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ESTIMATION OF RADIATION DOSES FROM ABDOMINAL COMPUTED TOMOGRAPHY SCANS

Adnan Lahham[1,*] and Hussein ALMasri[1,2]
[1]Center For Radiation Science & Technology, Al-Quds University, East Jerusalem, Palestine
[2]Medical Imaging Department, Al-Quds University, East Jerusalem, Palestine

*Corresponding author: lahham@staff.alquds.edu

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A total of 120 adult female and male patients randomly selected from 10 hospitals in the West Bank and Gaza Strip were investigated for organ and effective doses from abdominal computed tomography scan. The organs considered in this study are liver, stomach and colon. Assessment of radiation doses was performed by using a commercially available Monte Carlo based software VirtualDose™ CT, a product of Virtual Phantoms, Inc. The software utilizes male and female tissue equivalent mathematical phantoms of all ages and sizes from new born up to morbidly obese patients. The corresponding phantom was selected for every patient according to patient's demographic parameters. Patient demographic data, scanning parameters and dose indicators (including patient body mass index (BMI), milliampere-second (mAs), X-ray tube kilovoltage (kVp), computed tomography dose index ($CTDI_{vol}$), dose length product (DLP), manufacturer, name and type of operated CT scanner) were recorded for every examination. The collected parameters were used to calculate the organ and effective doses for every patient. The highest estimated patient organ doses were 25 mGy for liver, 20 mGy for stomach and 30 mGy for colon for a male patient with BMI of 30 kg/m^2 and 90 kg of weight. This patient correspondent effective dose was 9 mSv. The average effective dose for the entire patient population was 5.5 mSv with a range between 2 and 10 mSv. The highest effective dose was found for a female patient with a BMI of 26.6 kg/m^2, and 77 kg of weight. This patient correspondent organ doses were 14, 9 and 14 mGy for the liver, stomach and colon, respectively. The average organs doses per patient estimated for patients from all investigated hospitals were 13.1, 7.6 and 13.2 mGy for liver, stomach and colon, respectively. Both effective dose and organ doses increase with BMI and body weight. In general, the estimated radiation doses from abdominal CT examinations in this study are low and comparable with those published in the literature.

INTRODUCTION

The use of ionizing radiation in medicine in both diagnosis and therapy has increased in recent decades and so the concerns among radiologic professionals and the public regarding the possible health effects associated with the absorption of ionizing energy by the body of patients. Sources of ionizing radiation in the environment of Man are various and include naturally occurring and man-made sources. The main source of exposure however is from natural background, medical sources being the second contributor to the total dose received by man. From medical exposure, computed tomography (CT) is currently one of the major contributors to the collective population radiation dose both because it is relatively high dose procedure and increasing number of people are subjected to CT examinations many times during their lifetime(1). Stochastic effects of radiation are related to occurrence of carcinogenesis and may occur years after exposure. These effects are a risk from exposure to the low levels of radiation used in medical imaging, including CT examinations. The literature on cancer risks from CT includes several examples. Exposure to ionizing radiation is of concern, because evidence has linked exposure to low-level radiation at doses used in medical imaging to the development of cancer(2). A retrospective cohort study published in The Lancetin 2012 assessed the risk of leukemia and brain tumors in children and young adults following CT scans. According to Pearce *et al.*(3), the true risk from low-dose radiation exposure from CT scans is uncertain. The probability for absorbed x-rays to induce cancer or heritable mutations leading to genetically associated diseases in offspring is thought to be very small for radiation doses of the magnitude that are associated with CT procedures. Such estimates of cancer and genetically heritable risk from x-ray exposure have a broad range of statistical uncertainty, and there is some scientific controversy regarding the effects from very low doses and dose rates(4).

It has been estimated that there is a 5% probability per 1 Sv for the stochastic effects to occur(5). If we accepted this assumption (5% probability per 1 Sv for the occurrence of carcinogenesis or hereditary effects), this means that a CT examination that result in an effective dose of 10 mSv (which is similar to the diagnostic reference level for chest and abdomen–pelvis CT) involves a 0.05% probability for the occurrence of such effect. Equivalently, for every 10 000 CT examination performed (of 10 mSv each) approximately five individuals may be expected to develop a fatal cancer or hereditary effects as a result of the radiation exposure[6]. Even though the risk to an individual patient may be small, the increasingly large number of people exposed, coupled with the increasingly high exposure per examination, could translate into many cases of cancer resulting directly from the radiation exposure from CT. It is important to understand how much radiation medical imaging delivers, so this potential for harm can be balanced against the potential for benefit[7]. The particular radiation dose will depend on the size of the body part examined, protocol and type of CT scanner and its operation.

Standard radiographic examinations have average effective doses that vary by over a factor of 1000 (0.01–10 mSv). Computed tomographic examinations tend to be in a narrower range but have relatively high average effective doses (~2–20 mSv)[8]. Organ doses from CT scanning are considerably larger than those from corresponding conventional radiography; typical organ dose to the stomach from anterior–posterior abdominal x-ray examination is ~0.25 mGy, while typical stomach dose from abdominal CT is ~10 mGy[9]. The radiation doses to particular organs from any given CT study depend on a number of factors. The most important are the number of scans, the tube current and scanning time (mAs), the patient's size the axial scan range, the scan pitch, the tube voltage (kVp) and the specific design of the scanner used[10]. CT scans of the abdomen can provide more detailed information about abdominal organs and structures than standard X-rays of the abdomen, thus providing more information related to injuries and/or diseases of the abdominal organs. Abdominal CT scan is considered as a high radiation dose examination due to the large number of radiosensitive organs in the field of view[11]. In literature, different typical effective doses were reported for abdominal CT scan; according to McCollough *et al.* the typical effective dose is 8 mSv, Stocker *et al.* reported a 10 mSv effective dose while in a study by Wolbrast *et al.* a 5 mSv was reported as a typical effective dose for abdominal CT scan[12–14].

In Palestine, there are 28 CT scanners of different types distributed in the West Bank and Gaza Strip[15]. Recently there are a lot of effort from scientific community to evaluate radiation doses received by patients undergoing different CT examinations towards the optimization of radiation protocols and the reduction of doses received by patients and keep it as low as reasonably achievable. This issue became very crucial after the increase of public and professional community concerns as well on the possible effects of radiation doses received mainly from CT examinations because the use of this medical imaging modality has increased rapidly in the recent time. Therefore, there is a need for accessible scientific information on the levels of received doses and associated radiation risk to the population. The aim of this work is to provide information about one of the most frequently prescribed CT examination, the abdominal CT scan by the estimation of radiation doses received by patients underwent abdominal CT scan in 10 hospitals from the West Bank and Gaza Strip.

MATERIALS AND METHODS

For each patient undergoing abdominal CT scan, demographic data (weight, height, age, gender) technical parameters of the scanner and dose report data (scanner type, scan length, scan time, Pitch, kVp, mAs, $CTDI_{vol}$ and dose length product) were extracted from the CT images. Data was collected from May to November 2016. The effective dose and organ doses are then estimated using the VirtualDose™ CT software, a product of Virtual Phantoms, Inc. The software is web-based in a way that allows users to access organ dose data via a browser. It utilizes male and female tissue equivalent mathematical phantoms of all ages and sizes from new born up to morbidly obese patients. The software is based on a comprehensive database of organ doses derived from Monte Carlo simulations involving a library of 25 anatomically realistic phantoms that represent patients of different ages, body sizes and masses, and pregnancy stages[16]. VirtualDose™ CT enables users to assess organ doses, in addition to the $CTDI_{vol}$ and DLP data provided by each CT scanner. It is ready for use with the latest CT scanners and utilizes both ICRP-60 and ICRP-103 standards on effective dose[17]. Based on dose indicators and demographic patient tomographic data, organ doses for liver, stomach and colon as well as effective doses were estimated using the VirtualDose™ CT software.

Effective dose reflects the overall exposure to radiation and is a frequently used physical quantity for the comparison of doses from different CT scan technologies, organ doses however are more appropriate measures of the lifetime risk of induced cancer associated with exposure to ionizing radiation. Abdominal organs considered in this study are liver, stomach and colon. These organs are expected to receive high radiation doses from abdominal CT examination because of their large surface areas and due to higher radiosensitivity. Additionally, other organs may potentially receive high radiation doses such as bladder and gonads. However, bladder and gonads were not included in the current study. Patients population were selected randomly from 10 hospitals and consists of 64 females and 56 males. Their ages ranges from 20 to 70 years with a mean age of 40 years, body mass index (BMI) ranges from 16.6 to 46 kg/m^{2}with an overall mean of ~28 kg/m^2. The mean BMI for females was 26.9 kg/m^2 and for males 30.21 kg/m^2. These figures indicate, that most of the patients are over weighted (72.2% of them have BMI above 25 kg/m^2) according to the classification of World Health Organization (WHO). BMI is calculated as follows: BMI = weight (kg)/(height (m))^2[18]. Table 1 presents the number of patients selected from each hospital, their mean weight and height per hospital and calculated BMI.

BMI = body mass index = weight/(height)^2.

Table 2 presents scanners specifications, exposure settings and dose indicators in all investigated hospitals. Exposure indicators were extracted from image record for every examination and averaged over the patients of individual hospital. Maximum peak voltage for abdominal CT protocol was the same in all hospitals and equals 120 kVp.

RESULTS AND DISCUSSION

The corresponding mean values of patient effective dose and organ doses for the liver, stomach and colon are presented in Table 3 per hospital.

As we can see from Table 3, the values of organ doses are distributed widely between hospitals depending on many factors mainly mAs, and scanner parameters as well as the patient tomographic data. The highest organ doses estimated for any patient (25 mGy for liver, 20 mGy for stomach and 30 mGy for colon) were found for a 45 years male patient from H2 hospital with BMI = 30 kg/m^2, weight 90 kg. The corresponding effective dose for this patient was 9 mSv. The average organs doses per patient estimated for patients from all investigated hospitals were 13.1, 7.6 and 13.2 mGy for liver, stomach and colon, respectively. The relationship between organ dose and body weight was also investigated in this work. Figure 1 shows this relationship for the three selected abdominal organs; liver, stomach and colon. For all organs, the radiation absorbed dose increases with increasing body weight in a fashion seems to be non-linear. This relationship

Table 1. Summary of study population (patients demographic data).

Hospital	No. of patients	Mean age (y)	Mean weight (kg)	Mean height (m)	Mean BMI (kg/m^2)
H1	15	43.8	73.2	1.64	27
H2	10	47.9	80.6	1.69	27.9
H3	15	47.8	81.6	1.69	28.5
H4	15	39.5	80.8	1.7	28
H5	15	47.6	76.8	1.65	27.8
H6	10	45.3	79.1	1.66	28.4
H7	10	42.4	82	1.67	29.5
H8	10	40	78.4	1.67	27.6
H9	10	44.1	79.1	1.7	27.1
H10	10	48.7	83.7	1.65	29.4

Table 2. Scanners specifications, exposure settings and average dose indicators of all investigated hospitals.

Hospital	Scanner model	mAs	Scan time (s)	$CTDI_{vol}$ (mGy) per 100 mAs	$CTDI_w$ (mGy) per 100 mAs	Pitch	DLP (mGy cm)
(H1)	Philips Brilliance iCT BIG Bore, 128 slices	200	7	6.5	6.76	1.04	425
(H2)	Philips Brilliance iCT BIG Bore, 128 slices	250	10	6	6	1	460
(H3)	Philips Brilliance iCT BIG Bore, 128 slices	200	6	10	10	1	700
(H4)	Philips Brilliance MX 16 slices	200	20	6	5	0.9	750
(H5)	Siemens SOMATOM AS$^+$ 128 slices	182	3	4	4.8	1.2	177
(H6)	Philips Brilliance 64 channel with Essence technology	300	9	8	8	1	700
(H7)	Siemens SOMATOM Emotion 16 slices	250	12	5	4.5	0.9	700
(H8)	Philips Brilliance 16 slices	230	10	8	7	0.9	500
(H9)	Philips Brilliance iCT BIG Bore, 128 slices	250	5	6	6	1	400
(H10)	Philips Brilliance 16 slices	300	14	7	6	0.9	500

$CTDI_w = CTDI_{Vol} \times$ pitch; DLP = $CTDI_{vol} \times$ scan length.

is similar for the stomach and the liver, for the colon however the tendency is different to some extent. This may be attributed to the geometry of this organ in the abdomen. We have conducted statistical analysis of the relationship between patient weight and organ dose and it was found that, the non-linear regression better describes this relationship than linear regression as shown in Figure 1.

The value of effective dose varies from patient to patient ranging from 2 to 10 mSv. Mean effective dose per hospital ranges from 2 to 7 mSv with an average for the entire patient population of ~5.5 mSv. The maximum effective dose for any patient of 10 mSv was found for a 46 years old female patient from hospital H7 with a BMI of 26.6 kg/m^2, weight 77 kg. The higher effective dose was found for a female patient probably because the female genital radiosensitive organs are included within the scanning range nevertheless the highest organ doses was found for a male patient (his effective dose is 9 mSv). As in the case of organ doses, effective doses are also widely distributed between different hospitals with H5 having the lowest mean value and H10 the highest mean value of effective dose. For the same abdomen protocol, hospital H5 which has 128 slices Somatom scanner applying a 182 mAs and 3 s scanning time, while the scanner used in H10 is Philips Brilliance 16 slices applying 300 mAs and 14 s scanning time for abdominal CT protocol. Hospital H5 utilizes a scanner that has a very short exposure time. Siemens Somatom AS$^+$ 128-slice CT scanner uses Straton X-ray tube (Siemens Medical Solutions, Erlangen, Germany) that creates two focal spots on the anode in the *z*-direction to generate two distinct X-ray projections simultaneously[19]. This dual *z*-sampling enables two beams to pass through the patient at two different angles. Therefore, it enables acquiring twice the data with a substantial decrease in the scan time. Short scanning time of 3 s applied in this hospital is the reason why the resultant organ and effective doses are lower than those found in other hospitals.

Effective dose is also a function of patient body parameters. Figure 2 shows positive linear relationship between BMI and mean effective dose per hospital. Statistical analysis of this relationship was performed using IBM SPSS (version 22.0) to test its

Table 3. Mean effective doses and organ doses per hospital.

Hospital	Mean effective dose (mSv)	Mean organ dose (mGy)		
		Liver	Stomach	Colon
(H1)	3.5	11	7	12
(H2)	5.5	17	10	19
(H3)	4	16	8	15
(H4)	5	11	6	12
(H5)	2	4	3	5
(H6)	4.5	17	9	17
(H7)	5	16	9	15
(H8)	3	11	5	11
(H9)	3.5	9	5	11
(H10)	7	19	14	15

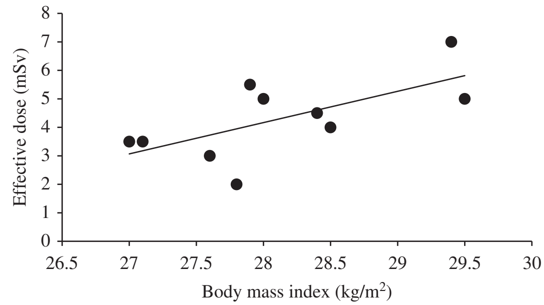

Figure 2. The relationship between effective dose and body mass index.

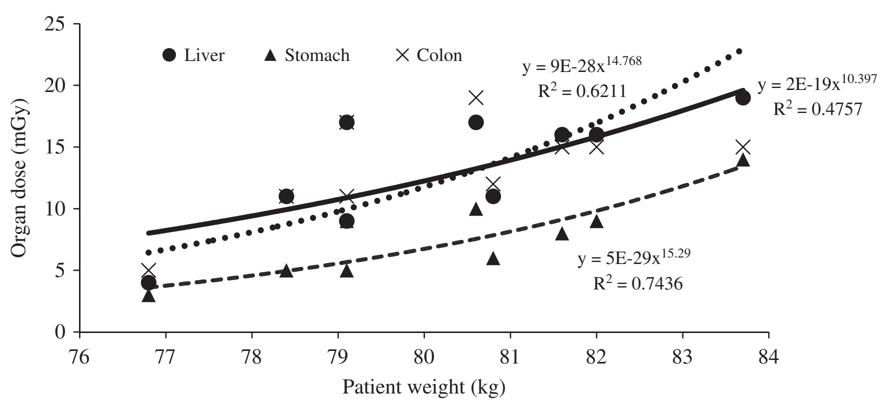

Figure 1. Organ dose as a function of patient's weight for liver, stomach and colon.

Table 4. Comparison of mean effective and organ doses estimated in this study with the values reported in different countries[21–31].

Country or study	This study	UK	Germany	Netherlands	Japan	Italy[a]	EU[b]	USA	Tanzania	Malaysia
Liver dose (mGy)	13.1	20.4	15	35	27.8	20.5	—	—	34.1	13.1
Stomach dose (mGy)	7.6	22.2	15.4	38.5	26.9	21.6	—	—	35.6	14.5
Colon dose (mGy)	13.2	—	—	—	—	0.7	—	—	—	12.9
Effective dose (mSv)	5.5	5.6	12.2	8	5.7	6.2	11.3	10	—	6.9

[a]Effective doses and organ doses are reported for a single routine upper abdomen CT.
[b]Minimum effective dose for EU population is 2.6 mSv, maximum is 28.7 mSv.

statistical significance. The least square simple linear regression for effective dose on BMI is as follows[20]:

$$\text{Effective dose} = -26.6 + 1.1 * \text{BMI}$$

Since the P-value for testing the significance of the slope is 0.038, we conclude that the relationship between effective dose and BMI is significant. Furthermore, according to the value of R^2, which is 0.43, we can say, that 43% of the variation in effective dose can be explained by BMI.

To understand the figures regarding effective dose received from any source of radiation, its practical to compare this dose with natural background. The mean effective dose received from abdominal CT examination per patient found in this study is ~5.5 mSv. A comparison also is made between results of radiation doses obtained in this work and those published in literature for other countries. Results are summarized in Table 4.

Effective dose obtained from this study is comparable with that reported for the UK, Japan, Italy and Malaysia. Its value is very close to that reported for the UK. Organ doses however are distributed widely for different countries; from colon dose 0.7 mSv reported for Italy up to 13.2 reported in this study. Colon dose estimated in this study is very close to that reported from Malaysia. All doses reported from different countries for the stomach are higher than that estimated in our study. Liver dose estimated here is the same as that reported from Malaysia, close to that of Germany and lower from all others. As stated before, important differences remain also between hospitals investigated in this study, which is again attributed to the differences between the scanners used and other technical parameters applied for the same protocol.

CONCLUSION

This work is a small-scale study on the radiation doses received by patients from one of the frequent CT protocols, abdominal CT examination. The results on medical exposure from CT scans provided by this study are comparable or mostly less than that reported from other countries with higher levels of health care. However, we still have much to do to have a complete picture on the radiation doses in medical exposure in our country towards optimizing radiation protection in medical exposure and keeping the doses to patients as low as reasonably achievable.

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