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ARTICLE

Radiation risk during thoracic CT scan for diagnostic and radiotherapy planning procedures in Hassan II, Hospital, Agadir Morocco

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Abstract – Objective: This study aims to establish diagnostic reference levels and radiation-induced risk for the diagnostic CT-scans and the radiotherapy planning CT-scans of the thorax in the regional hospital of Agadir, Morocco.
Materials and methods: Data from two groups of patients undergoing thoracic CT-scans with either diagnostic CT-scans (G1, n = 120) or radiotherapy planning CT-scans (G2, n = 120) are collected. All acquisitions were helical. DRLs is calculated for each type of thoracic CT-scan by estimating the 75% percentile of the CTDIvol and the DLP. The total cancer risk RC was calculated according to the ICRP publication 103. The data are statistically analyzed by SPSS Statistics V21.0. The student's t-test was used to establish the relationship between gender, clinical indication, and effective dose. The Spearman test was used to establish the relationship between age, BMI, and effective dose.
Results: DRLs in terms of $CTDI_{vol}$ and DLP for radiotherapy planning of thorax were 19.37 mGy and 851.9 mGy cm, respectively. In diagnostic CT-scans, DRLs in terms of $CTDI_{vol}$ for pulmonary embolism, infectious lung disease, Chronic Obstructive Pulmonary Disease (COPD) were 11.13 mGy, 10.26 mGy, and 7.37 mGy respectively, and DRLs in terms of DLP were 417.73 mGy cm, 451.9 mGy cm and 317.78 mGy cm respectively. The cancer risk for radiotherapy planning CT-scans is ranged between 209 and 1564 with a mean value of 715 per 1 million of CT-scan. For diagnostic CT-scans, the cancer risk is ranged between 199 and 626 with a mean value of 357 per 1 million for pulmonary embolism, between 238 and 668 with a mean value of 369 per 1 million for infectious lung disease, and between 130 and 393 with a mean value of 244 per 1 million for COPD.
Conclusion: Optimizing the doses received by patients in medical imaging, particularly CT, has become an obligation. Reviewing practices and procedures and promoting a radiation protection culture can help to better manage the radiation doses received by the patient.

Keywords: CT scan / $CTDI_{vol}$ / DLP / effective dose / cancer risk / thorax procedure

1 Introduction

Computed tomography (CT) has become an essential imaging modality in clinical practice. This was the first non-invasive technique to provide images of the internal structures of the human body that are not influenced by the superimposition of distinct anatomical features (Buzug, 2008). CT images used in radiotherapy treatment planning allow precise identification of the location of the tumour as well as surrounding healthy tissue and organs at risk, with a high level of geometric accuracy. In addition, these images provide a complete representation of the electron density of various tissues. This information is crucial for dose calculation in the Treatment Planning System (TPS) (Davis *et al.,* 2017). In the case of CT, the dose received by the patient can be considerably higher than that received using other imaging techniques. The main reason for this excessive dose is often

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attributed to a lack of optimisation of radiographic protocols for CT, although it may also be due to the poor condition of the equipment (IAEA, 2012). Overall, CT plays a crucial role in estimating the collective effective dose from diagnostic imaging worldwide, which is approximately 4 million person-Sv/year (AAPM, 2008). In addition, approximately 2% of all cancer cases in the United States can be attributed to CT and fluoroscopy (Shyu, 2016).

The optimization of various parameters can be employed to decrease the amount of radiation exposure experienced by patients during CT scans. These parameters include tube current, tube potential, patient positioning, scan range, reconstructed slice thickness, and pitch, as noted by Raman *et al.* (2013). The INWORKS study shows an increase in the relative rate of mortality from solid cancers with increasing cumulative exposure to ionizing radiation at low doses to which nuclear workers are generally exposed in France, the United Kingdom, and the United States (Richardson *et al.,* 2023). The use of CT scans for radiotherapy planning differs from diagnostic CT scans in terms of technique, radiation dose, and associated risk. Sanderud *et al.* (2016) demonstrated that the absorbed radiation dose is significantly higher for radiotherapy planning CT scans than for diagnostic CT scans of the thorax. One of the fundamental principles in optimizing protection against medical exposure is the implementation of diagnostic reference levels (DRLs). DRLs are effective tools for optimizing the protection of patients undergoing diagnostic and interventional procedures. DRLs are not intended for use in radiation therapy. However, they should be considered for imaging purposes in treatment planning, treatment rehearsal, and patient set-up verification in radiotherapy (ICRP, 2017).

In general, DRLs have been established on the basis of the anatomical region explored. However, the current trend is toward establishing DRLs based on clinical indications. In this context, the ICRP introduced the clinical approach to DRLs several years ago (Vañó *et al.,* 2017), and many countries have recently implemented DRLs based on clinical indications (DRLci), and others are considering doing so soon. Furthermore, the European Society of Radiology (ESR) has identified the development of DRLci for both adults and children as one of its key objectives (Bauhs *et al.,* 2008).

In Morocco and more precisely in the Souss Massa region, we lead a program that aimed at optimizing the doses delivered to patients in medical imaging and improving radiation protection procedures and practices. These studies cover several fields such as optimization in medical imaging (Amaoui *et al.*, 2019, Semghouli *et al.*, 2022a, Semghouli *et al.*, 2022b, El Fahssi *et al.*, 2023a, 2023b, Semghouli *et al.*, 2023), prevention of radiation-induced risks (Aabid *et al.*, 2019; Semghouli *et al.,* 2022c), and practitioners' knowledge of patient radiation protection (Amaoui *et al.*, 2023).

Following on from this work, this study aims to establish diagnostic reference levels and radiation-induced risk for the diagnostic CT-scans and the radiotherapy planning CT-scans of the thorax in the regional hospital of Agadir, Morocco.

2 Materials and methods

2.1 Populations studied

Data from two groups of patients undergoing thoracic CT-scans with either diagnostic CT-scans (G1, $n=120$) or Radiotherapy planning CT-scans (G2, $n=120$) were collected between January and March 2023.

For diagnostic CT scans, three clinical indications were selected: pulmonary embolism, infectious lung disease and chronic obstructive pulmonary disease (COPD), with 40 CT examinations per indication.

Our data are collected from two types of scanners, Optima General Electric 16-slice for diagnostic CT-scans and Aquilion Lb Canon-Thoshiba16-slice for radiotherapy planning CT-scans. The type of acquisition of these two scanners is helical. The scanner acquisition parameters, number of series, use of contrast medium, rotation time in addition to slice thickness, computed tomography dose index (CTDIvol), and dose length product (DLP) were explicitly delineated for each examination.

2.2 Dose assessment and cancer risk

DRLs were calculated for each type of thoracic CT-scans by estimating the 75% percentile of the $CTDI_{vol}$ and the DLP. For the effective dose (E_{eff}), it is calculated according to the following formula (Delchambre, 2012):

$$E_{\mathrm{eff}}(\mathrm{mSv}) = F_{\mathrm{CD}} \times \mathrm{DLP}, \quad (1)$$

where: F_{CD} is the effective dose conversion factor for CT scan of the Thorax ($\approx$0.014 mSv mGy^{-1} cm^{-1}).

The total cancer risk R_C is calculated according to the ICRP publication 103 as follow (ICRP, 2007):

$$R_C = E_{\mathrm{eff}}(\mathrm{mSv}) \times F_{\mathrm{cr}}, \quad (2)$$

where E_{eff} is the effective dose in Sv. – $F_{cr}=5.5 \times 10^{-2}$ Sv^{-1} is the risk coefficient factor.

2.3 Data analysis

The data are statistically analysed by SPSS softwareV21.0. The student's *t*-test was used to establish the relationship between gender, clinical indication, and effective dose. The Spearman test was used to establish the relationship between age, BMI, and effective dose.

3 Results

According to Tables 1 and 2, the population studied was made up of 55% men and 45% women for diagnostic CT scans and 40% men and 60% women for radiotherapy planning CT scans. The mean age for diagnostic CT scans was 51 years and that for radiotherapy planning CT scans was 52 years. The average BMI for diagnostic CT scans was 24.34 kg/m^2 and that for radiotherapy planning CT scans was 25.71 kg/m^2. The acquisition parameters for each type of CT scan are presented in Table 3.

Table 1. Distribution of the population studied by gender.

Gender	Radiotherapy planning CT		Diagnostic CT	
	Male	**Female**	**Male**	**Female**
	48 (40%)	72 (60%)	66 (55%)	54 (45%)

Table 2. Distribution of the population studied by age and BMI.

	Radiotherapy planning CT			Diagnostic CT		
	Mean	**SD**	**Min–Max**	**Mean**	**SD**	**Min–Max**
Age	52	14.29	27–77	51	16.76	23–92
BMI	25.71	3.02	20.10–32.36	24.34	3.13	17.15–30.07

Table 3. Acquisition parameters per type of CT scan

	Radiotherapy planning CT-scans	Diagnostic CT-scans		
	Mean	**Pulmonary embolism**	**Infectious lung disease Mean**	**COPD**
Pitch	1	0.94	1.75	1.75
Voltage (kV)	120	120	120	120
Intensity (mAs)	90	125	150	150
Slice thickness (mm)	2	1.25	1.25	1.25

Table 3 shows that the voltage used during diagnostic and radiotherapy planning CT-scans is 120 kV for all patients, and the intensity is modulated according to patient morphology and the protocol used. The average intensity for radiotherapy planning CT-scans is 100 mAs. In diagnostic CT-scans, the average intensity is 125 mAs for the pulmonary embolism protocol and 150 mAs for other protocols. The pitch is constant in radiotherapy planning CT-scans, and varies according to the protocol used in diagnostic CT-scans. The slice thickness is 1.25 mm and 2 mm for diagnostic CT-scans and radiotherapy planning CT-scans respectively.

The distribution of the CTDIvol, DLP and effective dose, as well as the diagnostic reference levels, are summarized in Tables 4 and 5. Table 4 shows that the $CTDI_{vol}$ varies between 4 mGy and 35.20 mGy, with an average value of 14.58 mGy in radiotherapy planning CT-scans. The DLP value ranges from 215 mGy cm to 1606.80 mGy cm, with an average value of 735 mGy.cm. The effective dose ranges from 3.80 mSv to 28.44 mSv, with an average value of 13 mSv.

In diagnostic CT, the mean CTDIvol values for pulmonary embolism, infectious lung disease, and COPD were 9.64, 9.14, and 6.53 mGy, respectively. The mean DLP values were 367.15 mGy cm, 380 mGy cm, and 250.94 mGy cm for the same indications, respectively. The mean effective doses were 6.49, 6.72, and 4.44 mSv for the same indications, respectively.

Table 5 shows that the DRLs calculated in terms of CTDIvol and DLP for radiotherapy planning CT-scans were 19.37 mGy and 851.9 mGy cm, respectively. For diagnostic CT-scans, DRLs calculated in terms of CTDIvol were 11.13 mGy, 10.26 mGy, and 7.37 mGy for pulmonary embolism, infectious lung disease, and COPD, respectively. DRLs in terms of DLP were 417.73 mGy cm, 451.9 mGy cm, and 317.78 mGy cm for the same indications, respectively.

The distribution of the mean cancer risk associated with each CT-scan and the correlation of this risk with the CTDIvol, DLP and effective dose are illustrated in Tables 6 and 7. As shown in Table 6, the cancer risk for radiotherapy planning CT-scans is ranged between 209 and 1564 with a mean value of 715 per 1 million. For diagnostic CT-scans, the cancer risk is ranged between 199 and 626 with a mean value of 357 per 1 million for pulmonary embolism, between 238 and 668 with a mean value of 369 per 1 million for infectious lung disease, and between 130 and 393 with a mean value of 244 per 1 million for COPD.

As summarized in Table 7, in the radiotherapy planning CT-scans, the correlation coefficients (p-values) for gender, age, and BMI against effective dose are 0.076, 0.212, and 0.00 respectively.

Concerning diagnostic CT-scans, the correlation coefficients (p-values) for gender, clinical indication, age, and BMI against effective dose are 0.111, 0.001, 0.036, and 0.231 respectively.

4 Discussion

This section discusses the main results of this study in the light of previous work and the recommendations of international bodies on radiation protection in medical imaging.

Table 4. Distribution of $CTDI_{vol}$, DLP and effective dose per type of thorax CT scan.

			Min	Max	Mean	SD
Radiotherapy planning CT-scans		$CTDI_{vol}$ (mGy)	4.00	35.20	14.58	8.68
		DLP (mGy.cm)	215.0	1606.80	735.23	352.63
		Effective dose (mSv)	3.80	28.44	13.01	6.24
Diagnostic CT-scans	Pulmonary embolism	$CTDI_{vol}$ (mGy)	5.48	15.83	9.64	3.29
		DLP (mGy.cm)	205.35	643.10	367.15	137.60
		Effective dose (mSv)	3.63	11.38	6.49	2.43
	Infectious lung disease	$CTDI_{vol}$ (mGy)	7.08	12.27	9.14	1.69
		DLP (mGy.cm)	244.74	686.21	380.05	133.40
		Effective dose (mSv)	4.33	12.14	6.72	2.36
	COPD	$CTDI_{vol}$ (mGy)	4.55	10.63	6.53	2.17
		DLP (mGy.cm)	133.80	403.70	250.94	82.87
		Effective dose (mSv)	2.36	7.14	4.44	1.46

Table 5. : DRLs calculated in terms of $CTDI_{vol}$ and DLP per type of Thorax CT scan.

	Radiotherapy planning CT-scans	**Diagnostic CT-scans**		
		Pulmonary embolism	**Infectious lung disease**	**COPD**
DRLs in term of CTDIvol (mGy)	19.37	11.13	10.26	7.37
DRLs in term of DLP (mGy.cm)	851.9	417.73	451.9	317.78

Table 6. Mean Cancer risk calculated per 1 million of Thoracic CT-scan.

	Radiotherapy planning CT-scans	**Diagnostic CT-scans**		
		Pulmonary embolism	**Infectious lung disease**	**COPD**
Mean risk (Per1 million exams)	715 (209–1564)	357 (199–626)	369 (238–668)	244 (130–393)

Table 7. Correlation coefficients (*p*-values) for gender of patients, clinical indication, age, BMI and the effective dose.

		Effective dose (*p*-value)	
		Radiotherapy planning CT	**Diagnostic CT**
Gender	Student's *t*-test	0.076	0.111
Clinical indication			0.001
Age	Spearman correlation	0.216	0.036
BMI		0.000	0.231

** Correlation is significant at the 0.05 level (two-tailed).

4.1 Population studied

In fact, body mass influences the dose received by the patient. In this context, it is essential to assess the patient's morph type as accurately as possible in order to select and apply the appropriate examination protocol according to the machine's capabilities, with the aim of limiting doses to the patient (OTIMROEPMQ, 2016).

4.2 Acquisition parameters

The results of this study show that the voltage used during diagnostic and radiotherapy planning CT-scans is 120 kV for all patients, and the intensity is modulated according to patient morphology and the protocol used. The average intensity is 100 mAs for radiotherapy planning CT-scans. In diagnostic CT-scans, the average intensity is 125 mAs for the pulmonary

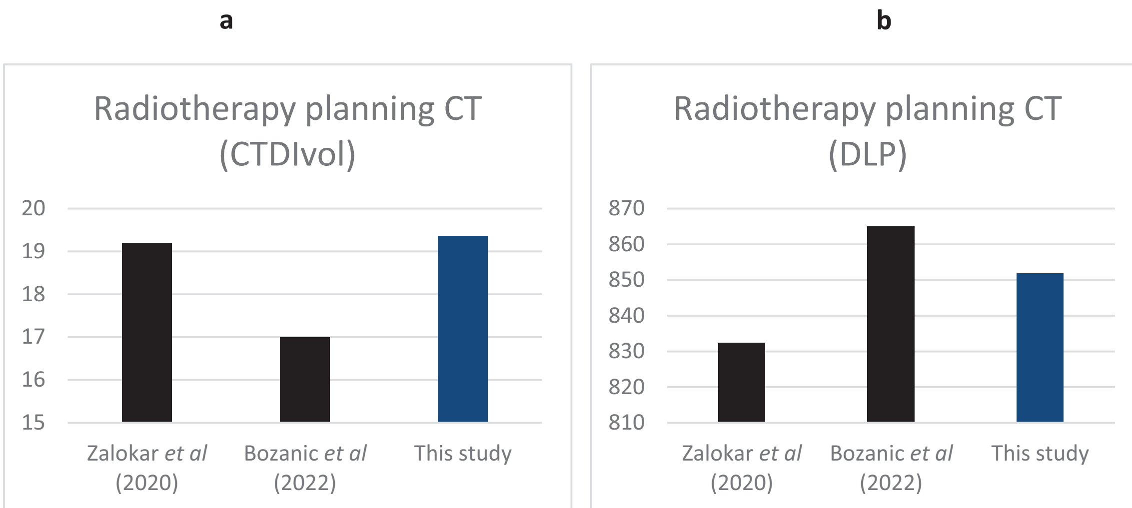

Fig. 1. DRL in terms of (a) CTDIvol and (b) DLP calculated by this study for radiotherapy planning CT compared to other previous studies.

embolism protocol and 150 mAs for other protocols. The pitch is constant in radiotherapy planning CT, and varies according to the protocol used in diagnostic CT. In reality, the dose has an inverse relationship with the pitch, and doubling the milliampere-seconds (mAs) will result in a 100% increase in dosage. It is therefore advisable to choose the highest pitch value and lowest mAs that correspond to the clinical diagnosis required (IAEA, 2012). However, an understanding of mAs and pitch is not sufficient to determine X-ray tube power in computed tomography (CT), as it also relies on factors such as X-ray tube characteristics, X-ray tube voltage, and beam filtering. In contrast, CTDIvol values, measured in a standardised phantom size and with a quality X-ray beam, offer a universal measure to quantify the amount of radiation incident on any patient undergoing any type of examination (Tipnis, 2016).

4.3 Estimation of delivered doses:

For the radiotherapy planning CT scan, the DRL calculated in terms of $CTDI_{vol}$ is 19.37 mGy, which is slightly higher than the DRLs of Slovenia (19.2 mGy) (Zalokar, 2020), and lower than that of Croatia (17 mGy) (Božanić, 2022). The DRL calculated in terms of DLP is 851.9 mGy cm, which is higher than the DRLs of Slovenia (832.4 mGy cm), and lower than that of Croatia (865 mGy cm).

For thoracic diagnostic CT scan, the “pulmonary embolism” indication recorded the highest DRL in terms of $CTDI_{vol}$ (11.13 mGy), while the "COPD" indication recorded the lowest DRL value (7.37 mGy). In terms of DLP, the “Infectious lung disease” indication recorded the highest DRL value (451.9 mGy cm), and the “COPD” indication recorded the lowest DRL value (317.78 mGy cm). These variations in terms of reported dosimetric values would be due to some protocols used for some clinical indications which were not specifically adapted for that clinical indication Public Ukoha *et al.* (2023). In addition, DRL in terms of $CTDI_{vol}$ which was reported for pulmonary embolism (11.13 mGy) is less than the DRL reported by Kanal *et al.* (2017) (19 mGy), and Foley *et al.* (2012) (13 mGy), and higher than that reported by Geryes *et al.* (2019) (8 mGy). DRL in terms of DLP calculated for pulmonary embolism (417.73 mGy cm) was less than that reported by Kanal *et al.* (2017) (557 mGy cm), and Foley *et al.* (2012) (432 mGy cm), and higher than that reported by Geryes *et al.* (2019) (310 mGy cm).

In this context, DRL in terms of CTDIvol for infectious lung disease (10.26 mGy) was lower than that reported by the Public Health of England (2016) ; 12 mGy) and Salama *et al.* (2017 (22 mGy), and the Danish Health Authority (2015) (13 mGy). DRL in terms of DLP for this indication (451.9 mGy cm) was higher than that reported by the Public Health of England (2016) (350 mGy cm) and Salama *et al.* (2017) (421 mGy cm), and lower than that calculated by the Danish Health Authority (2015) (500 mGy cm).

The DRLs of this study for the COPD indications in terms of CTDIvol and DLP were 7.37 and 317.78 mGy cm, respectively. These values are higher than those reported by Geryes *et al.* (2019), which were 4.1 mGy and 185 mGy.cm, respectively.

The results of this study show that the DRLs in terms of $CTDI_{vol}$ and DLP calculated in radiotherapy planning CT-scans are higher than those calculated in diagnostic CT-scans. The high observed $CTDI_{vol}$ values in radiotherapy planning scans indicate that the employed protocols are not optimized according to the patient’s size (McCollough *et al.,* 2013). Moreover, the magnitude of radiation exposure is contingent upon the dimensions of the patient, exhibiting a substantial association between patient size and absorbed radiation dose, a relationship that can also be observed in thoracic CT scans (Menke, 2005). In fact, a large number of factors can affect the dose and image quality in CT examinations such as radiographic protocol or scan parameter, equipment, image reading condition and patient related factors which can usually be controlled through adjustments in the scan parameters (IAEA, 2012). Figures 1–3 show the DRLs in terms of DLP and CTDIvol for radiotherapy planning CT and diagnostic CT compared with other previous studies.

The results show also that the mean effective dose in radiotherapy planning CT-scans is 13 mSv, which is almost three times lower than the effective dose calculated by

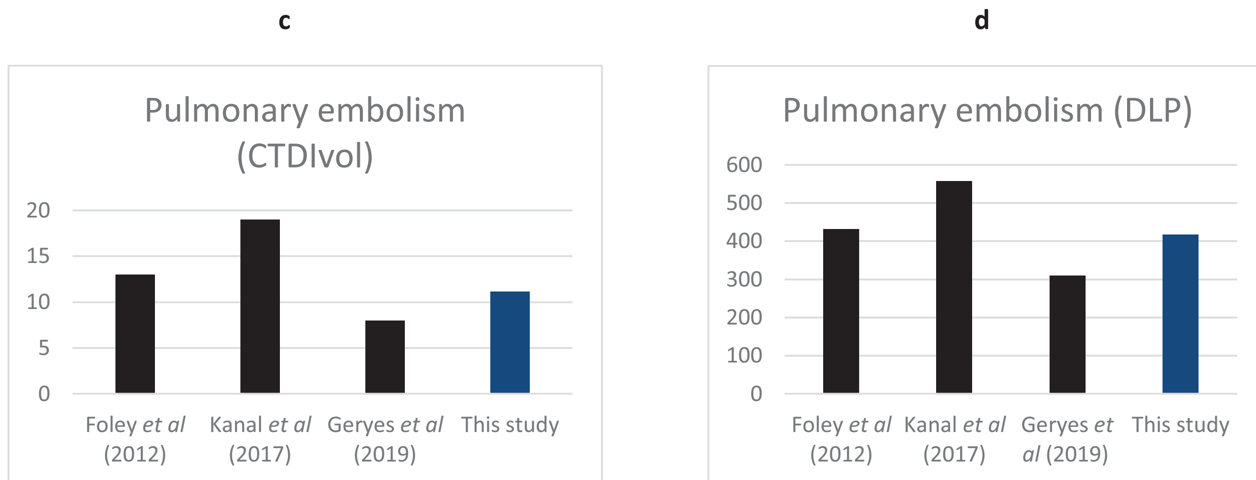

Fig. 2. DRL in terms of (c) CTDIvol and (d) DLP calculated by this study for pulmonary embolism indication compared to other previous studies.

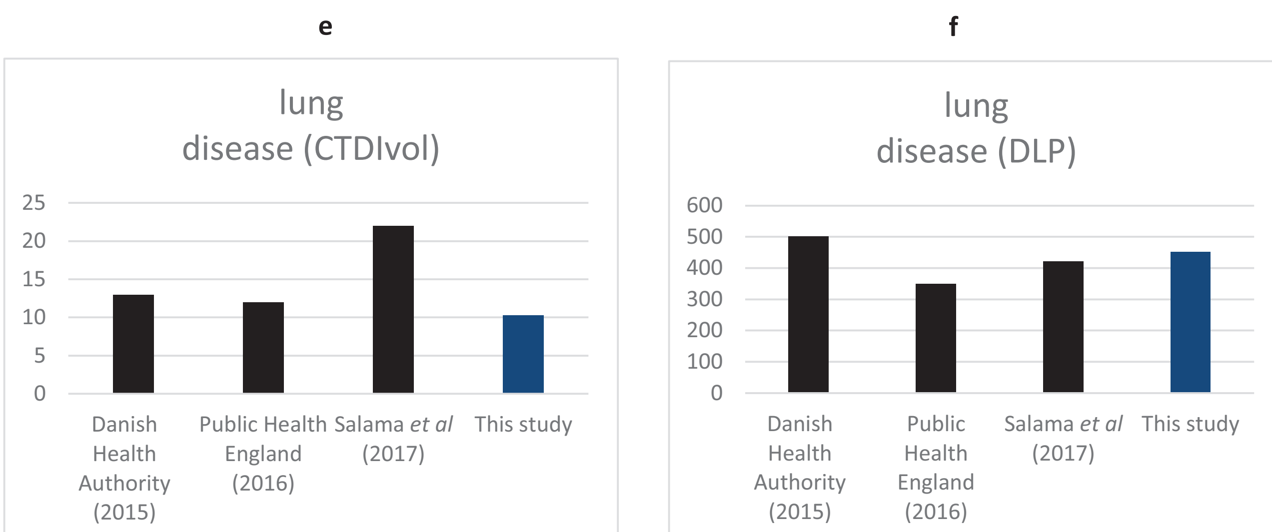

Fig. 3. DRL in terms of (e) CTDIvol and (f) DLP calculated by this study for lung disease indication compared to other previous studies.

Sanderud *et al.* (2016) (30 mSv). The mean effective doses for thoracic diagnostic CT-scans are 6.49 mSv, 6.72 mSv, and 4.44 mSv for pulmonary embolism, infectious lung disease, and COPD respectively. These values are all lower than the effective dose calculated by Sanderud *et al.* (2016) (7.7 mSv). In this context, the use of effective doses can facilitate comparisons between doses administered through various diagnostic and therapeutic procedures, as well as in evaluating the radiation risks associated with different technologies, hospitals, or countries (AAPM, 2008). Moreover, the significant difference in the radiation dose that patients receive may be due to factors linked to the equipment itself or to the different techniques used by practitioners (Pedrosa *et al.,* 2023).

The results show a significant relationship between BMI and the effective dose and no relationship between gender, age, and the effective dose for CT radiotherapy planning CT. for diagnostic CT, there was a significant relationship between clinical indication, age, and the effective dose and no relationship between gender, BMI, and the effective dose. In addition, the results obtained in this study show differences in DRL between diagnostic CT scans and CT scans for radiotherapy planning, as well as a difference between clinical indications. Therefore, we suggest that prescribing physicians and radiologists consider clinical indications when managing thoracic CT scans. Note that a correlation between the exposure parameters and the effective dose is not useful since these parameters are linked to each other through constant factors.

4.4 Estimation of the risk of radiation-induced cancer:

The mean cancer risk calculated for radiotherapy planning CT-scans of the thorax is 715 per 1 million, which is higher than the mean cancer risk calculated for thoracic diagnostic CT-scans: pulmonary embolism (357 per 1 million), infectious lung disease (369 per 1 million), and COPD (244 per 1 million). The International Commission on Radiological Protection (ICRP) has recommended reinforcement of the principle of protection optimization in medical imaging to mitigate the risk of irradiation. This principle should be applicable to all exposure situations, with individual dose and risk constraints imposed on planned exposure situations and reference levels established for emergency and existing exposure situations. In addition, the ICRP has proposed the development of a framework to demonstrate radiological protection of the environment (ICRP, 2007).

During this investigation, we have analysed data related to chest CT procedures for diagnosis and radiotherapy planning in Hassan II Hospital, Agadir. We recommend the use of the DRLs established in this study by medical imaging practitioners to optimize their radioprotection practices for these procedures until the establishment of the NDRLs by the Moroccan Nuclear and Radiological Safety and Security Agency (AMSSNuR).

5 Conclusion

It has become essential to strictly control the doses received by patients during CT examinations, and to make comparisons based on various factors such as: acquisition parameters, acquisition mode, and clinical diagnosis. Furthermore, we recommend that subsequent studies at local, regional and national levels should focus on the evaluation of patient doses according to clinical indication and specific size, for a more precise and accurate determination of exposure doses. These measures will be used to improve the optimization process, the quality of patient care, as well as to develop ongoing training initiatives for healthcare professionals.

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Conflicts of Interest

The authors declare that they have no conflicts of interest in relation to this article.

Data availability statement

The data that has been used is confidential.

Author contribution statement

S. Semghouli, M. El Fahssi, designed the study, performed the statistical analysis and wrote the first draft of the manuscript. B. Amaoui, A. Choukri managed the reviewing and editing. All authors read and approved the final version of the manuscript.

Ethics approval

This study did not carry out activities that would require approval by a research ethics committee.

Informed consent

This article does not contain any studies involving human subjects.

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