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ARTICLE

Assessment of the likely stochastic effects associated with the effective dose and renal dose delivered to patients during an abdominopelvic examination in a Moroccan imaging department

M. Benamar[1], A. Housni[1,2,*], F.Z. Ouifaya[1], K. Amazian[2,3], A. Essahlaoui[1] and A. Labzour[1]

[1] Laboratory of Engineering Sciences, Polydisciplinary Faculty of Taza, USMBA, Morocco.
[2] Laboratory of Health Sciences, Care and Techniques, Higher Institute of Nursing Professions and Health Techniques, Fez, Morocco.
[3] Human Pathology, Biomedicine and Environment Laboratory, Faculty of Medicine and Pharmacy, USMBA, Fez, Morocco.

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Abstract – The objective of this study was to evaluate the effective dose and the renal dose delivered to patients during an abdominopelvic examinations, in order to estimate the likely stochastic effects and to judge the need for optimization of CT examination protocols. Data from 287 abdominopelvic examinations of adult patients referred to three Moroccan radiology departments were collected. The mean effective doses, mean renal doses, cancer and hereditary risks assessment were estimated using the weighting factors defined in ICRP 103. During the abdominopelvic CT exam, the effective dose received by the patient varies from 8.99 to 12.09 mSv with an average value of 10.29 mSv, and, the renal dose varies between 5.15 and 8.71 mSv with an average value of 7.56 mSv. The risk of induction of abdominopelvic and kidney cancer ranges from 49.44 to 66.49 and from 28.32 to 47.9 for 10^5 procedures, respectively. For the hereditary risk of abdominopelvic and renal exposure, it was in the range of 17.98 to 21.86 and 10.3 to 17.42 for 10^6 procedures, respectively. The results obtained show a wide variation in exposure doses during abdominopelvic CT scans from one hospital to another. Even so, the average effective dose and renal dose was generally lower than that recommended by the ICRP.

Keywords: Computed tomography / effective doses / renal dose / stochastic effects / optimization

1 Introduction

Chronic kidney diseases are truly a global public health problem (Obrador *et al.*, 2002), they are among the main non-communicable diseases like diabetes, hypertension and cardiovascular disease, also it is the 12th cause of death. The estimated prevalence of chronic kidney disease in Morocco in 2020 was 4.4% (Moustakim *et al*., 2020).

Over the years, Computed Tomography (CT) scans have played a central role in the exploration of the abdomen thanks to their low sensitivity to motion artifacts, allowing an exploration of almost the whole body in short time, with simple accessibility. It is considered as a reference method for exploring of abdominal emergencies (Linard *et al*., 2011), and has become a leading imaging modality for renal exploration (Renard-Penna *et al*., 2012).

Patients with chronic kidney disease regularly undergo CT scans during their diagnostic and post-therapeutic management (Tzou *et al.*, 2019). The repeated exposure of the kidneys during CT scans increases the effective dose received by this organ. As a result, it increases the risk of cancer and hereditary diseases induced by ionizing radiation.

Although X-rays delivered by CT scans are considered low doses, below approximately 100 mSv, the International Commission on Radiological Protection (ICRP) considered, for radiological protection purposes, that knowledge of fundamental cellular processes, coupled with data on the dose-effect relationship, support the view that in the low dose range, it is scientifically plausible to assume that the incidence of carcinogenic or hereditary effects increases in proportion with the increase in the equivalent dose received by the organs and tissues concerned (ICRP 2007).

The concept of effective dose was introduced by the ICRP, is defined by the weighted sum of equivalent doses received by tissues, and it is an estimate that takes into account the future risk of cancers and hereditary effects, depending on the type of the irradiated organ, linked to exposure to ionizing radiation (stochastic effects) (Tzou *et al.*, 2019).

Radiation protection in the low-dose range is primarily concerned with protection against radiation-induced cancers and hereditary diseases. These effects are considered to be of a

*e-mail: a.housni@ispitsfes.ac.ma

Table 1. Volumetric CT dose index (CTDI vol) (mGy) and dose length product (DLP) (mGy.cm) dosimetric indicators for abdominal exams.

Hospital	Number of acquisitions	CTDIvol per acquisition		DLP per acquisition	
		75th percentile	Range	75th percentile	Range
all Hospitals	530	9.4	2.77-18.4	464.65	101.5-907
H1	193	8.6	2.9-15.8	423.8	101.5-757.1
H2	175	11.3	2.9-15.3	517.4	118.2-753
H3	162	9.56	2.77-18.4	472.5	104-907

probabilistic nature, with no threshold, and with a frequency that increases proportionally with the radiation dose. For detriment-adjusted cancer risk, the ICRP proposes a nominal risk coefficient equal to 5.5 10^{-2} Sv^{-1} for the population as a whole. For hereditary effects, the nominal risk coefficient adjusted for detriment is estimated at 0.2 10^{-2} Sv^{-1} for the population as a whole (ICRP 2007).

In line with ICRP recommendations, the aim of this study was to assess the effective dose delivered to patients during an abdominopelvic examination, as well as the renal dose, in order to estimate the likely stochastic effects.

2 Materials and methods

We conducted a retrospective quantitative multicenter study, covering a four-month period from June 01 to September 31, 2022. Data collection was carried out on DICOM (Digital Imaging and Communication in Medicine) consoles in the medical imaging departments of three Moroccan hospitals.

The examinations were carried out on three scanners, two of which were of the same brand, HITACHI Supria, while the third was GE. All three scanners were multi-slice, 16-slice, 1.25×16 collimation and helical acquisition mode. Examinations were carried out according to predefined standard protocols, the only parameter that could be modified was the acquisition length adapted to the patient's size. Voltage was set at 120 kV for scans carried out in hospitals H1 and H2, and 130 kV for the examinations in hospital H3. The tube current was modulated automatically by IntelliEC (3D), a software package integrated into the scanners.

Information on dosimetric indicators was recorded manually from a post-acquisition dosimetric report, on which the CTDIvol and DLP for each acquisition and for the entire examination were recorded, along with voltage (kV) and effective load (mAs).

Mean effective doses, mean renal doses, Cancer and Hereditary Risks Assessment were estimated using the weighting factors defined in ICRP Publication 103 (ICRP, 2007), the formulas used are:

$$E_{eff}(mSv) = 0.0152 \times DLP \quad (1)$$

$$E_{kidney}(mSv) = 0.0086 \times CTDI_w \times mAs \quad (2)$$

$$C_{risks} = E_{eff}(Sv) \times 5.5\,10^{-2}\left(Sv^{-1}\right) \quad (3)$$

$$H_{risks} = E_{eff}(Sv) \times 0.2\,10^{-2}\left(Sv^{-1}\right) \quad (4)$$

With:

E_{eff} : The effective dose received per patient for a given CT scan;

DLP : Dose length product for a given scan examination;

E_{kidney}: Renal dose received per patient for a given CT scan;

CTDIw : Computed Tomography Dose Index weighted;

mAs : Load for a given CT scan;

C_{risks}: The overall cancer risk per procedure;

H_{risks}: The risk for hereditary diseases up to the second generation per procedure.

The collected data was entered into an Excel spreadsheet and analyzed using statistical analysis software (Statistical Package for Social Sciences (SPSS)). The examinations are divided into four groups according to the location where the examination was conducted.

3 Results

Our study included 287 abdominopelvic examinations of adult patients of both genders (46.38% male and 53.62% female). The average age of the sample is 48 years (17 − 82 years).

Table 1 shows the 75th percentile CTDIvol and dose length product (DLP) values per abdominopelvic scan for the three hospitals, H1, H2, H3 and all H. These values are compared to the NRD published in other countries. The 75th percentile CTDIvol values per abdominopelvic scan for the three hospitals, H1, H2, H3 and all H were 8.6, 11.3, 9.56, and 9.4 m Gy respectively (Tab. 1). These values are lower than the locally reported values in Morocco, France (IRSN 2023) and Australia (Lee *et al.*, 2020), Only the hospital H2 at a CTDIvol value higher than the value obtained by the El Mansouri study (Tab. 2).

Similarly, the 75th percentile DLP values per acquisition were 423.8, 517.4, 472.5, 464.65 mGy.cm for H1, H2, H3 and all H respectively (Tab. 1). These values are lower than those observed locally in Morocco (El Mansouri *et al.*, 2022), France (IRSN 2023) and Australia (Lee *et al.*, 2020) (Tab. 2).

The mean values for CTDIvol per acquisition varied between 7.68 and 8.29 mGy, and DLP per examination varied between 591.22 and 795.93 mGy.cm (Tab. 3). H3's CTDIvol and DLP values were higher compared to those of the other hospitals.

Table 2. Comparison of the 75th percentile values of the dosimetric indicators.

	75th percentile all Hospitals	75th percentile (Benamar *et al., 2023*)	75th percentile (El Mansouri *et al.2022*)	France (IRSN 2023) DRL (2019)	France (IRSN 2023) 75th percentile (2019-2021)	DRL Australia (Lee *et al., 2020*)
CTDIvol (mGy)	9.4	11.3	10.9	13	9.5	13
DLP (mGy.cm)	464.65	517.1	714	625	475	600

Table 3. The mean values for kVp, mAs, CTDIvol (mGy) and DLP (mGy.cm) for all the abdominopelvic procedures and per Hospital.

Hospital	N	kV	mAs ± SD	CTDIvol ± SD	DLPtotal ± SD
all Hospitals	287	120	90.42 ± 28.34	7.95 ± 2.28	677.25 ± 342.12
H1	101	120	99.62 ± 19.17	7.68 ± 1.43	683.67 ± 284.28
H2	111	120	98.56 ± 36.37	7.98 ± 3.23	591.22 ± 359.85
H3	75	130	65.99 ± 15.94	8.29 ± 2.01	795.93 ± 343.26

Table 4. The mean and range for the effective dose E_{eff} and kidney dose E_{k} for all procedures and per hospital.

Hospital	E_{eff} (mSv)		E_{K} (mSv)	
	Mean ± SD	Range	Mean ± SD	Range
all Hospitals	10.29 ± 5.2	1.8 – 38.55	7.56 ± 4.37	0.98–74.08
H1	10.39 ± 4.32	2.56 – 27.34	7.46 ± 2.7	1.24–29.78
H2	8.99 ± 5.47	1.8 – 37.26	8.71 ± 6.27	1.01–71.51
H3	12.09 ± 5.22	3.28 – 38.55	5.15 ± 2.48	1.33–22.9

Table 5. Cancer and hereditary risks per abdominopelvic CT procedure and per hospital.

Hospital	Cancer Risk per 10^5 procedures CT		Hereditary Risk per 10^6 procedures CT	
	abdominopelvic	kidney	abdominopelvic	kidney
all Hospitals	56.59	41.58	20.58	15.12
H1	57.14	41.03	20.78	14.92
H2	49.44	47.90	17.98	17.42
H3	66.49	28.32	24.18	10.3

For the effective dose (E_{eff}) received by the patient during an abdominopelvic CT scan ranges from 8.99 to 12.09 mSv, with a mean value of 10.29 mSv. The renal dose (E_K) varies between 5.15 and 8.71 mSv, with a mean value of 7.56 mSv (Tab. 4).

The risk of induction of abdominopelvic and kidney cancer ranged from 49.44 to 66.49 and from 28.32 to 47.9 per 10^5 procedures, respectively (Tab. 5). The hereditary risk of abdominopelvic and renal exposure ranged from 17.98 to 21.86 and from 10.3 to 17.42 per 10^6 procedures, respectively.

4 Discussion

In Morocco, recent studies have been conducted to investigate the radiation dose from CT scans during diagnostic radiological examinations. They have emphasized that the establishment of local DRLs is an important step in the control and optimization of patient radiation protection (Benamar *et al.*, 2023; El Mansouri *et al.*, 2022). In this regard, the Moroccan Agency for Nuclear and Radiological Safety and Security (AMSSNuR) is working on establishing DRLs in terms of examination indications, so that professionals can use this tool to optimize their practice.

The purpose of this study was to compare radiation doses received by our adult patients undergoing abdominopelvic CT with other national and international studies. Secondly, the study aims to help fill some gaps in the evaluation of the effective dose and renal dose received by the patient during an abdominopelvic CT examination in Morocco. Additionally, it aims to estimate the biological effects (cancer risk and hereditary risk) that may result from such procedures.

The 75th percentile values of CTDIvol and DLP per acquisition varied significantly among the three study centers; these variations may be explained by differences in acquisition protocols used by radiology technicians, and these differences depend on the technicians' training and experience. A study by Tahiri suggests that effective initial and continuing training of health care staff and the implementation of referral guidelines for medical imaging could lead to improve practitioners' knowledge of patient radiation protection and consequently could reduce radiation dose (Tahiri *et al.*, 2022).

The overall comparison between the 75th percentile values resulting from our study and the values from other recent local studies and DRLs from other countries revealed a substantial average reduction, reflecting a significant improvement in the process of optimizing the dose delivered to the patient during a CT scan in our departments.

The radiation dose received by patients in all three hospitals was expressed in terms of mean CTDIvol and total DLP values. These data show that hospital examinations (H3) showed the highest values. These results could be attributed to the use of a higher tube voltage (130 kV) compared to the other hospitals. Considering that the kilovoltage has an effect on the dose (Pesenti Rossi *et al.*, 2012), increasing the voltage from 120 kV to 140 kV, for instance, increases the dose by approximately 40% (Cordoliani & Boyer, 2004). In our study the abdominopelvic examinations were systematically performed with a voltage of 120 kV. However, a study recommends the use of lower tube voltages (80 or 100 kV) to optimize the dose in these more vulnerable regions (Tang *et al.*, 2012). In addition, the values of the tube current-time product should be adapted to the size of the patient, and the dose requirements of each examination type. As well as, the use of load modulation automatic with a limit value would be sufficient to reduce the patient dose and to achieve diagnostic images with a good quality.

Regarding the effective doses and renal dose received by patients during abdominopelvic CT examination in the three hospitals, the values of the effective dose were completely different for the three study hospitals, the ANOVA test revealed a significant difference between the three Hospitals in terms of effective dose (F E_{eff} (mSv) = 5.14; p 0.01). The average effective dose in Hospital H3 is much higher than the other hospitals, this variation could be attributed to the increase in the total average DLP value, this increase may be due to data acquisition conditions and especially the number of phases per examination. On the other hand, multiplying the number of scans on the same region with the same amount of radiation generally triples the transmitted energy and increases the effective dose by less than 10% (Ware *et al.*, 1999).

With regard to renal dose, all hospitals showed statistically significant differences (F E_k (mSv) = 7.01; $p \leq 0.01$). However, the mean renal dose in Hospital H3 was much lower than the other hospitals. This variation could be attributed to the mean value of mAs used, which was the lowest compared to the other hospitals.

Several epidemiological studies directly support excess cancer risks associated with low-dose ionizing radiation. Furthermore, the magnitude of the cancer risks from these low-dose radiation exposures was statistically compatible with the radiation dose-related cancer risks of the atomic bomb survivors (Michael Hauptmann *et al.*, 2020). Moreover, epidemiological studies suggest that the lowest dose of ionizing radiation for which there are good evidences of an increase in cancer risk in humans is 10 to 50 mSv for acute exposure and 50 to 100 mSv for prolonged exposure (Yasser *et al.*, 2020; Abbott *et al.*, 2015, Tubiana *et al.*, 2006).

Generally, in our work, the mean values of the effective dose and renal dose of all hospitals were 10.29 mSv and 7.56 mSv respectively. These results prompts us to continuing to improve our protocols and our professional practice associated with an awareness and qualification of operators in patient radiation protection in CT scan.

Furthermore, the results of our study showed variations in cancer risk and hereditary risk whether by abdominopelvic or the kidney and also among the various hospitals. In general, these variations are the result of differences between the effective dose values received per patient region and per hospital. In fact, cancer risk and hereditary risk are proportional to effective dose by factors of 5.5 10^{-2} (Sv^{-1}) and 0.2 10^{-2} (Sv^{-1}) respectively. Thus, any increase in the value of effective dose necessarily induces an increase in cancer risk and hereditary risk.

Although any effort and innovation, whether technical, material and/or computer, to optimize the dose delivered to the patient will have a positive impact on the optimal reduction of the harmful risks of ionizing radiation, education on radiation protection remains an essential point. In fact, several studies have shown that initial training as well as continuing training in radiation protection for operators remain a major issue in health facilities (Bertho *et al.*, 2023, Housni *et al*., 2023, Mohebbi *et al*., 2023). In addition, the establishment of Diagnostic Reference Levels (DRLs), which are still considered an effective means of evaluating and optimizing professional practices, will significantly improve the radiation protection of the patient who is our focus (El Mansouri *et al*., 2022, Benamar *et al*., 2023).

5 Conclusion

The objective of this study is to assess the effective dose and the renal dose delivered to patients during an abdominopelvic examination and to estimate the associated likely stochastic effects. This works show that the doses received by patients during abdominopelvic CT examinations in the study departments are lower than those usually observed in other national and international studies. These results encourage us to continue in the process of supporting and raising the awareness of radiology operators with regard to radiation protection of professionals and patients. Our actions in this field are focused, among other things, on promoting scientific research in the area of best practices in radiation protection during the preparation of end-of-study projects for future professionals, radiology technicians and physicists.

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Conflicts of Interest

The authors declare that they have no conflict of interest.

Data availability statement

Data associated with this article cannot be disclosed due to ethical reason.

Author contribution statement

All authors contributed to the writing and discussion of this article.

Ethics approval

Ethical approval was not required.

Informed consent

The article does not contain any studies involving human subjects.

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