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European DRLs for specific applications of CT in multi-modality systems

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1. Introduction

The concept of diagnostic reference values (DRLs), first introduced by the International Commission on Radiological Protection (ICRP), has been proven to be an effective tool for the optimisation of medical exposures [1,2]. In that context, The Council Directive 2013/59/Euratom requires DRLs to be established and used in different areas of medical radiodiagnostics, interventional radiology and nuclear medicine practices [3]. In fact, national DRLs should be compared with available European DRLs whenever these values have been established or updated. If for a specific clinical application national DRLs are consistently exceeded, corrective actions should be undertaken without undue delay (Article 58 f, Council Directive 2013/59/Euratom BSS).

In diagnostic imaging, DRL values for a variety of CT procedures are available in most European countries [4]. However, most of these DRLs are defined for a body region without specification of the clinical indication or task. In nuclear medicine, CT acquisitions can be used for attenuation correction and/or better localisation of the SPECT or PET emission data. In other cases, CT is used for diagnostic reasons. Hence, depending on the clinical purpose in hybrid imaging, CT image quality requirements and corresponding patient radiation doses may differ considerably.

Published national DRL values in Europe for CT acquisitions used in hybrid imaging are rather scarce. So far, DRL values are available from France (PET/CT) [5], Switzerland (SPECT/CT and PET/CT) [6], the UK (SPECT/CT and PET/CT) [7], Bulgaria (SPECT/CT) [8,9], and recently, the Nordic countries (SPECT/CT and PET/CT) [10].

This deliverable, 2.10, is part of Task 2.3 “Dose evaluation and optimisation of multimodality imaging” of the MEDRIAD project, and linked to Subtask 2.3.1, where one of the goals is to propose the first-ever European diagnostic reference levels (DRLs) for specific applications of computed tomography (CT) in hybrid SPECT/CT and PET/CT.

2. European CT dose survey for hybrid imaging

To establish European CT DRLs for hybrid imaging, the recommendations of ICRP Publication 135 were taken into account [2]. Regional DRLs (such as for Europe) could be based on the median of the available national DRLs, as a guidance value for those countries where such DRLs are not yet available. However, the latter method is not applicable for hybrid CT acquisitions due to a lack of data.

Alternatively, a single survey of a representative sample of facilities drawn from the entire European region needs to be conducted. Normally, results from at least 20 nuclear medicine facilities should be sufficient to establish the DRLs in the first instance [2]. However, since there are substantial differences in applied imaging protocols in nuclear medicine, a dataset retrieved from 20 departments is far too limiting for establishing European DRLs. In fact, some of the selected nuclear medicine departments do not use CT in some specific clinical areas (e.g. cardiac scans), whereas for other applications they do. In addition, the clinical utilisation of the CT acquisition methods (attenuation correction, anatomical localisation or diagnostic CT) might vary between departments, thereby further subdividing the original sample of departments into smaller groups.

In a previous MEDIRAD survey, the current status of multi-modality systems in nuclear medicine was studied [11]. In the survey, 95 nuclear medicine departments throughout Europe expressed their interest to share CT dose data for specific nuclear medicine purposes. Electronic CT dose data collection forms (Microsoft Excel) were sent out to each of these departments. An example of such a form for ^{18}FDG-PET/CT can be found in Figure 1.

Questionnaire for patient dose data of hybrid imaging examinations

PET/CT
FDG-PET

If possible, please provide us of patient dose data from 30 patients or more.

Center/Institution:
Country:

Equipment
Manufacturer:
Model:
No. of slices
Installation date:

Extra information*:

* Optional

If you allow us to contact you for more information, please enter your contact details below.
Contact: Name: First name: e-mail:

No.	Date	Patient				PET exposure parameters			CT exposure parameters														
		Gender	Age	Height	Weight	Radio-pharmaceutical	Radio-nuclide	Administered activity	Clinical purpose CT scan	kVp	$CTDI_{vol}$	DLP	Contrast injection	TCM	Breath holding technique	Iterative CT reconstruction	Current *	Rotation time *	mAs *	Scan length *	Slice thickness *	Pitch factor *
	(dd/mm/yyyy)	(M or F)	(y)	(cm)	(kg)			(MBq)	diagnostic, localisation + attenuation correction, attenuation correction only)	(kV)	(mGy)	(mGy*cm)	(YES or NO)	(YES or NO)	(YES or NO)	(YES or NO)	(mA)	(s)		(cm)	(mm)	
1																						

Figure 1: Layout of the CT dose questionnaire for ^{18}FDG-PET/CT

With these forms, information was collected on:

- *the nuclear medicine department*: country, university hospital (yes/no)
- *the instrumentation*: brand, type, number of CT slices, data of installation
- *patient-specific information*: gender, age, height, and weight
- *the clinical purpose of the CT scan*: attenuation correction, anatomical localisation, diagnostic CT with or without contrast medium
- *CT scanner protocol used*: kVp, tube current modulation (yes/no), iterative reconstruction (yes/no), tube current, pitch, slice thickness, scan length
- *CT dose indicators*: CT dose index ($CTDI_{vol}$) and dose-length product (DLP)

Participating centres were asked to complete the form for up to 30 patients per examination of the most frequently performed hybrid imaging studies in their department.

In order to obtain a dataset linked to a standard-sized patient weighing 70 ± 10 kg, departments were requested to provide CT dose data from adult patients with a weight between 50 and 90 kg [2]. All forms were checked on the weight criterion. If patients with a weight outside the predefined range were included in the received forms, these data points were not taken into account for further calculations.

3. Results of the European CT dose survey for hybrid imaging

3.1 General overview

From October 2018 until February 2020, datasets were continually received from 50 nuclear medicine departments from 20 European countries. An overview is presented in Table 1. Twenty-two (44%) of the departments were linked to a university hospital.

Table 1: Number of responses per country

Country	N° of responses	Country	N° of responses
Austria	2	Ireland	1
Belgium	10	Italy	4
Bulgaria	1	Luxembourg	1
Croatia	1	Netherlands	4
Czech Republic	3	Norway	1
Denmark	1	Poland	2
Finland	1	Portugal	1
France	3	Spain	2
Germany	5	Sweden	2
Hungary	1	UK	4

For all datasets, a mean weight of 70 ± 10 kg was found. Data were received for ^{18}FDG PET/CT half body (from vertex to mid-thigh), PET/CT brain, ^{99m}Tc-bone SPECT/CT (main body), ^{99m}Tc-bone SPECT/CT (extremities), Parathyroid SPECT/CT, Octreotide and MIBG SPECT/CT and ^{99m}Tc-Cardiac SPECT/CT scans. As recommended by the ICRP, median $CTDI_{vol}$ and DLP values from each dataset were calculated. InTtable 2, an overview of the statistical descriptors (minimum, 25th percentile, median, 75th percentile, maximum) for the distribution of these median values is presented, as well as the number of facilities and countries where the datasets came from.

Table 2: Summary statistics for the distribution of the median $CTDI_{vol}$ and DLP for each examination and clinical purpose

Examination	Clinical purpose*	# Depts	# Countries	$CTDI_{vol}$ (mGy)					DLP (mGy.cm)				
				min	25th%	median	75th%	max	min	25th%	median	75th%	max
^{18}FDG PET/CT half body	AC	10	7	0.6	1.3	2.0	2.5	3.4	61	132	201	230	321
	AL	20	12	1.6	3.3	4.3	6.3	14.2	151	292	376	575	1302
	D	12	7	4.0	5.6	9.5	10.8	16.3	354	565	843	925	1436
PET/CT brain	AC	17	12	0.7	2.1	4.0	6.4	8.7	15	62	110	156	245
	AL	8	6	2.9	11.5	21.0	25.5	31.1	62	246	430	550	670
^{99m}Tc-bone SPECT/CT (trunc)	AL	37	19	1.7	2.5	3.8	4.4	10.5	25	85	141	158	272
	D	9	6	10.5	13.1	14.8	16.6	21.6	523	579	636	679	754
^{99m}Tc-bone SPECT/CT (extremities)	AL	7	5	1.0	5.1	7.0	11.5	22.1	42	153	235	322	451
Parathyroid SPECT/CT	AL	21	17	0.9	1.9	3.8	4.4	10.5	25	86	141	158	272
Octreo/MIBG SPECT/CT	AL	8	6	1.7	3.3	6.5	9.8	14.0	43	170	561	705	931
^{99m}Tc-Cardiac SPECT/CT	AC	20	15	0.5	1.1	1.6	3.1	7.1	7	22	34	59	105

*AC = attenuation correction only; AL = attenuation correction and anatomical localisation; D = diagnostic CT

25^{th} % = 25^{th} percentile value of the distribution of the median dose indicator

75^{th} % = 75^{th} percentile value of the distribution of the median dose indicator

3.2 ^{18}FDG PET/CT

In Figure 2, the calculated 75th percentile values of the distribution of median values for $CTDI_{vol}$ and DLP are presented for ^{18}FDG PET/CT. The MEDIRAD values (in red) are linked to the current study and distinguish CT for attenuation correction, anatomical localisation and diagnosis. For comparison, available national DRL values for ^{18}FDG PET/CT (half body) in Europe [5-7,10] are included as well as the most common DRLs for diagnostic chest, abdominal and lumbar spine CT as presented in the European Commission project 'Dose Datamed 2' [4].

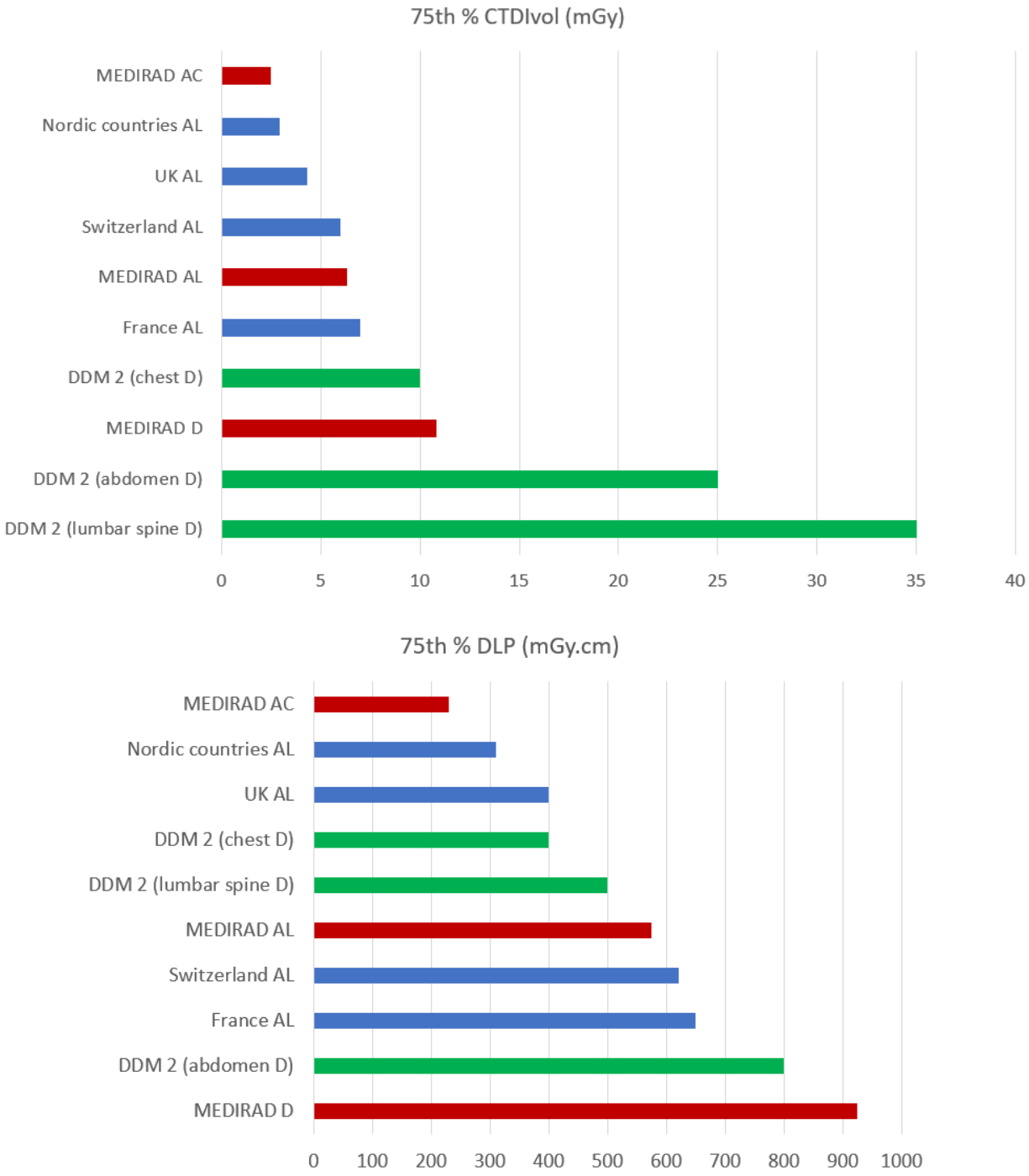

Figure 2: Calculated 75th values of the distribution of median CT dose indicator values for different CT applications for ^{18}FDG-PET/CT. (AC = attenuation correction only; AL = attenuation correction and anatomical localisation; D = diagnostic CT; DDM 2 = Dose Datamed 2 study [4])

75th percentile $CTDI_{vol}$ and DLP values for attenuation correction alone are significantly lower, compared to hybrid CT for localisation or diagnosis. Yet, large variations (max/min) in median doses are observed (Table 2). For attenuation correction and localisation CTs this variation is as large as a factor of 5 and 9, respectively. When CT is claimed to be diagnostic in ^{18}FDG PET/CT, the applied scan parameters result in similar 75th percentile $CTDI_{vol}$ values as for diagnostic chest CT, yet DLP values are much higher due to the longer scan range with PET/CT.

Four out of ten departments used fixed mA values for attenuation correction CT. In comparison with departments using automatic tube current modulation, this resulted in a significant lower DLP (Mann-Whitney U test p = 0.003) as consistently low mA values were used irrespective of the size of the patient (Figure 3).

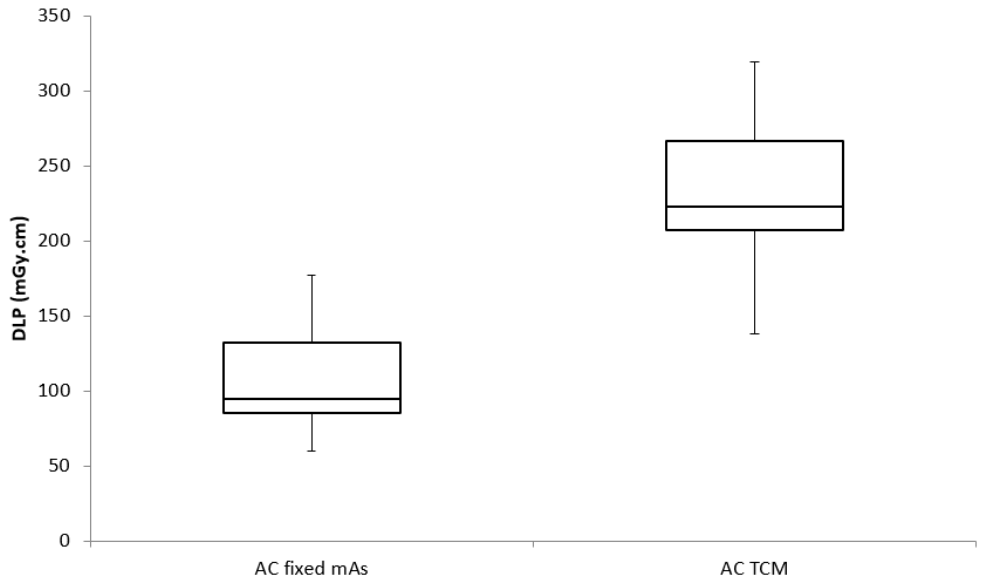

Figure 3: Box plot comparing DLP for fixed mA and automatic tube current modulation for attenuation correction ^{18}FDG-PET/CT.

Twelve out of 20 departments used iterative reconstruction for their localisation CTs in^{18}FDG PET/CT. The latter departments used a significantly lower DLP (Mann-Whitney U test p = 0.012), compared to those using the conventional filtered-back reconstruction technique (Figure 4).

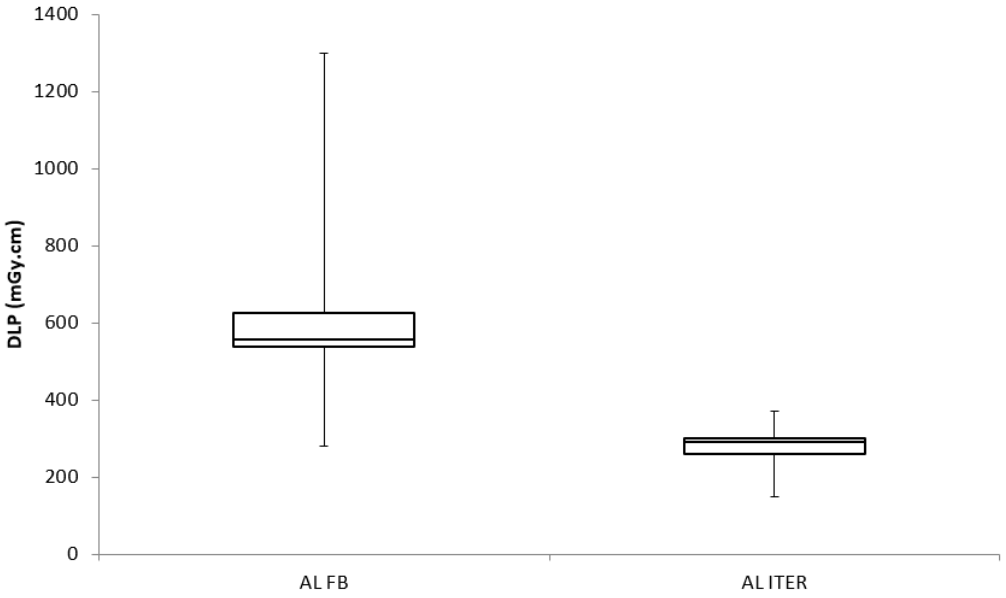

Figure 4: Box plot comparing the DLP for systems using filtered-back reconstruction or iterative reconstruction in localisation ^{18}FDG-PET/CT.

3.3 Brain PET/CT

In Figure 5, the calculated 75th percentile values of the distribution of median values for $CTDI_{vol}$ and DLP are presented for brain PET/CT. The MEDIRAD values (in red) are linked to the current study and distinguish between CT for attenuation correction and anatomical localisation. For comparison, available national DRL values for brain PET/CT [6,10] in Europe are included as well as the most common DRL for diagnostic brain CT (European Dose Datamed 2 study [4]).

Again, large variations (max/min) in median doses are observed (Table 2). For attenuation correction and localisation CTs in brain PET/CT the observed variations in median doses were as large as a factor of 16 and 11 respectively. All but one department used automated tube current modulation and iterative reconstruction in the brain PET/CT datasets. Hence no statistical comparisons could be made.

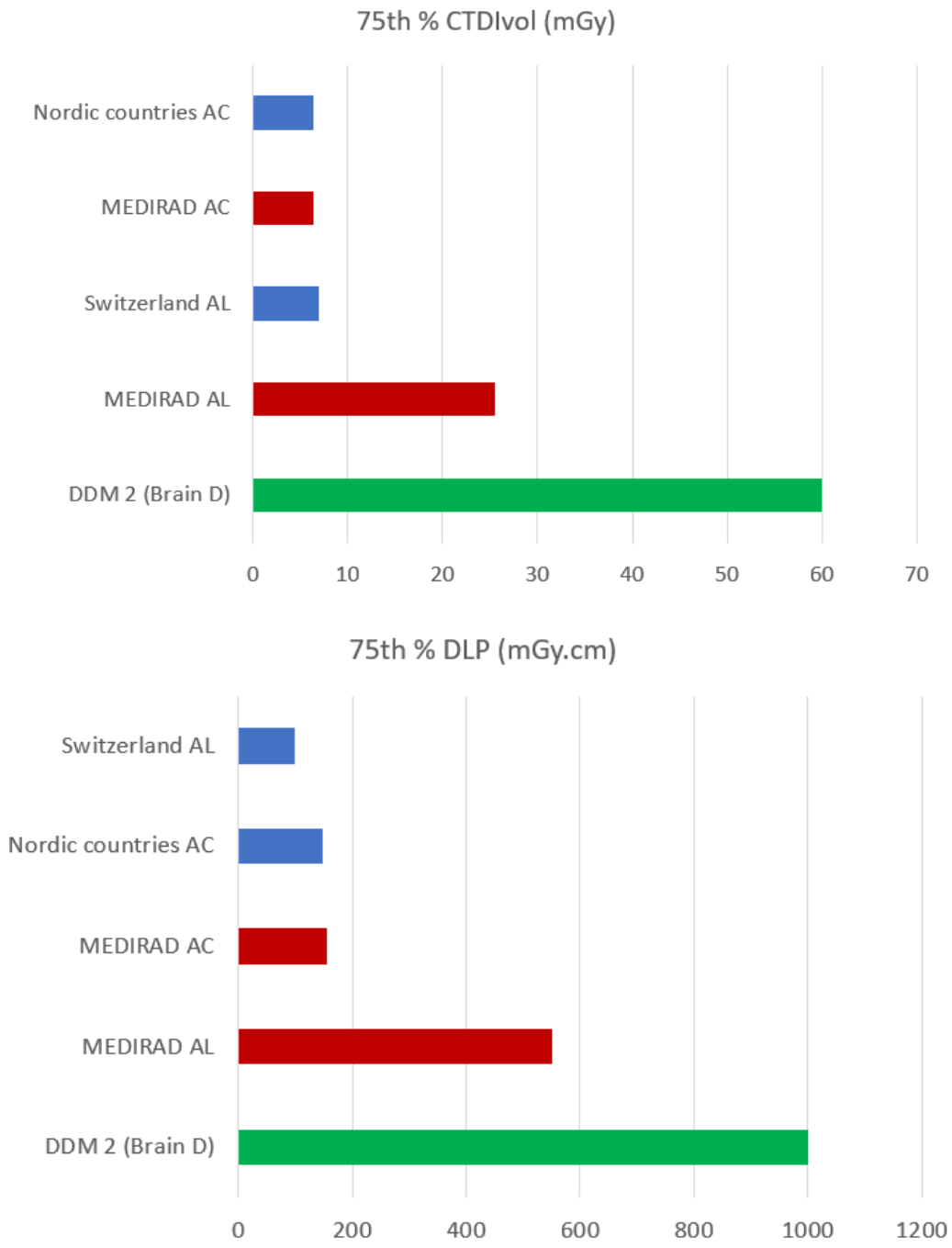

Figure 5: Calculated 75th values of the distribution of median CT dose indicator values for different CT applications for brain PET/CT. (AC = attenuation correction only; AL = attenuation correction and anatomical localisation; D = diagnostic CT; DDM 2 = Dose Datamed 2 study [4])

3.4 ^{99m}Tc-bone SPECT/CT

In Figure 6, the calculated 75th percentile values of the distribution of median values for $CTDI_{vol}$ and DLP of ^{99m}Tc-bone SPECT/CT are presented. The MEDIRAD values (in red) are linked to the current study and distinguish between CT scans of the main body (localisation and diagnostic CT) and extremities (localisation CT). For comparison, available national DRL values for bone SPECT/CT [6-8, 10] in Europe are included as well as the most common DRL for diagnostic lumbar spine CT as presented in the European Dose Datamed 2 study [4].

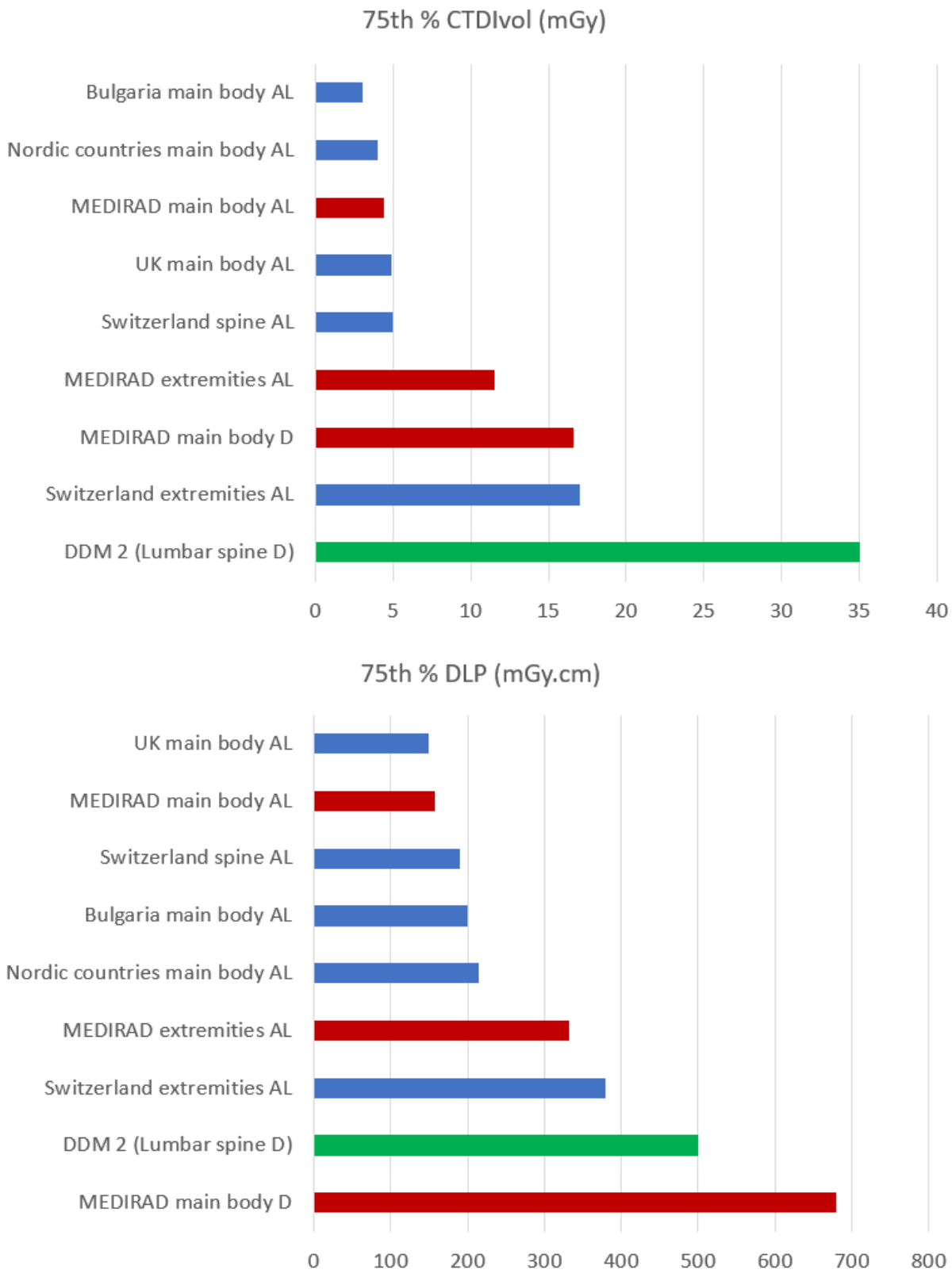

Figure 6: Calculated 75th values of the distribution of median CT dose indicator values for different CT applications for ^{99m}Tc-bone SPECT/CT. (AL = attenuation correction and anatomical localisation; D = diagnostic CT; DDM 2 = Dose Datamed 2 study [4])

For the localisation CTs the observed variations in median doses were as large as a factor of 11 (Table 2). For diagnostic CTs in hybrid scanning, the dose values were much more consistent (variation of about 40%). For the localisation CTs with bone SPECT/CT in this dataset, no significant differences could be found linked to the use of automated tube current modulation and/or iterative reconstruction. The diagnostic CTs were acquired with $CTDI_{vol}$ values considerably lower than the most common DRL value for diagnostic lumbar spine CT, yet DLP values were much higher due to the longer scan length.

Our data demonstrated higher dose settings for the localisation CTs of the extremities, when compared to localisation CTs of the main body. However, the latter conclusion is based on a very limited amount of datasets (7 in total).

3.5 Parathyroid SPECT/CT

In Figure 7, the calculated 75th percentile value of the distribution of median values of $CTDI_{vol}$ and DLP for localisation CT in parathyroid SPECT imaging is presented. For comparison, available national DRL values for parathyroid SPECT/CT [6-8, 10] in Europe are included as well as the most common DRL for diagnostic neck CT (Dose Datamed 2 study [4]).

Again, variations up to a factor of 11 in median dose indicators were observed. No significant differences were found linked to the use of automated tube current modulation and/or iterative reconstruction.

3.6 Octreotide and MIBG SPECT/CT

In Figure 8, the calculated 75th percentile value of the distribution of median values of $CTDI_{vol}$ and DLP of octreotide and MIBG SPECT/CT is presented. The MEDIRAD values (in red) are linked to the current study and focus on anatomical localisation CTs. For comparison, available national DRL values for octreotide and MIBG SPECT/CT [6,7] in Europe are included.

In our datasets a large variation of a factor of about 22 in median DLP was observed. Again, no significant differences were found linked to the use of automated tube current modulation and/or iterative reconstruction.

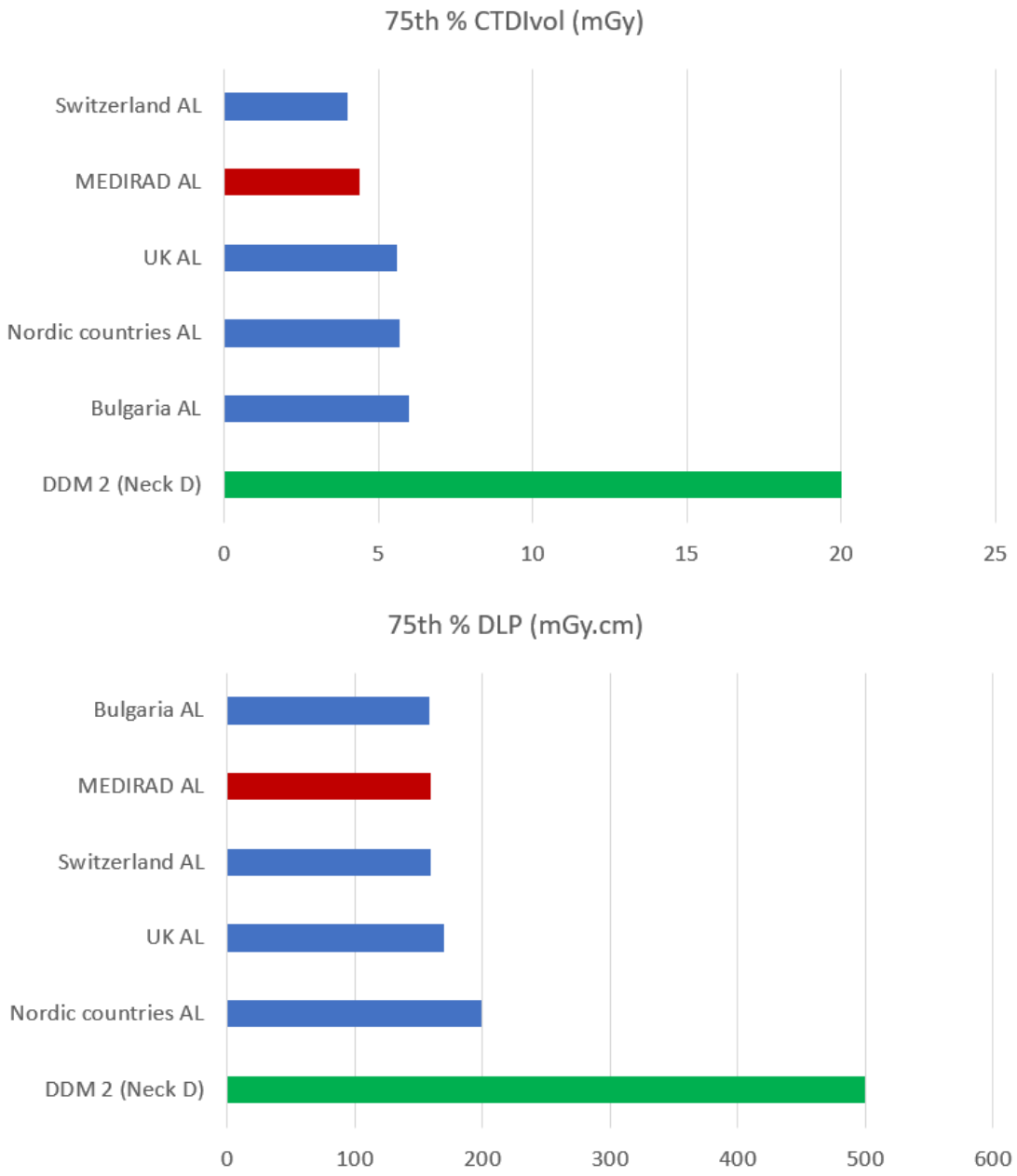

Figure 7: Calculated 75th values of the distribution of median CT dose indicator values for anatomical localisation CT in parathyroid SPECT/CT. (AL = attenuation correction and anatomical localisation; D = diagnostic CT; DDM 2 = Dose Datamed 2 study [4])

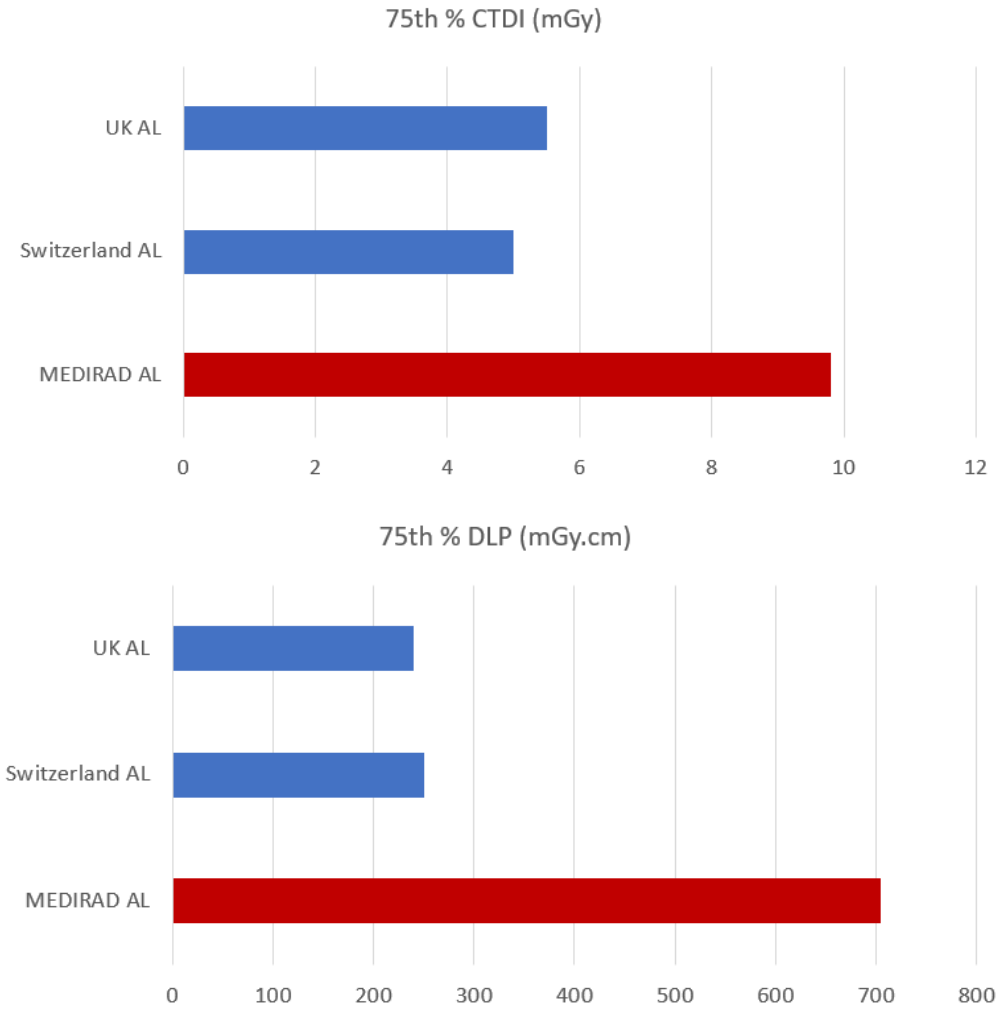

Figure 8: Calculated 75th values of the distribution of median CT dose indicator values for anatomical localisation CT applications in octreotide and MIBG SPECT/CT

3.7 Cardiac SPECT/CT

In Figure 9, the calculated 75th percentile value of the distribution of median values of $CTDI_{vol}$ and DLP for attenuation correction CT in cardiac SPECT is presented, together with the available national DRL values for attenuation correction cardiac SPECT/CT [6-8,10] in Europe.

Here, median dose variations of a factor 15 were found. No iterative reconstruction was used in the departments providing the data. No significant impact of the use of automated tube current modulation was found.

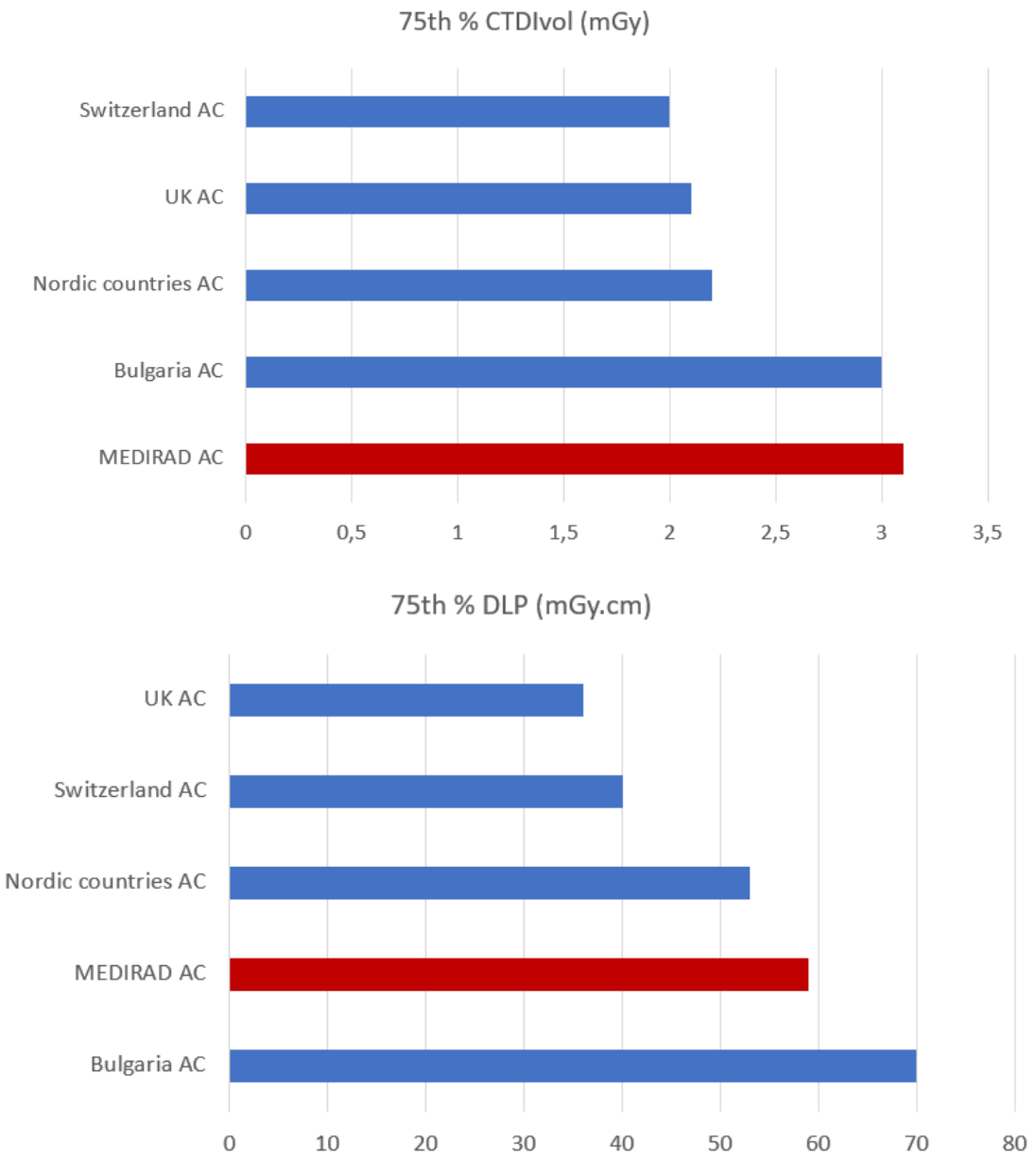

Figure 9: Calculated 75th values of the distribution of median CT dose indicator values for attenuation correction CT in cardiac SPECT/CT

4. Suggested European DRLs for CT applications in nuclear medicine

From the data presented in Table 1, European DRL values for $CTDI_{vol}$ and DLP can be derived for a set of typical CT applications in nuclear medicine. According to ICRP Publication 135, at least 20 facilities should be included to define DRL values [2]. DRL values that comply with this recommendation are indicated in **bold** in Table 3. Suggested European DRLs for localisation CTs of PET/CT half-body, bone, and parathyroid SPECT/CT scans are listed. In addition, a suggested European DRL for attenuation correction CT in cardiac SPECT is presented.

In some studies [10], DRLs are derived even if the number of facilities is as low as 10. Table 3 also includes a suggested European DRL value *in italics* for the attenuation correction CT for half-body and brain PET/CT, based on the data of 10 and 17 facilities respectively.

In all cases, DRLs for $CTDI_{vol}$ are linked to the actual calculated 75th percentile value of the distribution of the median values. DRLs for DLP were calculated in a similar manner, but rounded numbers are presented in Table 3.

Together with the DRL values, achievable values are presented as well. The latter values represent the median value of the same distribution of medians as used for the DRL calculations. The latter values can be used as an additional guidance for further optimisation, as recommended by the ICRP [2].

Table 3: Suggested European diagnostic reference levels and achievable doses for the most common examinations and clinical purposes in hybrid imaging

Examination	Clinical purpose*	EU DRL (75th %)		Achievable Level (median)	
		$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)
^{18}FDG PET/CT half-body	*AC*	*2.5*	*230*	*2.0*	*200*
	AL	**6.3**	**580**	**4.3**	**380**
^{18}FDG PET/CT brain	*AC*	*6.4*	*160*	*4.0*	*110*
^{99m}Tc-bone SPECT /CT (trunc.)	**AL**	**4.4**	**160**	**3.8**	**140**
Parathyroid SPECT/CT	**AL**	**4.4**	**160**	**3.8**	**140**
^{99m}Tc-Cardiac SPECT/CT	**AC**	**3.1**	**60**	**1.6**	**30**

5. Conclusions

- Data collection for the retrieval of European DRLs for specific applications of CT in multi-modality nuclear medicine imaging is challenging. Even with a large number of departments providing data, datasets are subdivided into subgroups (that are too small) linked to the differences in clinical use of CT in nuclear medicine.
- CT radiation exposure in nuclear medicine is far from standardized. Large variation in CT dose indicators are observed even when the specific purpose of the CT is taken into account. As a result, there is room for significant optimisation.
- Based on at least 20 datasets, initial European DRLs and achievable levels are proposed in terms of $CTDI_{vol}$ and DLP for localisation CT for half-body ^{18}FDG PET, ^{99m}Tc-bone SPECT ,and parathyroid SPECT. In addition, first European DRL and achievable dose levels for attenuation correction CT in cardiac SPECT could be derived.

6. References

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