—	781 (16)
EC 2004 DLP ($CTDI_w$) [6]	1050 (60)	650 (30)	780 (35)	570 (35)	—

The technology in medical imaging is constantly evolving to meet new demands in the field [58]. The changes introduced include several reconstruction algorithms that play a part in regulating dose and image quality. In one systematic review, iterative reconstruction (IR) has been shown to surpass filtered-back projection (FBP) which was commonly used in reducing radiation dose and enhancing image quality [59]. However, it is uncertain which types of reconstruction methods institutions are using and who is using what [59]. This, along with the time the national study was conducted, are vital factors in establishing an appropriate DRL [3]. This poses an issue for countries that fail to update their NDRL due to outdated, unreliable data [3]. The ICRP and EC recommend constant updating of the NDRL to set optimised protocols and achieve a further reduction in ionising radiation dose for patients [3, 6]. Furthermore, the new European Directive 2013/59/Euratom obliges the Member States to establish a DRL and emphasises the need for continuous reviews to ensure appropriate radiation dose delivery and take corrective actions when they are exceeded [60].

Within the scope of this study, data were collected from 51 countries in individual and collective studies. Only 23 (45%) countries have established NDRLs in the past 5 years. Some countries have not updated their NDRL in over 10 years, such as Oman [61] and India [46]. Of the current 195 countries on Earth, only 26% have established an adult NDRL, which is alarming. Järvinen *et al* proposed some explanations for the lack of efforts in some countries to establish NDRLs or to regularly update them [62]. The main problems might be associated with a lack of funding and policies, the awareness of staff about radiation protection, or the appropriateness of dose-collecting systems [62]. In addition, patient dose recording and documentation is not required in some countries, which makes data validation difficult [62]. On the other hand, a few nations update their NDRL regularly through established governmental online platforms, such as Australia [17] and the UK [63]. According to Järvinen *et al*, these countries demonstrated extensive cooperation between authorities and professional medical teams [62].

Multiple nations, such as Austria [64], reported measurements such as effective doses rather than $CTDI_{vol}$ or DLP in their most recent studies. Such measurements are not as reliable as DLP or $CTDI_{vol}$ due to the difficulty in radiation dose evaluation and differences in calculation methods [3]. Consequently, this lack of standardisation makes it difficult to compare the DRL values on an international level.

Local DRLs (LDRL) have been established by several institutions or provinces. The EC urges LDRLs to be compared to the NDRL or European DRL to ensure they do not exceed the established values [6]. In case the LDRL exceeds a newly updated NDRL, further monitoring or abiding by the NDRL should be required [6]. The ICRP also brought forth the concept of clinical DRL, based on clinical indications. While existing DRLs mostly focus on anatomical locations, clinical indications could present different protocols that correspond to different radiation doses delivered. As there remainseveral countries that are yet to establish a NDRL, implementing clinical DRL still seems far-fetched [65].

The global means give us an idea of how all nations are performing altogether. The values reported are shown to be below the proposed DRL provided by the EC and ACR. The next step for nations is to revisit their NDRLs and establish updated ones based on the technology they are performing with. This would include the type of scanners and reconstruction methods that are being utilised. Studies in Japan [25] and Australia [66] have established previous DRLs based on reconstruction methods. From these studies, the authors emphasised the importance of using dose-reducing technology, such as IR, by portraying the resultant decrease in radiation dose. Additionally, consistency in reporting DRL should be established for body regions, as several studies report the abdomen and pelvis as a whole while others as separate regions. This could be in correspondence to systemic protocols and should further be assessed.

The literature displays a range of NDRL values that varies greatly from country to country. With countries that have established multiple NDRLs, there was an observed reduction or increase in dose values over time, as displayed in table 3. A reduction in radiation dose is explicable for a few reasons. Technological advancements such as the implementation of IR algorithms was shown to play a major role in reducing radiation dose and is reported by some countries [25, 59, 66]. Although several studies failed to report this information, it can be assumed that these innovations contributed to the dose reduction; however, the lack of data in these studies cannot support this claim. Another explanation for this reduction could be due to the establishment of previous DRLs that have set a standard for modern CT protocols and examinations. This can be seen by comparing the current DRL to the previous NDRL, shown in table 3, and to the earlier DRL set by the ACR and EC, showing how the implementation of the DRL contributed to dose reduction. The International Atomic Energy Agency highlighted this point by pointing out the two-fold decrease of UK DRL over the last 20 years.

Within the searched literature, there were gaps in knowledge and research that need to be addressed. To begin with, there are still many countries that have not established an NDRL, which leaves room for plenty of research. From those that have established an NDRL, several have failed to provide the necessary data for full data collection, analysis and interpretation. This includes demographic data, the type of technology (if) used and the type of dose reported (i.e. effective dose versus DLP). These are gaps in knowledge that should be addressed by researchers, not only to study the effectiveness and reliability of the collected data within the study, but to accurately analyse and determine the underlying factors behind the dose outcomes and benchmark them to international standards. These factors should be assessed to allow international organisations to establish global reference levels for institutions depending on technology, parameters and patient demographics. Achieving a global standard for routine protocols is the first step that brings us a step closer to standardising protocols based on clinical indications, technology and other factors.

4.1. Limitations

Despite the extensive searches in multiple databases and after careful review of the articles, there were shortcomings to our study. First, there were several countries that presented effective doses in their most recent studies; however, when recording data, these were not standardised measured values. Second, there is a probability of missing some data from studies that have not come up in our search. Third, not all studies reported the type of CT scanners and image reconstruction algorithms employed, which could potentially bias the results between the FBP and IR techniques. Fourth, due to the variation in the presented data, we were unable to provide the statistical significance between countries and determine the current status of change in NDRLs. Finally, the calculation of the global means for the DLP and $\mathrm{CTDI}_{\mathrm{vol}}$ values does not include all countries, since some countries have not established an NDRL.

4.2. Conclusion

This systematic review is aimed at collectively gathering the available data on NDRL. Several studies failed to report data in areas such as demographics and the type of technology used (if any) and it is shown that some countries fail to update NDRL regularly. This brings their current data into question and also whether techniques to reduce the delivered radiation dose are being practiced. The global means calculated from the available data were shown to be slightly lower and significantly lower than the reported DLP and $\mathrm{CTDI}_{\mathrm{vol}}$ values of the ACR and EC, respectively. This brings forth the need for an international standardisation for head and body DRL for improved comparable global measurement of dose variations across CT sites and radiation delivery monitoring.

Appendix

Scopus

(((TITLE-ABS-KEY ((gray OR sv OR sievert OR gy) W/2 (unit OR units OR radiation))) OR (TITLE-ABS-KEY ((radiation W/2 (monitor* OR protection OR scatter* OR count* OR measur* OR value* OR amount OR dose? OR dosage? OR exposure* OR absorb* OR absorption?)) OR radiometer OR radiometry OR dosimeter OR dosimetry))) AND ((TITLE-ABS-KEY (((dose OR reference OR normal) W/2 (range* OR value* OR standard* OR level* OR product*)))) OR (TITLE-ABS-KEY (standard W/2 (range* OR value* OR level*))) OR (TITLE-ABS-KEY (((radiodiagnos* OR radio-diagnos* OR diagnos*) W/2 (dose* OR dosage))))) AND (TITLE-ABS-KEY (tomograph* OR ct OR cts OR tomodensitometr* OR tomo-densitometr* OR (multi-detector W/4 ct) OR (multidetector W/4 ct) OR (multi W/1 detector W/4 ct) OR (multi W/3 slice W/4 ct) OR (multislice W/4 ct)))) OR ((TITLE-ABS-KEY (tomograph* OR cts OR tomodensitometr* OR tomo-densitometr* OR (multi-detector W/4 ct) OR (multidetector W/4 ct) OR (multi W/1 detector W/4 ct) OR (multi W/3 slice W/4 ct) OR (multislice W/4 ct))) AND (TITLE-ABS-KEY (drl OR drls OR ndrl OR ndrls OR dlp OR dlps OR (length W/2 product*) OR 'diagnostic PRE/0 reference PRE/0 level')))

Medline

Database: Ovid MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations and Daily < 1946 to 5 February 2019 >

Search Strategy:

1. Radiometry/or Radiation Dosage/(71 086)
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4. Absorption, Radiation/(531)
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Embase

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#10	Search dosimeter [tw] OR dosimetry [tw]	25 366
#9	Search radiation monitor* [tw] OR radiation protection [tw] OR radiation scatter* [tw] OR radiation count [tw] OR radiation measur* [tw] OR radiation value* [tw] OR radiation amount* [tw] OR radiation dose* [tw] OR radiation dosage* [tw]	114 563
#8	Search radiometer [tw] OR radiometry [tw]	33 692
#7	Search (gray unit* [tw] gray radiation [tw] OR sievert unit* [tw] OR sievert radiation [tw] OR gy unit* [tw] OR sv radiation [tw])	1102
#6	Search radiation scattering [mesh: noexp]	27 063
#5	Search radiation protection [mesh: noexp]	20 168
#4	Search radiation absorption [mesh: noexp]	531
#3	Search radiation exposure [mesh: noexp]	2217
#2	Search radiation monitoring [mesh:noexp]	13 470
#1	Search radiometry [mesh:noexp]	31 799

9. (radiat* adj2 (monitor* or protection or scatter* or count* or measur* or value? or amount or dose? or dosage? or exposure? or absorb* or absorption?)).mp. (146 693)

10. dosimet*.mp. (35 151)

11. Reference Values/or Reference Standards/(195 194)

12. (((dose? or reference* or normal) adj2 (range? or value? or standard? or level? or product?)) or (standard? adj2 (range? or value? or level?))).mp. (419 396)

13. ((radiodiagnos* or radio-diagnos* or diagnos*) adj2 (dose? or dosage?)).mp. (1181)

14. (DRL? or NDRL? or DLP? or (length adj2 product?) or diagnostic reference level?).mp. (4631)

15. tomography/or exp tomography, x-ray/or tomography, x-ray computed/or exp cone-beam computed tomography/or four-dimensional computed tomography/or exp tomography, spiral computed/or imaging, three-dimensional/or Tomography Scanners, x-ray Computed/or Spiral Cone-Beam Computed Tomography/(457 916)

16. (tomograph* or CT or CTS or tomodensitometr* or tomo-densitometr* or multi-detector? or multidetector? or (cat adj4 scan*) or (multi adj2 detector?) or (mutlislice adj4 ct) or (multi-detector adj4 ct) or (multidetector adj4 ct) or three-dimensional imaging).mp. (776 532)

17. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 (189 692)

18. 11 or 12 or 13 (420 392)

19. 15 or 16 (816 651)

20. 17 and 18 and 19 (3961)

21. 14 and 19 (1398)

22. 20 or 21 (4219)

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References

[1] Miglioretti D L and Smith-Bindman R 2011 Overuse of computed tomography and associated risks *Am. Fam. Physician* **83** 1252–4

[2] Sarma A, Heilbrun M E, Conner K E, Stevens S M, Woller S C and Elliott C G 2012 Radiation and chest CT scan examinations: what do we know? *Chest* **142** 750–60

[3] Vañó E, Miller D L, Martin C.J, Rehani M.M., Kang K, Rosenstein M, Ortiz-López P, Mattsson S, Padovani R and Rogers A 2017 Diagnostic reference levels in medical imaging. ICRP Publication 135 *Ann. ICRP* **46** 1–144

[4] Saravanakumar A, Vaideki K, Govindarajan K, Devanand B, Jayakumar S and Sharma S 2016 Establishment of CT diagnostic reference levels in select procedures in South India *Int. J. Radiat. Res.* **14** 341

[5] Huda W and Mettler F A 2011 Volume CT dose index and dose-length product displayed during CT: what good are they? *Radiology* **258** 236–42

[6] European Commission 1999 *European Guidelines on Quality Criteria for Computed Tomography EUR 16262 EN* (Luxemburg Office for Official Publications of the European Communities)

[7] Liberati A, Altman D G, Tetzlaff J, Mulrow C, Gøtzsche P C, Ioannidis J P A, Clarke M, Devereaux P J, Kleijnen J and Moher D 2009 The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration *BMJ* **339** b2700

[8] Moher D, Liberati A, Tetzlaff J and Altman D G 2009 Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement *Br. Med. J.* **339** 332–6

[9] Simantirakis G, Hourdakis C J, Economides S, Kaisas I, Kalathaki M Koukorava C *et al* 2015 Diagnostic reference levels and patient doses in computed tomography examinations in Greece *Radiat. Prot. Dosim.* **163** 319–24

[10] Salama D H, Vassileva J, Mahdaly G, Shawki M, Salama A and Gilley D *et al* 2017 Establishing national diagnostic reference levels (DRLs) for computed tomography in Egypt *Physica Med.* **39** 16–24

[11] Arandjic D, Ciraj-Bjelac O, Hadnadjev D, Stojanovic S, Bozovic P Ceklic S *et al* 2014 Radiation doses in adult computed tomography practice in Serbia: initial results *Radiat. Prot. Dosim.* **162** 135–8

[12] Tack D, Jahnen A, Kohler S, Harpes N, De Maertelaer V Back C *et al* 2014 Multidetector CT radiation dose optimisation in adults: short- and long-term effects of a clinical audit *Eur. Radiol.* **24** 169–75

[13] Rehani M M, Ciraj-Bjelac O, Al-Naemi H M, Al-Suwaidi J S, El-Nachef L Khosravi H R *et al* 2012 Radiation protection of patients in diagnostic and interventional radiology in Asian countries: impact of an IAEA project *Eur. J. Radiol.* **81** e982-e9

[14] Roch P, Celier D, Dessaud C and Etard C 2018 Using diagnostic reference levels to evaluate the improvement of patient dose optimisation and the influence of recent technologies in radiography and computed tomography *Eur. J. Radiol.* **98** 68–74

[15] European Commission (EC) 2014 *Dose Datamed 2 (DDM2) Project Report Part 2: Diagnostic Reference Levels (DRLs) in Europe* (Luxembourg: Publications Office of the European Union)

[16] Muhogora W E, Ahmed N A, Beganovic A, Benider A, Ciraj-Bjelac O Gershan V *et al* 2009 Patient doses in CT examinations in 18 countries: initial results from International Atomic Energy Agency projects *Radiat. Prot. Dosim.* **136** 118–26

[17] Australian Radiation Protection and Nuclear Safety Agency 2019 Current Australian national diagnostic reference levels for multi detector computed tomography (available at: www.arpansa.gov.au/)

[18] Lhotska L, Sukupova L, Lacković I and Ibbott G ed 2018 Elaboration of new NDRLs as part of third national patient dose survey in diagnostic radiology in Bulgaria, Lhotska L, Sukupova L, Lacković I and Ibbott G eds vol **68/2** *IFMBE Proc.* (Singapore Springer)

[19] Wardlaw G M and Martel N 2016 Canadian computed tomography survey: national diagnostic reference levels: sci-thur pm–colourful interactions: highlights 07 *Med. Phys.* **43** 4932–3

[20] Lajunen A 2015 Indication-based diagnostic reference levels for adult CT-examinations in Finland *Radiat. Prot. Dosim.* **165** 95–97

[21] Schegerer A, Loose R, Heuser L J and Brix G 2019 Diagnostic reference levels for diagnostic and interventional x-ray procedures in Germany: update and handling *RoFo Fortschr. Geb. Rontgenstr. Nuklearmed.* **21** 21

[22] Najafi M, Deevband M R, Ahmadi M and Kardan M R 2015 Establishment of diagnostic reference levels for common multi-detector computed tomography examinations in Iran *Australas. Phys. Eng. Sci. Med.* **38** 603–9

[23] Foley S J, McEntee M F and Rainford L A 2012 Establishment of CT diagnostic reference levels in Ireland *Br. J. Radiol.* **85** 1390–7

[24] Palorini F, Origgi D, Granata C, Matranga D and Salerno S 2014 Adult exposures from MDCT including multiphase studies: first Italian nationwide survey *Eur. Radiol.* **24** 469–83

[25] Matsunaga Y, Chida K, Kondo Y, Kobayashi K, Kobayashi M Minami K *et al* 2019 Diagnostic reference levels and achievable doses for common computed tomography examinations: results from the Japanese nationwide dose survey *Br. J. Radiol.* **92** 20180290

[26] Korir G K, Wambani J S, Korir I K, Tries M A and Boen P K 2016 National diagnostic reference level initiative for computed tomography examinations in Kenya *Radiat. Prot. Dosim.* **168** 242–52

[27] Kim M C, Han D K, Nam Y C, Kim Y M and Yoon J 2015 Patient dose for computed tomography examination: dose reference levels and effective doses based on a national survey of 2013 in Korea *Radiat. Prot. Dosim.* **164** 383–91

[28] Ministry of Health Malaysia 2013 *Malaysian Diagnostic Reference Levels in Medical Imaging (Radiology)* (Putrajaya: Federal Government Administrative Center)

[29] Zarb F, McEntee M and Rainford L 2012 Maltese CT doses for commonly performed examinations demonstrate alignment with published DRLs across Europe *Radiat. Prot. Dosim.* **150** 198–206

[30] van der Molen A J, Schilham A, Stoop P, Prokop M and Geleijns J 2013 A national survey on radiation dose in CT in The Netherlands *Insights Imaging* **4** 383–90

[31] Ekpo E U, Adejoh T, Akwo J D, Emeka O C, Modu A A Abba M *et al* 2018 Diagnostic reference levels for common computed tomography (CT) examinations: results from the first Nigerian nationwide dose survey *J. Radiol. Prot.* **38** 525–35
[32] Friberg E G, Widmark A and Hauge I H R 2008 *National Collection of Local Diagnostic Reference Levels in Norway and Their Role in Optimization of X-ray Examinations* (Osteras : Norwegian Radiation Protection Authority)
[33] Kluszczynski D and Pankowski P 2017 The first approach to set up the diagnostic reference levels in CT based on the Poland-wide DLP data *European Congress of Radiology*, (*Vienna, Austria*) ECR 2017
[34] Santos J, Foley S, Paulo G, McEntee M and Rainford L 2013 The establishment of computed tomography diagnostic reference levels in Portugal *Radiat. Prot. Dosim.* **158** 307–17
[35] Kharuzhyk S A, Matskevich S A, Filjustin A E, Bogushevich E V and Ugolkova S A 2010 Survey of computed tomography doses and establishment of national diagnostic reference levels in the Republic of Belarus *Radiat. Prot. Dosim.* **139** 367–70
[36] Sulieman A, Mahmoud M Z, Serhan O, Alonazi B, Alkhorayef M Alzimami K *et al* 2018 CT examination effective doses in Saudi Arabia *Appl. Radiat. Isot.* **141** 261–5
[37] Treier R, Aroua A, Verdun F, Samara E, Stuessi A and Trueb P R 2010 Patient doses in CT examinations in Switzerland: implementation of national diagnostic reference levels *Radiat. Prot. Dosim.* **142** 244–54
[38] Kharita M H and Khazzam S 2010 Survey of patient dose in computed tomography in Syria 2009 *Radiat. Prot. Dosim.* **141** 149–61
[39] Yeh D M, Tsai H Y, Tyan Y S, Chang Y C, Pan L K and Chen T R 2016 The population effective dose of medical computed tomography examinations in Taiwan for 2013 *PLoS One* **11** e0165526
[40] Atac G K, Parmaksiz A, Inal T, Bulur E, Bulgurlu F Oncu T *et al* 2015 Patient doses from CT examinations in Turkey *Diagn. Interventional Radiol*. **21** 42
[41] Alsuwaidi J S, Alawadhi H, Rahanjam A, Hallag M A E, Janaczek J and Kaabi F A, *et al* ed 2011 National survey on medical exposure to patients undergoing diagnostic radiology examinations: an initial overview on CT doses at UAE hospitals *IEEE 1st Middle East Conf. on Biomedical Engineering, MECBME* pp 400–2
[42] Shrimpton P C, Jansen J T and Harrison J D 2016 Updated estimates of typical effective doses for common CT examinations in the UK following the 2011 national review *Br. J. Radiol.* **89** 20150346
[43] Klosterkemper Y, Appel E, Thomas C, Bethge O T, Aissa J Kropil P *et al* 2018 Tailoring CT dose to patient size: implementation of the updated 2017 ACR size-specific diagnostic reference levels *Acad. Radiol.* **25** 1624–31
[44] Meddad F, Merad A, Guedioura D and Khelassi-Toutaoui N ed 2018 Study to establish diagnostic reference levels of adults CT chest examinations in Algeria *AIP Conf. Proc.* **1994** 060009
[45] Narciso L, Lima N, Dartora C, da Silva M A*et al* 2015 A contribution to the establishment of diagnostic reference levels in computed tomography in Brazil Jaffray D ed *IFMBE Proc.* vol 51 (Berlin: Springer) pp 737–40
[46] Tsapaki V, Aldrich J E, Sharma R, Staniszewska M A, Krisanachinda A Rehani M *et al* 2006 Dose reduction in CT while maintaining diagnostic confidence: diagnostic reference levels at routine head, chest, and abdominal CT—IAEA-coordinated research project *Radiology* **240** 828–34
[47] Hayton A, Wallace A, Marks P, Edmonds K, Tingey D and Johnston P 2013 Australian diagnostic reference levels for multi detector computed tomography *Australas. Phys. Eng. Sci. Med.* **36** 19–26
[48] Vassileva J, Borisova R, Stoyanov D, Dimov A, Avramova-Cholakova S Ingilizova K *et al* 2010 National survey in diagnostic radiology in Bulgaria 2007–2009 *Rentgenologiya I Radiologiya* **49** 251–64
[49] Schmidt C W 2012 CT scans: balancing health risks and medical benefits *Environ. Health Perspect.* **120** A118–A121
[50] Nakada Y, Okuda Y, Tsuge T, Suzuki J, Sakamoto H Yamamoto T *et al* 2018 Automatic acquisition of CT radiation dose data: using the diagnostic reference level for radiation dose optimization *Radiat. Prot. Dosim.* **181** 156–67
[51] Korir G K, Wambani J S and Korir I K 2012 Patient doses using multidetector computed tomography scanners in Kenya *Radiat. Prot. Dosim.* **151** 267–71
[52] Choi J, Cha S, Lee K, Shin D, Kang J Kim Y *et al* 2010 The development of a guidance level for patient dose for CT examinations in Korea *Radiat. Prot. Dosim.* **138** 137–43

[53] Aroua A, Besançon A, Buchillier-Decka I, Trueb P, Valley J F Verdun F R *et al* 2004 Adult reference levels in diagnostic and interventional radiology for temporary use in Switzerland *Radiat. Prot. Dosim.* **111** 289–95

[54] Tsai H Y, Tung C J, Yu C C and Tyan Y S 2007 Survey of computed tomography scanners in Taiwan: dose descriptors, dose guidance levels, and effective doses *Med. Phys.* **34** 1234–43

[55] Shrimpton P C, Hillier M C, Lewis M A and Dunn M 2006 National survey of doses from CT in the UK: 2003 *Br. J. Radiol.* **79** 968–80

[56] Radiology ACo 2008 ACR practice guideline for diagnostic reference levels in medical x-ray imaging (available at: www.acr.org 2011)

[57] Butler P F and Kanal K M 2018 Diagnostic reference levels for adult patients in the United States *J. Am. Coll. Radiol.* **15** 932–3

[58] Hsiao K H, Dinh M M, McNamara K P, Bein K J, Roncal S Saade C *et al* 2013 Whole-body computed tomography in the initial assessment of trauma patients: is there optimal criteria for patient selection? *Emergency Med. Australas.* **25** 182–91

[59] Qiu D and Seeram E 2016 Does iterative reconstruction improve image quality and reduce dose in computed tomography *Radiol. Open J* **1** 42–54

[60] European Society of Radiology (ESR) 2015 Summary of the European Directive 2013/59/Euratom: essentials for health professionals in radiology *Insights Imaging* **6** 411–17

[61] Goddard C C and Al-farsi A 1999 Radiation doses from CT in the Sultanate of Oman *Br. J. Radiol.* **72** 1073–7

[62] Järvinen H, Vassileva J, Samei E, Wallace A, Vano E and Rehani M 2017 Patient dose monitoring and the use of diagnostic reference levels for the optimization of protection in medical imaging: current status and challenges worldwide *J. Med. Imaging* **4** 031214

[63] Public Health England 2018 National diagnostic reference levels: 22 January 2016 to 14 November 2018 (available at: www.gov.uk/government/publications/diagnostic-radiology-national-diagnostic-reference-levels-ndrls/national-diagnostic-reference-levels-ndrls)

[64] Homolka P, Leithner R, Billinger J and Gruber M 2014 Results of the Austrian CT dose study 2010: typical effective doses of the most frequent CT examinations *Z. Med. Phys.* **24** 224–30

[65] Damilakis J, Frija G, Hierath M, Jaschke W, Mayerhofer-Sebera U Paulo G *et al* 2018 *Report and Review on Existing Clinical DRLs* (European Commission)

[66] Thomas P, Hayton A, Beveridge T, Marks P and Wallace A 2015 Evidence of dose saving in routine CT practice using iterative reconstruction derived from a national diagnostic reference level survey *Br. J. Radiol.* **88** 20150380