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Detailed CT Dosimetry in 4 Moroccan Hospitals as a Preparation for the Development of National DRLs

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A B S T R A C T

Introduction: Diagnostic reference levels (DRLs) can prevent excessive, unnecessary radiation exposure to patients and reduce the dose variation during different practices. This study aims to establish local DRLs for computed tomography (CT) procedures corresponding to Head, Chest, and Abdomen-Pelvis examinations (single acquisition) in Moroccan hospitals.
Material and Methods: A total of 1917 diagnostic CT examinations were included in this study: head, chest, abdomen–pelvis, lumbar, cervical, chest-abdomen–pelvis (CAP), and scanopelvimetry. Firstly, we analyzed the CT dose indicators in terms of the Volume computed tomography dose index (CTDIvol) and the dose length product (DLP) of all the examinations collected. Local diagnostic reference levels were proposed just for the head, thorax, and abdomen-pelvis due to the lack of data for the other examinations. Furthermore, we calculated the effective dose for chest examination using CT-expo software to estimate the effective and organ dose for chest CT.
Results: The estimated local DRLs expressed as the 3rd quartile using $CTDI_{vol}$ were 48 mGy, 14 mGy, and 12 mGy for the head, chest, and abdomen-pelvis, respectively, and 986 mGy.cm, 496 mGy.cm, and 651 mGy.cm for DLP, respectively. Moreover, the proposed average effective dose for chest CT examinations was 6,3 mSv.
Conclusion: This work establishes local DRLs for CTDIvol and total DLP for head, chest, and abdomen-pelvis procedures and proposes effective doses for chest CT examinations in adult patients. The study shows that the results are conforming to the literature.

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Introduction

Over the last few decades, in Morocco, at the international level, the use of computed tomography (CT) has become an indispensable x-ray tool for diagnostic diseases. This technique gives a significant radiation dose compared to conventional x-ray imaging procedures. Dose optimization in CT procedures should be a major topic to discuss. Indeed, we have to verify that all CT examinations are performed for justified and appropriate clinical reasons. Furthermore, they respect the ALARA (as low as reasonably achievable) principle. In general, for European countries, a recent study [1] pointed out that the number of computed tomography scans has increased relative to the population. The highest numbers of CT scanners were performed in France; there were 13.1 million scans, with the following highest numbers in Germany with12.7 million (2017 data), Italy (5.7 million), and Spain (5.6 million). In the U.S., more than 70 million CT scans are performed every year [2, 3, 4]. Therefore, several commissions and scientific communities have studied the impact of computed tomography on patients and have evaluated the radiation risks of different CT protocols.

Morocco has more than 360 scanner units, including 99 in the public sector [5, 6, 7]. During the pandemics Coronavirus disease (COVID-19) period, several protocols in Morocco introduced the use of scanner images to diagnose more sensitive cases to enhance the early detection of the lesions related to coronavirus. Thus, implementing local DRLs and monitoring doses in the CT department is recommended to estimate and evaluate doses and cancer risks to the patients.

The implementation of diagnostic reference levels in medical imaging has been an essential subject in the (ICRP) International Commission on Radiological Protection [8] to reduce dose variations and improve optimization as the ALARA principle. As indicated by

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the ICRP, the commission recommends setting local and national DRLs values based on the third quartile of dose distribution, which is considered to be the upper limit of good medical practice [9]. Therefore, DRLs are a well-respected part of quality assurance programs, and they have been used successfully in Europe in the optimization process for many years [8,9,10].

Currently, more and more efficient CT systems are called upon for the early detection of small details, allowing a good diagnosis. Therefore an effective treatment at the right time. The case of the recent pandemic is a strong example. For this, quality control, image quality, and dose optimization should be considered. The establishment of local and national DRLs represents the first step in this direction. In addition, the present investigation can lead to the detection of possible defects of the CT system, intervention when necessary, and consequently avoid the repetition of the exposure and result thus in radiation dose optimization.

The first purpose of the present study was to establish local DRLs and analyze the $CTDI_{vol}$ and DLP dose indicators of the following examinations head, Chest, and Abdomen-pelvis. The second objective was to calculate the effective dose and acquire the organ doses for a chest CT examination using the CT-expo software (version2.4). The results were compared to those of previous studies.

Materials and Methods

The present work is part of the 'Radiology as a Steward for Quality in Moroccan HealthCare' (RASQUAM) of the VLIRUOS (Flanders, Belgium).This investigation was carried out in four public and private hospitals located in three different cities in Morocco from February 2019 until July 2020. The survey included patients aged 18 years and older to investigate the most frequent and common diagnostic CT examinations for adult patients (table 1).

Data collection and survey

The study was investigated in four hospitals with four modern CT systems (table 2); data were collected from the DICOM header or data displayed on the CT scanner consoles by our research team of medical physicists and radiographers working in the hospitals.

For each center, we recorded from the CT console the following parameters for each patient: age, gender, tube potential, tube current adjusted using the Automatic Exposure Control system (AEC), pitch, number of scan series (table 3), anatomical region of the CT examination, $CTDI_{vol}$ (mGy), DLP (mGy.cm) per acquisition, and total DLP (mGy.cm).

The final sample size included is 1917 adult patients performed in 4 hospitals, of which 363 patients had head CT (brain and cerebrum), 351 patients had a routine chest CT, 415 patients had a routine abdomen–pelvis CT (single phases), 311 patients had a routine abdomen–pelvis CT (multiple phases) 161 patients had a lumbar CT, 76 patients had a cervical CT, 233 patients had a chest- abdomen–pelvis (CAP) CT, and 7 patients had a scanopelvimetry**,** which is a pelvis CT scan examination for pregnant women [11].

All examinations used are single phases, except abdomen-pelvis and CAP. Although, abdomen-pelvis CT is divided into two groups single-phase group and a multi-phase group. Indeed, the reason regarding the separation of the abdomen-pelvis CT data for two groups is that it was observed that all the institutions in their practice used single-phase (without contrast) and multiphase (with contrast) protocols. For multiphase CT, a mean $CTDI_{vol}$ for all the phases and Total DLP was determined by adding DLP for each phase.

The purpose was to estimate local DRLs on Head, Chest, and Abdomen-pelvis procedures based on $CTDI_{vol}$ and DLP quantities (figures 1 and 2) as recommended by the ICRP [9] and to calculate the effective dose for chest examination using the CT-EXPO spreadsheet calculator (figure 3). Indeed all the results compared with international recommendations [12, 13, 14, 15].

As cervical, CAP, lumbar, and scanopelvimetry dose data were not available in some centers, where we have collected data for less than 10 patients, just a descriptive statistics analysis was done for these examinations.

The CT-Expo software

CT-Expo V 2.4 is an MS Excel application written in Visual Basic for the calculation of the patient dose in CT examinations. The data inputs required for the dose calculations are age group, gender, scan range, scanner model, tube voltage U [kV], current-time product Q [mAs], total collimation [mm], table feed [mm], reconstructed slice thickness [mm], number of scan series. The software allows the calculation of the following dose quantities: Weighted CTDI (CTDIw), $CTDI_{vol}$, DLP, organ doses, and effective dose (according to ICRP 60 and 103). [16].

Statistical analysis

The CT data were analyzed using the statistical analysis package Microsoft Office Excel 2016.

The data were investigated using descriptive statistics. Quantities variables for the examinations are expressed as several samples, mean kVp, and mean mAs, $CTDI_{vol,}$ and DLP data from each hospital were calculated as mean, 1st quartile, and 3rd quartile, to estimate a local DRL for each hospital.

Ethical considerations

According to the Ethical approval to collect data from the hospitals, this study was done with complete anonymization of the data and the hospitals, which removes any possibility of identifying the individual patients or hospital.

Table 1. Computed tomography equipment used for each hospital

Hospital	Manufacturer	Brand	Detector configuration	Year of installation
1	GE	Bright speed	16	----
2	GE	OPTIMA 520	16	2012
3	SIEMENS	SOMATOM DEFINITION AS	128	2015
4	GE	Discovery STE	16	2011

Table 2. Sample size and scan parameters per type of examination

Hospital	Examination	Number of samples	Age	kVp	mAs
1	Head	23	59	120	144
	Chest	25	57	120	220
	Abdomen-pelvis$_a$	38	52	120	247
	Abdomen-pelvis$_b$	19	53	120	241
	CAP	12	61	120	187
	Scanopelvimetrie	7	28	100	40
2	Head	21	50	120	165
	Chest	114	52	120	242
	Abdomen-pelvis$_a$	51	55	120	218
	Abdomen-pelvis$_b$	35	57	120	220
	Lumbar	34	60	120	197
	Cervical	22	55	120	195
3	Head	298	52	-----	-----
	Chest	174	60	110	115
	Abdomen-pelvis$_a$	316	54	-----	-----
	Abdomen-pelvis$_b$	247	53	-----	-----
	Lumbar	127	49	-----	-----
	CAP	168	58	-----	-----
	Cervical	54	50	-----	-----
4	Head	21	56	120	187
	Chest	38	58	120	197
	Abdomen-pelvis$_1$	10	60	120	237
	Abdomen-pelvis$_2$	10	62	120	230
	CAP	53	64	120	165

1: single-phase CT
2: multi-phase CT

Results

The doses related to the Computer Tomography (CT) were estimated for the most frequent clinical examination protocols at four Radiology Department in three different cities in Morocco for a total of 1970 patients, 46% men and 54% women. The numbers of CT devices and patient's data collected in 2019/2020 are displayed in Tables 1 and 2. The median age of patients was 55 years. Table 3 details the descriptive statistics for the surveyed examinations in both $CTDI_{vol}$ and DLP.The range, the first quartile, the mean, and the third quartile values recorded for $CTDI_{vol}$ and DLP per CT examination were calculated for each site and used to compare doses across CT centers. Figures 1 and 2 represent, respectively, the third quartile of $CTDI_{vol}$ and DLP results obtained for each procedure in the 4 CT scanners.

The goal of the second part of the present study was to estimate the effective and organ doses for patients undergoing single-slice chest CT using CT-expo (V2.4) CT dosimetry spreadsheet and to compare the results with international references.

The effective dose (ED) was determined based on the recommendations of the publications 103 [10] of the International Commission on Radiological Protection. Table 4 reports the results of the female (F), male (M), and total effective dose for the Chest region in four CT facilities using the CT-EXPO spreadsheet calculator.The average effective dose value from each the scanners is presented in a graph (figure 3).

During effective dose calculation, the scan range Z was fixed for adult patients, from 38 Z- to 67 Z+ for women and from 41 Z- to 71 Z+ for men (form lung apex to adrenals glands) [17]. This to avoid overlap scan range data, and to prevent achieve an error in estimating the organ and effective doses. To compare the organ doses with the literature, we considered the following organs: Thyroid, breasts, Oesophagus, lungs, liver, bone surfaces, thymus, and heart (figure 4).

The proposed 3rd quartile $CTDI_{vol}$ for head, chest and abdomen-pelvis are 48 mGy, 14 mGy, and 12 mGy,respectively (table 5). The corresponding DLPs are 986 mGy.cm, 496 mGy.cm, and 651 mGy.cm respectively (table 5). The effective dose for Chest CT was 6,3 mSv (table 6).

Table 3.CTDI$_{vol}$ and DLP values expressed in different anatomical regions for each hospital

Examination Anatomical region	Hospital	CTDI$_{vol}$ (mGy)				DLP (mGy*cm)		
		Slice Thickness mean (mm)	1st quartile	Mean	3rd quartile	1st quartile	Mean	3rd quartile
Head	1	4,25	40,7	44,6	56,7	732,1	781,6	1009,7
	2	0,7	37,8	44,5	45,3	680,4	875,9	1035,4
	3	----	38,7	39,1	38,7	681,6	735,21	778,3
	4	2,4	26,8	37,12	51,7	605,4	834,6	1048,9
CHEST	1	4,4	7,0	8,8	10,3	265,2	302,9	343,7
	2	1,2	7,1	9,7	12,6	262,9	357,7	458,6
	3	5	5,3	6,9	8,3	193	257,1	307,0
	4	4,3	12,1	17,5	23,2	500,9	691,4	872,0
Abdomen Pelvis [1]	1	5	10,3	10,1	10,7	411,6	444,9	503,7
	2	1,2	6,3	8,8	11,3	305,8	417,6	534,6
	3	----	5,7	8,4	9,8	252,8	406,8	498,3
	4	1,25	12,3	15,6	17,1	485,6	769,4	1067,4
Abdomen pelvis [2]	1	5	10,2	10,1	10,7	838,4	1108,1	1443,1
	2	1,2	6,3	8,5	10,7	768,1	1097,3	1410,2
	3	----	5,9	8,1	9,5	251	380,2	454
	4	1,22	13,0	14,5	16,6	739,1	1798,3	2677,9
CAP	1	5	7,7	9,3	10,6	616,3	896,9	1108,2
	3	----	7,2	9,2	11,3	1005,6	1366,3	1633,5
	4	2	11,4	13,5	15,3	1923,5	2665,9	3424,6
Lumbar	2	1,2	18,4	25,7	32,9	638,7	819,6	984,3
	3	----	21,3	23,2	24,9	706	843,0	931
Cervical	2	1,2	29,8	33,4	32,9	639,4	474,1	858,5
	3	----	16,6	19,7	22,6	320	429,6	537

1: single-phase CT
2: multi-phase CT

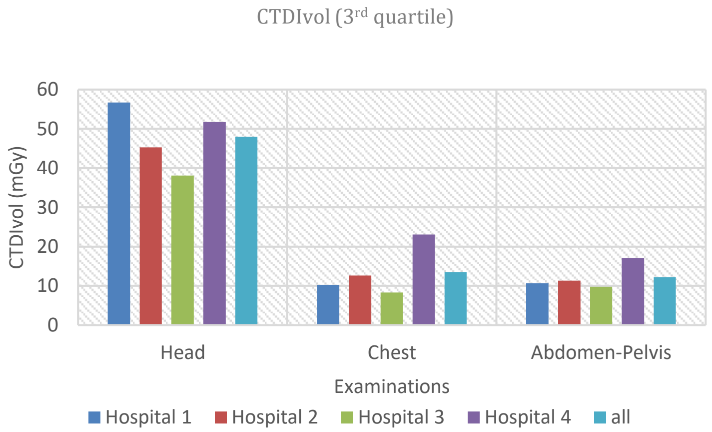

Figure 1. 3rd quartile of CTDI$_{vol}$ vs. hospitals for Head, Chest, and abdomen-pelvis CT

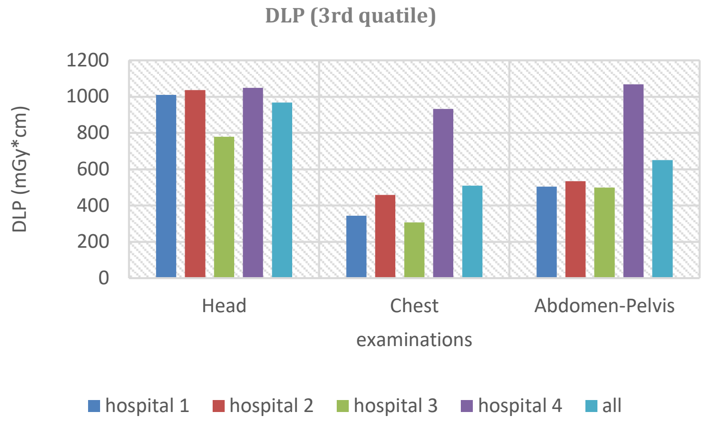

Figure 2. 3rd quartile of DLP vs. hospitals for Head, Chest, and Abdomen-pelvis CT

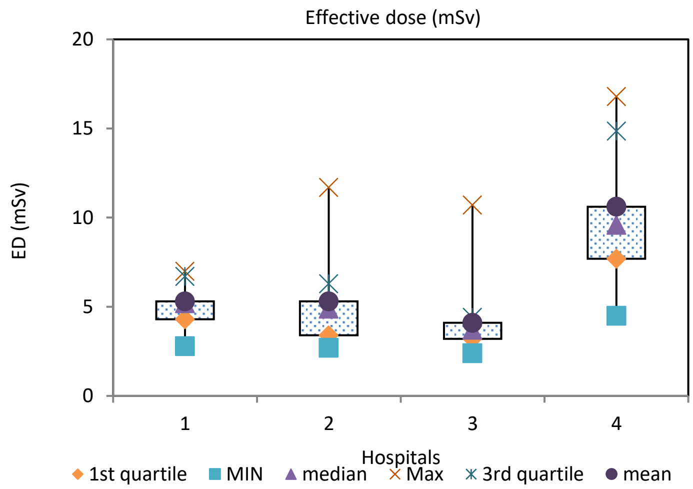

Figure 3. Box plot representing effective doses for Chest CT procedure vs. hospitals.

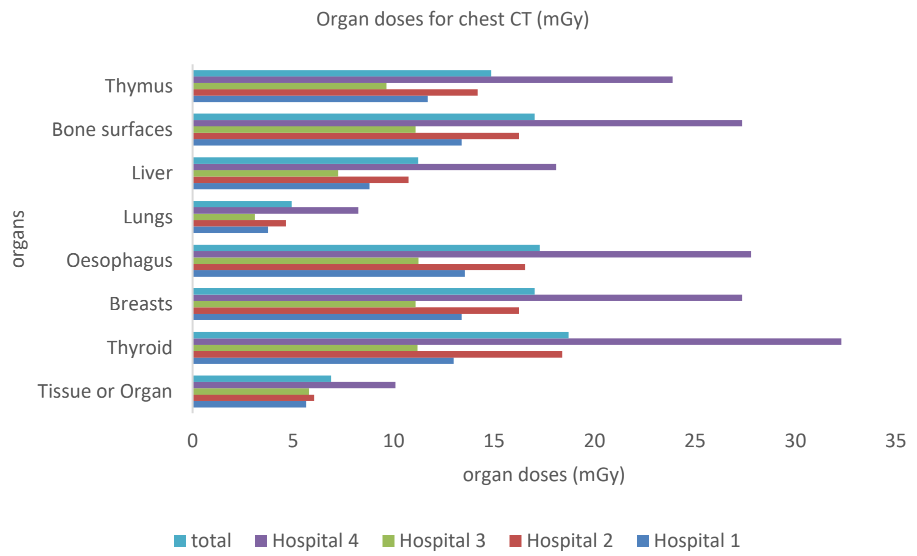

Figure 4. Comparison of organ doses calculated using CT-Expo software between the hospitals.

Table 4. Chest CT effective doses distribution expressed for female, male, and all patients using CT-Expo calculator

			ED (mSv)								
			Female (F)			Male (M)			TOTAL		
Hospital	% F	% M	1st quartile	Mean	3rd quartile	1st quartile	Mean	3rd quartile	1st quartile	Mean	3rd quartile
1	80	20	4.5	5.7	6.7	3.0	3.7	4.45	4.3	5.3	6.7
2	34	66	5.1	7.2	9.2	3.2	4.3	5.4	3.4	5.3	6.3
3	59	41	3.5	4.5	5.4	2.7	3.4	3.9	3.2	4.1	4.4
4	74	26	8.4	12.1	16.0	4.6	6.5	9.1	7.7	10.6	14.8

%F and %M: female and male percentage

Discussion

Table 3 shows great variability from one CT device to another. This is due to the clinical indications and to the difference in radiological practices. Higher doses are observed for oncology CT examinations (hospital 4), especially for multiphasic protocols in the CAP and abdomen-pelvis. These cases were scanned in two to four phases with a mean DLP of 1,322 mGy cm and 1,167 mGy cm for the reason to evaluate tumors in the liver and kidney. More radiation is required for the detection of cancer in order to distinguish between objects with intrinsically low differences in attenuation [9,10].

A great variability shown in patient doses in terms of $CTDI_{vol}$ is mainly observed in head and chest examinations (figure 1). This reflects the variations in protocols used in different hospitals and the absence of National or local DRLs on which operators can refer to evaluate their practice. Head exams, $CTDI_{vol}$ is less than all the previous works described in table 5 [12-36], except those from Egypt and South Africa [18,19]. These variations depend on differences in clinical indication, patient size, and CT units [13]. However, for Chest exams, $CTDI_{vol}$ and DLP values are slightly lower than the US and Nigeria references [20,21]. Indeed, DLP variation is due mainly to different patient sizes. Whereas DLP increases with an increase in scan length. Thus scanning must be restricted to what is essential and should minimize overlap when scanning two contiguous body regions.

Table 4 shows the effective chest doses for females and males and the average **for** both. The average effective dose varied from one CT equipment to another. Patients undergoing chest CT for cancer detection (hospital 4) have the highest effective dose value (figure 3). According to the references below (table 6), the mean ED proposed in the present work was the lowest. This is related to the various technical parameters, protocols, methods, and software employed for the calculation of the effective dose. Indeed this result shows that our hospitals have utilized a low mAs comparing to these studies (Table 6).

The last part of this study was to estimate organ doses (Thyroid, breasts, esophagus, lungs, liver, bone surfaces, thymus, and heart) during chest CT examinations for female and male patients using the spreadsheet CT-EXPO (figure 4). Several studies have estimated organ doses using software or the Thermoluminescent dosimeter (TLD) method (table 7). These reports highlight the importance of the examination type choice before proceeding to the chest exposure. ICRP gives a ratio of 400 relative to an effective dose of 8 mSv CT scanner and 0.02 mSv for chest radiography. Table 7 recalls that, emphasizes that, although it is not the main target of the radiological examination, the breast receives a dose of the order of that received by the lungs, sometimes higher. Particular attention must then be paid in the event of exposure of women to the scanner.

Estimating cancer risk from the effective dose is given by the ICRP 2007 guideline [10]. However, several studies have estimated the cancer risk rate for patients using the effective dose data. Although, it is preferable to consider the patient's age, gender, and organ doses when carrying out the study for examinations associated with medical imaging. For example, the risk of lung cancer is probably higher when radiation exposure occurs at an older age, as well as breast cancer, where the risk of developing cancer is higher with exposure at a younger age [22]. Indeed, patients with lung cancer are often vulnerable to radiation-induced carcinogenesis due to both advanced age and tobacco smoke.

This work represents the first step for a more in-depth and broader investigation with the objective of establishing national DRLs for all CT exams for adults and children. A preliminary study focusing on DRLs of the head in the pediatric case has been carried out in our country [23].

Table 5. Comparison of the present local DRLs results with those published in the literature

	Head			Chest			Abdomen-pelvis		
Reference	N	DLP (mGy.cm)	$CTDI_{vol}$ (mGy)	N	DLP (mGy.cm)	$CTDI_{vol}$ (mGy)	N	DLP (mGy.cm)	$CTDI_{vol}$ (mGy)
OUR STUDY	363	986	48	337	496	13,6	413	651	12
Belgium 2020 [12]	----	800	50[1]	----	260	8	----	----	----
IAEA EU_DRL [13]	----	1050	60	-----	650	22	-----	-----	-----
EU 2014 [14]	----	1000	60	----	400	10	----	----	----
ACR AAPM SPR 2018 [15]	----	962	56	----	443	12	----	781	16
EGYPT 2017 [18]	900	1360	30	486	420	22	900	1323	31
South Africa [19]	100	767	32	100	593	32	100	386	7
US 2017 [20]	223908	1011	57	159909	545	15	201754	1004	20
NIGERIA 2018 [21]	720	1310	61	-----	735	17	----	1486	20
Australia 2018 [24]	----	880	52	----	390	10	----	600	13
Canada 2018 [25]	----	1302	----	----	521	----	----	874	----
Brazil 2015 [26]	120	950	50	120	350	10	----	----	----
UK 2019 [27]	----	970	60[2]	----	----	----	----	745	15
LIBIA 2018 [28]	57	1999	----	26	2284,9	-----	17	2840	----
IRELAND 2012 [29]	7778	940	66 [3]/58[4]	6152	390	9	7267	600	12
JAPAN 2012 [30]	4587	1120	----	2052	580	-----	281	350	-----
IRSN_2012 [31]	1121	1050	65	----	500	15	932	800	17
KENIA 2015 [32]	1234	1612	61	328	895	19	-----	-----	-----
PORTUGAL 2013 [33]	----	1010	75	-----	470	14	-----	-----	-----
SWITZERLAND 2010 [34]	----	1000	65	-----	400	10	----	650	15
GREECE 2014 [35]	1992	1055	67	2012	480	14	1999	760	16
IRAN 2018 [36]	----	708	53	----	283	9	----	531	31
UK 2011 [37]		970	60	----	610	12		745	15

1: Skull/ brain
2: brain and cerebrum
3: base of head sequence
4: base of head cerebrum sequence

Table 6. Comparison of the present proposed Chest CT effective dose (mean ED mSv) with a published studies

Reference	Effective dose (mSv) Mean
Palestine 2017 [38]	7,0
Japan 1991 [39]	6,86[1] / 6,85[2]
Italy2005 [40]	8,0
British Columbia 2006 [41]	9,3
Taiwan 2007 [42]	8,4
Our study	6,3

1: female patients
2: male patients

Table 7. Comparison of organ doses results for chest CT to those of previous studies

	Organ doses[mSv]						
Organ	Our study	Nishizawa et.al (1991) [39]	Akpochafor et.al (2019) [43]	Franck et.al (2018) [44]	Ngaile et.al (2006) [45]	Akpochafor et.al (2018) [46]	Sulemana et.al (2020) [47]
Thyroid	6,9	1,85		18	12,3	10,21	6,4
Breasts	18,73	15,9		15	26,1	26,41	17,1
Oesophagus	17,03						17,2
Lungs	17,29	19,6	13,08	14	31,5	30,63	17,4
Liver	4,94	8,96		13			
Bone surfaces	11,23	8,34					
Thymus	17,03						
Heart	14,86	11,5			29,93		

Conclusion

In general, the DRLs values obtained are lower than almost all of the anterior studies cited in this work, described in terms of $CTDI_{vol}$ for all protocols except Chest results. Referring to these studies and our results, it was clear that the most irradiated organs on a chest CT examination are breasts, lungs, and heart. The current study has shown that the chest CT examination can impart high radiation doses to the breast organ, which may increase the radiation risk for female patients.

This investigation highlights that the DRLs found by this study comply with international recommendations, and encourage to extend the study on Moroccan territory in order to give a global idea on a factor representing a key point for the optimization of the doses received by the patients.

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