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Radiation Dose Estimation for Live Kidney Donors)

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Abstract: The objective of this work was to evaluate the cumulative effective radiation dose (CED) delivered to live kidney donors (KD) undergoing renal pre-transplant assessment.

A multi-slice Computed Tomography CT scanner was utilized for this research. Detailed parameters for 50 live kidney donors, including weight, height, age, volume CT dose index ($CTDI_{vol}$), and dose length product (DLP), were recorded from the Picture Archiving System (PACS), radiology department, urology, and nephrology center, Mansoura University. For each Kidney Donor (KD), the effective dose (ED) was calculated.

The radiologic procedures are divided into conventional radiology, computed tomography (CT), and nuclear medicine (NM). CT represented the highest effective dose (>95%) of the total CED. CT angiography (CT angio) is the most common examination which consists of four main series (pre-contrast, arterial, venous, and delayed). The other examinations are non-contrast spiral CT abdomen-pelvis, and chest-abdomen-pelvis. In this case the $CTDI_{vol}$, DLP, and ED were found to be in the range (4.59–22.92) mGy, DLP (266.9–1561.8) mGy.cm, and ED (3.79–22.178) mSv, respectively. The total and average CED were 44.62-130.1 mSv and 71.63 mSv, respectively, during the pre-transplant assessment.

Our study showed that kidney donors receive a significant dose of ionizing radiation during the renal pre-transplant assessment.

keywords: Live kidney donors, Computed tomography, Ionizing radiation, contrast and non-contrast spiral CT , effective radiation dose

1.Introduction

Live kidney donors must undergo a thorough examination to rule out any physical or mental health issues that could harm them in the future [1], bearing in mind that they are healthy before performing this operation and that they play a major role in reviving the soul of a person who was suffering from major problems in his kidneys.

These kidney donors must, however, go through an extensive medical evaluation. They go through a complete pre-transplantation assessment which involves “a physical examination, urine and blood testing, a chest radiography, echocardiography, ultrasound examination, intravenous urography, and renal angiography” [2]. Thus, a detailed pre-transplantation screening which includes X-ray, Computed Tomography (CT) and Renogram (NM) are the most important examinations in our study.

It is essential to evaluate the dose of radiation given to people undergoing angiography screening and kidney transplantation operations from live kidney donors since these procedures can expose them to significant radiation doses [3].

The ionizing radiation becomes more important in medical uses from the discovery of X-ray. Ionizing radiation for medical purposes has risen greatly over the previous ten years, and as of 2006, healthcare uses of ionizing radiation accounted for 3.0 millisieverts (mSv), which is a significant increase over the estimated 2.4 mSv from background radiation [4]. The medical imaging by using the ionizing radiation becomes an issue for alarm threatens the public health [4-6]. The risk estimates originate from checks of mortality data based on those exposed to medical diagnostic or therapeutic operations, occupational nuclear workers, and survivors of the Japanese atomic bomb [7].

Due to the accuracy and dependability in identifying diseases, CT has grown rapidly. Given its ongoing development, CT is a useful and essential tool for identifying a variety of diseases in the field of medical imaging. CT contributes the largest radiation doses that exposed to patients about 60% of the total radiation from medical imaging. Also, about 9.8 million diagnostic imaging procedures utilizing ionizing radiation were carried out in the Netherlands in 2010. The number of CT studies among them increased by double since 2002 to 1.16 million [8]. CT regarded a very high dose imaging method from its launch, therefore, estimating the radiation dose has been a research topic for a long time [9].

The literature has shown that regional and national differences in patient doses exist due to a number of factors such as the design of CT scanner, technical parameters, and the protocol used. The construction of diagnostic reference levels aids in the improvement of clinical procedures and radiation safety. Countries that used these levels were estimated to reduce radiation dose [10-11] .National reference levels for CT, were published in Canada and Norway in 2016 and 2018 respectively [12-13], in order to minimize patient dose and comply with the "as low as reasonably achievable" (ALARA) principle while retaining acceptable image quality. The diagnostic imaging team can employ NDRLs and LDRLs as a reference to modify CT scanning techniques based on patient data. Medical imaging uses diagnostic reference levels (DRLs) to enhance clinical assessments. DRLs are used to a simply measured item in co-operation with the International Commission on Radiological Protection's (ICRP) guidelines. In order to evaluate patient doses for CT exams, hospitals can use DRLs to help discover excessively high doses within particular institutions [14]. If average doses are higher than these DRLs, it can help to find solutions to reduce the doses. It has been demonstrated that the use of DRLs results in a dosage reduction in the clinical context. The effective radiation dose of CT can be determined as the multiplying DLP by conversion factors [15-16].

The aim of the present work is to evaluate the total effective doses of radiation received by healthy kidney donors before donation and to predict the occurrence of any malignant diseases or cancers.

2. Materials and methods

The current study was done at a urology and nephrology center at Mansoura University, where kidney transplantation is one of its health care duties. Our institutional committee gave its approval to the present study.

A CT scanner (Brilliance, Philips Medical Systems, Eindhoven, Netherlands) with 64 slice rows was used in our study. A total of 50 kidney donors were involved in this study to assess the total effective radiation dose. Information's for every kidney donor's such as age, sex, and body mass index (BMI), the number of CT, x-ray, and gamma camera examinations done during the transplantation period were recorded. The study was done in 2018–2022. For every CT scan examination, the series number was recorded, and for each series, the kilo volt peak (KV_p), milliampere second (mAs), pitch, rotation time, volumetric CT dose index ($CTDI_{vol}$), and dose length product (DLP) were recorded from the dose reports. The renogram number was also recorded for nuclear medicine examinations, and chest X-ray, X-ray of the abdomen and pelvis (urinary track plain (UTP)) were recorded for every kidney donor during the donation process from PACS.

All the kidney donor's data were recorded from the Picture Archiving System (PACS) as illustrated in table 1 and table 2.

Table 1: kidney donor's data.

Gender	Number of cases	Age range	Height range	Weight range
male	15	28-79	160-185	64-113
female	35	22-60	150-168	60-112

Table 2: Examinations performed on live kidney donors.

Examination name	Total number of examinations
CT Angiography	51
Non contrast spiral CT(abdomen-pelvis)	34
Non contrast spiral CT (chest-abdomen, and pelvis)	11
Renogram	49
Chest X-ray	64
UTP	56

Radiation dose evaluation

For CT scans, we acquired estimates of the effective doses provided, measured in mSv, to quantify the radiation exposure for each imaging operation. We relied on the data in the dose report, whereas the effective dose is the product of the DLP and the recently developed ICRP-103-based K coefficient, which is specific only to the anatomic region scanned for multi-detector CT (for 120 kV: abdomen 0.0153; thorax-abdomen 0.0149; abdomen-pelvis 0.0141; thorax-abdomen pelvis 0.0142) [12–13].

The effective dose can be calculated from:

$$Effective\ dose = DLP \times k \qquad (1)$$

We counted CT with contrast, which has multiple series during the examination, such as pre-contrast, arterial, venous, and delayed (CT Angiography), and CT without contrast (non contrast spiral CT). The protocol used in our work are showed in table [3], where the total effective dose of radiation was expressed as the sum of the total effective doses over all the study periods, as shown in Table 2.

This research was carried out on 50 living kidney donors. The group under study contains 15 males and 35 females, with an age range of 22 to 79 years, a height range of 150 to 168 cm for females and 160 to 185 cm for males, and a weight range of 60 to 112 kg for females and 64 to 113 kg for males. The total number of CT angiography for kidney donors was 51; chest X-ray were 64; UTP were 56; non-contrast spiral CT (abdomen-pelvis) were 34; non-contrast spiral CT (chest-abdomen and pelvis) were 11; and renograms were 49 examinations.

Table 3: Scanning parameters for CT Angio and non-contrast spiral CT.

Scanning parameters	CT Angiography	Non contrast spiral CT
KVp	120	120
mA	AEC	AEC
Pitch(mm)	1	1.172
Gantry rotation(s)	0.75	0.75
collimation	64 * 0.625	64 * 0.625
Reconstruction Algorism	FBP	FBP
Slice thickness(mm)	3.5	4
matrix	512	512
Reference phantom(cm)	32	32

3. Results

The study included three types of CT scans, which are necessary for kidney donation:

3.1. The first one, and the main CT scan type, is CT angiography.

This examination includes four series (phases):

Pre-contrast series (phase), where the abdomen and pelvis are scanned with a CTDIvol ranging from 9.7 to 24.53 mG_y, a DLP ranging from 478.6 to 1396.8 mG_y.cm, and an effective dose ranging from 6.75 to 19.7 mG_y. Only one case conducted the pre-contrast series twice, and the effective dose reached 17.56 mSv.

Arterial series (phase), where the abdomen only is scanned with a CTDIvol ranging from 8.47 to 24.46 mG_y, a DLP ranging from 290.1 to 1050.1 mG_y.cm, and an effective dose ranging from 4.44 to 16.07 mSv.

Venous series (phase), where the chest, abdomen, and pelvis are scanned with a $CTDI_{vol}$ ranging from 12.94 to 19.36 mG_y, a DLP ranging from 668.6 to 1273.1 mG_y.cm, and an effective dose ranging from 10.23 to 29.35 mSv.

Delayed phase, where the abdomen and pelvis are scanned with a CTDIvol range of 8.34 to 20.98 mG_y, a DLP range of 396.2 to 1028.8 mG_y.cm, and an effective dose range of 6.54 to 49.72 mSv.

We noticed a very important point that we must shed light on in this research: 17 cases conducted delayed phase two times in the same CT scan, which raised the total effective dose for delayed phase only to reach 25.41 mSv; 4 cases conducted delayed phase three times in the same scan, which raised the total effective dose for delayed series only to reach 35.5 mSv; and 2 cases conducted delayed series four times, which led to the total effective dose reaching 49.72 mSv for delayed phase only[table 4].

3.2. The second CT examination is non-contrast spiral CT ("abdomen-pelvis"). This examination includes one series. In this series, the abdomen and pelvis are scanned with a CTDIvol range of 4.59–22.92 mG_y, a DLP range of 266.7–1561.8 mGy.cm, and an effective dose range of 3.79–22.178 mSv [table 4].

3.3. The third examination is non-contrast spiral CT, "chest-abdomen-pelvis".

This examination is contained one series. In this series, the chest, abdomen, and pelvis are scanned with a CTDIvol range of 10.35 to 19.36 mGy, a DLP range of 774.4 to 1338 mGy.cm, and an effective dose range of 10.71–19 mSv [Table 4].

Table 4: CT- Series examination effective.

Examination type	Series name	CTDIvol(mGy)	DLP (mGy.cm)	Effective dose(mSv)
CT ANGIO	Pre contrast	9.7- 24.53	478.6-1396.8	6.75-19.7
	arterial	8.47- 24.46	290.1-1050.1	4.44-16.07
	venous	12.94- 19.36	668.6-1273.1	10.23-29.35
	delayed	8.34- 20.98	396.2-1028.8	6.54-49.72
Non contrast spiral CT “abdomen-pelvis”	Non-contrast	4.59- 22.92	266.9- 1561.8	3.79-22.178
Non contrast spiral CT “chest-abdomen-pelvis”	Non-contrast	10.35-19.36	774.4-1338	10.712-19

Figures 1,2,3 and 4 indicates the relationship between $CTDI_{VOL}$ and Effective dose for all series which have been examined in our research. From these Figures, it very important to observe that, in general, the $CTDI_{VOL}$ are directly proportional with the Effective dose.

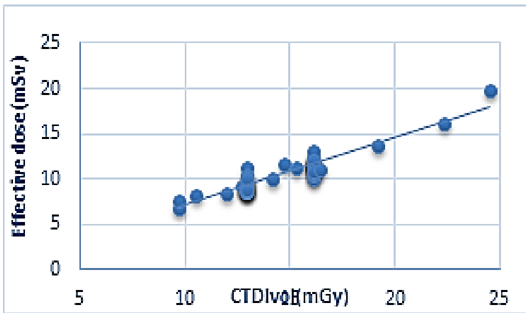

Figure1. The relation between ED and $CTDI_{VOL}$ for pre- abdomen series.

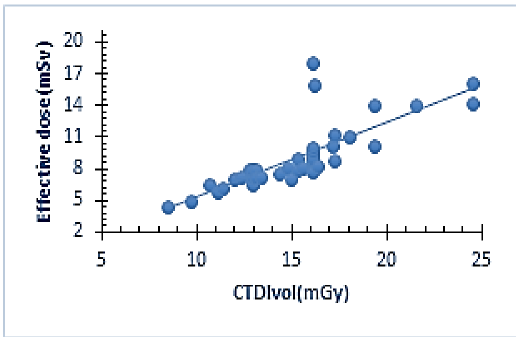

Figure 2. The relation between ED and $CTDI_{VOL}$ for arterial series.

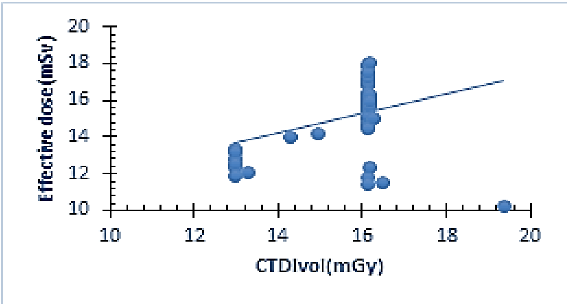

Figure 3. The relation between ED and $CTDI_{VOL}$ for venous series.

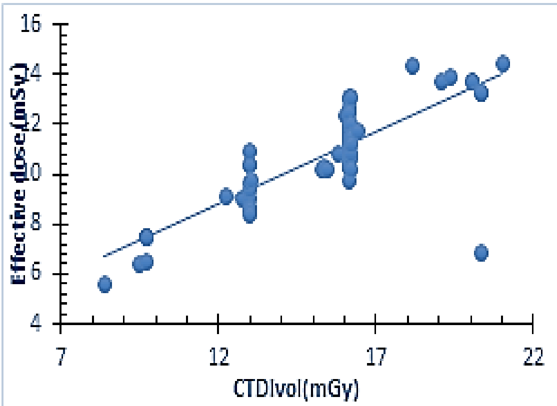

Figure 4: The relation between ED and CTDIVOL for delayed series.

On the other hand, it is observed, as illustrated in Figure 5, that there is no relationship between the cumulative Effective dose (CED) and age.

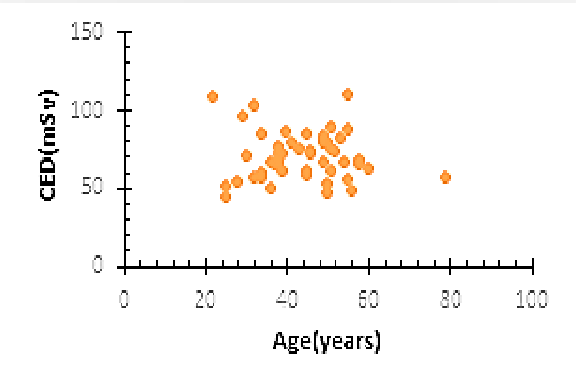

Figure 5. The relation between cumulative Effective dose and age.

It is very important to mention that, implantation period have been repeated different times for some cases, so we plotted the relation between total effective dose and implantation period, as illustrated in Figure 6, which implies the total effective dose in the range 44.62 - 130.1 mSv with average total effective dose 71.63 mSv.

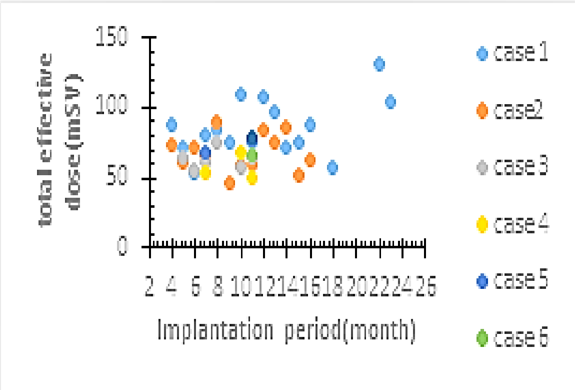

Figure 6: Relation between Total ED and Implantation period.

4. Discussion

This study provides a broad overview of the dose that live kidney donors received during pre-transplantation scanning, which may increase their chance of developing cancer. The estimated risk is eventually obtained from evaluations of mortality statistics based on survivors of the Japanese nuclear bomb [17], who were subjected to moderate radiation doses (around 40 mSv), comparable to the amount often received in two or three CT scans in adults. Strong evidence of an increased cancer mortality risk at equivalent doses greater than 100 mSv is provided by the atomic bomb data, as it is good evidence of an increased cancer risk for doses from 50 to 100 mSv and fair evidence for an increased cancer risk for doses between 10 and 50 mSv [18].

In our results, there were ten cases in the CED range (51.3–60.8) mSv, which are at risk of a brain tumor and leukemia as observed by Pearce et al. [19] for 180,000 people who had CT (average dose, 50–60 mSv).

Our results indicate that the total commutative effective dose (CED) was found to be ranged from 44.62 mSv to 130.14 mSv, which can be attributed mainly to CT, especially the CT angiography for kidney donors, due to the four series examination and some other series examination which are repeated two or more period times for the same scan.

Mathews et al. [20] have been found a mean effective dose of 4.5 mSv causes an absolute excess incidence of all malignancies of 9.38 per 100,000 person-years [21]. On the other hand, the Italian study group [22] were found that the mean total and annual CED, for 106 patients and a three-year follow-up, were 55.7 and 22.9 mSv, respectively.

Also, as mentioned by Kinsella et al. it is found that the average total CED and annual CED for HDP were 21.7 and 6.9 mSv/patient over 3.4 years, respectively. Higher dosages were given to patients who qualified for renal transplants: mean annual CED 30.5 vs. 18.4 mSv/year [23]. In addition to the radiation dose which is mainly exposed during CT scans, the donors were also given a small amount of radiation during X-ray radiography and nuclear medicine.

From our results, it is found that the mean CED of 71.63 mSv were recorded, which is very high dose compared to that obtained for different studies. So, all cases, in our study, are exposed to an incidence of all malignancies. There is no denying, from our study, that these donors' doses exceed the recommended maximum radiation exposure for occupational activities (100 mSv / 5 years and a maximum of 50 mSv annually) and also exceed the recommended maximum radiation exposure for the public (1 mSv per year) [16]. This dose also exceeds the ICRP 103 recommendation. So, live kidney donors, according to our studies, receive higher radiation doses (45 to 113 mSv) so kidney donors are at great cancer risk. All our trials proved that the total CED is very high and must be decreased, especially for CT which provided the largest contribution to the CED in all of these trials.

Based on research done on dialyzed individuals undergoing renal pre-transplant, cancer development could start after the first 5 years, which is the period of time known as the latency period following exposure [24]. So, nephrologists face the challenging task of balancing the cancer risk caused by ionizing radiation through imaging versus the risk of either not gathering enough data for an efficient transplant and follow-up or of not identifying and treating a particular disease.

By creating a specialized low dose protocol to reduce the number of images captured and the time of screening, it is feasible to further optimize the radiation dose given to donors. Reducing total CED is essential and required. There are various methods suggested to achieve this. First, fewer CT scans should be conducted, including repeat exams, and if possible, non-ionizing radiation imaging (magnetic resonance, ultrasound techniques) should be used. The radiation associated with each individual CT scan should be minimized by optimizing examination processes and techniques. Second, as recently advised by the American College of Radiology, the dose level for each patient should be followed and documented when they have repeated imaging over time.

5. Conclusion

According to our results, it can be concluded that the kidney donors are exposed to a high dose of radiation during the renal pre-transplant assessment, mainly from CT; therefore, a reducing ionizing radiation is necessary because kidney donors are generally healthy. This is done by using a low-dose protocol in CT scanning or changing the examination types by using non ionizing radiation imaging and following the ALARA principle

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