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Patient-Specific Radiation Dose and Cancer Risk in Computed Tomography Examinations in Ondo, Nigeria

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ABSTRACT

Introduction: The dose in computed tomography (CT) often approach or exceed the optimum levels, thereby increasing the probability of cancer induction. With wide application of this diagnostic test, it is expedient to determine the effective dose (ED) for each patient to estimate their cancer risk. This study was conducted to investigate the patient-specific dose (PSD) and cancer risk in CT examinations in Ondo, Nigeria.

Material and Methods: The study was conducted on 160 patients undergoing eight most common types of CT examinations performed at the center, from December 5, 2015 to February 28, 2016. Body mass index (BMI) was calculated for each patient using demographic data, PSD was determined and estimation of the lifetime attributable risk (LAR) of cancer was accomplished using the Biologic Effects of Ionizing Radiation VII (2006) report phase 2 models.

Results: From the results, radiation doses varied significantly within and between the types of CT examinations. The mean ED was 5.88±3.75 mSv in a range of 0.78-19.00 mSv. The mean PSD was 0.274±0.229 mSv/kgm^{-2} in a range of 0.024-1.555 mSv/kgm^{-2} and the mean LAR of cancer incidence was 0.04861±0.03996 Sv^{-1} in a range of 0.00004-0.21942 Sv^{-1}.

Conclusion: ED and PSD varied within and across the CT examinations. In this regard, the coefficients of variation of ED for abdominal, cranial, craniocervical, abdomen/pelvis, thoracic, thoracoabdominal, cervical spine, and pelvis were 5.7%, 6.6%, 3.9%, 8.9%, 3.7%, 6.0%, 44.7%, and 19.2%, respectively. Accordingly, the coefficients of variation of PSD were 9.0%, 7.9%, 7.0%, 10.1%, 5.6%, 23.8%, 47.7%, and 14.2%.

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Introduction

The common trend is that high radiation doses involve in computed tomography (CT) would lead to a reduction of patient per examination, otherwise is the case. This issue highlights the importance of managing patient dose. For example, a chest CT scan typically delivers radiation dose 100 times more than a routine frontal and lateral chest radiograph [1, 2]. Therefore, greater use of CT has resulted in a concurrent increase in the medical exposure to ionizing radiation [3].

Regarding this, a number of considerations should be taken into account to contribute to the optimization of radiation protection. These considerations include ensuring the appropriate justification of examinations, use of right technical parameters, proper quality control, and application of diagnostic reference levels of radiation dose [4].

The dose in CT scans usually approaches or exceeds the known dose, thereby increasing the probability of cancer development. The development of cancer has been associated with the use of low-level ionizing radiation in medical imaging [5]. The National Research Council of the National Academy of Sciences has comprehensively reviewed the biological and epidemiological data related to health risks from exposure to ionizing radiation and published them under the title of the Biological Effects of Ionizing Radiation (BEIR) VII Phase 2 report [5].

The long-term survivors of Hiroshima and Nagasaki atomic bombs that received the exposure of 10-100 mSv had an increased risk of cancer [6, 7]. This dose is equivalent to the dose received in a single CT scan; moreover, the patients may undergo multiple CT scans over time [8]. The use of CT and the amount of radiation dose is of great concern to the medical imaging community, regulatory bodies, and general public [4, 9]. The determination of radiation dose is necessary so as to balance the potential for the harm and the benefit it offers. Both physicians and patients should aware of the risks [10, 11].

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It is required to take specific exposure management measures because the radiation doses from the commonly performed diagnostic CT examinations are higher and more variable than generally quoted. Therefore, it is essential to perform standardization within and across institutions [9]. The patients should have their specific dose depending on their age, weight, and height [12].

With this background in mind, the present study was conducted to estimate the extent of the association of radiation exposure with the types of CT examinations performed most commonly in the Trauma and Surgical Centre Ondo, Nigeria. This study was also targeted toward the examination of the relationship between patient size and radiation doses, variation within and across study types, and the cancer risk associated with these examinations.

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Materials and Methods

The CT was accomplished using the Optima CT660 manufactured by General Electrical Healthcare popularly known as “GE Healthcare” (UK). This system is composed of a gantry, patient table, operator console, computer, power distribution unit, and interconnecting cables. The system includes image acquisition hardware, image reconstruction software, associated accessories, and connections/interfaces to accessories.

The data were collected at the Trauma and Surgical Centre Ondo, Nigeria. This center is located within the Medical Village in Ondo town about 4 km from the city of Ondo and 116 km from Benin. This center was selected for reviewing the existing protocols of CT examination because it is a new center and commenced delivering clinical and surgical services a few years ago.

Selection of Patients for the Study

This study was conducted on 160 patients undergoing different diagnostic CT examinations from December 5, 2015 to February 28, 2016. Both males and females from all age groups ware included in the study. The patients’ demographic data, such as age, gender, weight, and height were collected. In addition, the data related to the technique factors, such as scan length, tube voltage (kV), tube current (mA), rotation time, spiral pitch, and collimation from the control console of the CT machine, were recorded while the patients were on the couch undergoing their examinations.

Estimation of Effective Dose

Effective doses for the patients undergoing CT examinations were estimated using the ImPACT CT Patient Dosimetry Calculator (version 1.0.4) developed in St. George’s Hospital, London UK. This version is capable of computing effective dose using either International Commission on Radiological Protection (ICRP) 60 or ICRP 103 weighting factors. For this study, ICRP 103 weighting factors were employed. The ImPACT spreadsheet uses the dose data sets contained in the National Radiological Protection Board’s (NRPB) SR250 report [11]. To provide the organ and effective doses for the mathematical phantom, computations were performed for each of the 23 available dosimetry data sets provided in the dosimetry calculator.

Determination of Body Mass Index and Patient-Specific Dose

Body mass index (BMI) is used to identify weight problems. This index is a measure of weight adjusted for height, calculated as weight in kilogram divided by the square of height in meter $(kg\ m^{-2})$. The BMI is used in lieu of body size since the measurement is relatively simple, inexpensive, noninvasive, and quick [12]. In the current study, the BMI was calculated using *Equation 1*.

$$BMI(kg\ m^{-2}) = \frac{weight\ (kg)}{Height^2\ (m^2)} \qquad (1)$$

Patient-specific dose (PSD) is the ratio of patient effective dose to patient’s BMI. This variable is calculated so as to normalize effective dose based the body size. The PSD was determined for each patient using *Equation 2*.

$$PSD\ \left(\frac{mSv}{kg\ m^{-2}}\right) = \frac{Effective\ Dose\ (mSv)}{BMI\ (kg\ m^{-2})} \qquad (2)$$

The effective doses are weighted by BMI to normalize the effect of the non-uniform distribution of the BMI of the patients undergoing different CT examinations.

Estimating cancer risk

The lifetime attributable risk (LAR) of cancer incidence was estimated for each age and gender, from a 0.1 Gy equivalent dose using Table 12D-1 of the BEIR VII report [5]. In case the data were not available for a specific age, linear interpolation was performed based on the two nearest tabulated ages. The general expression for calculating the LAR of cancer incidence for all cancer types with respect to patient effective dose (mSv) is given mathematically in *Equation 3* [13], as follows:

$$LAR_{at\ an\ age} = \frac{ED(mSv)}{D} \times \frac{LAR\ (cancer\ incidence)_{at\ the\ age}}{100{,}000} \times 100\% \qquad (3)$$

Where, *D* is equal to 0.1 Gy.

The reference dose to the population considered in the BEIR VII report was utilized.

Results

Figure 1 depicts the various CT examinations performed according to the patients’ age distribution. The age groups with the highest and lowest frequency of CT examination were 56-65 (19.375%) and 86-94 years (0.625%), respectively, within the study period.

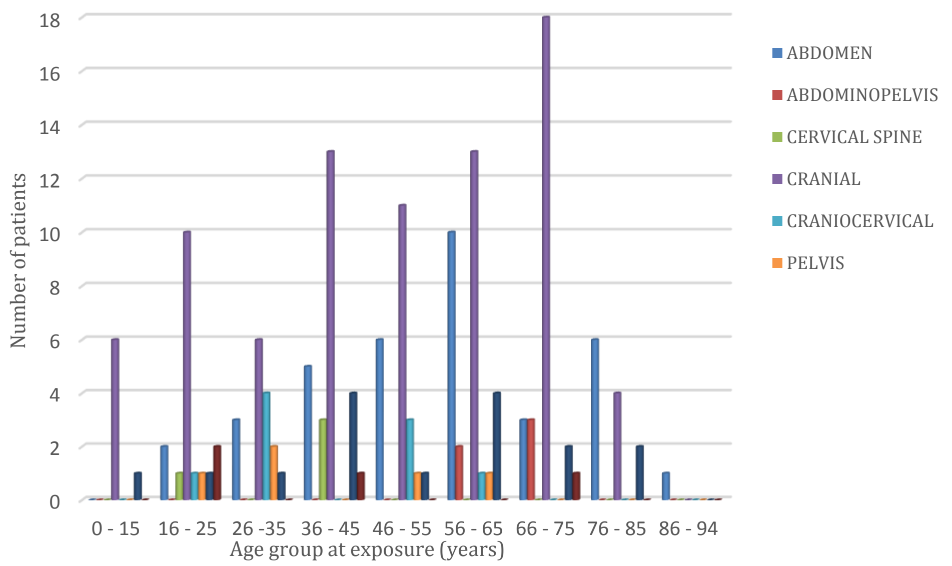

Figure 1. Types of computed tomography examination based on age group distribution

Table 1. Distribution of body mass index, effective dose, and patient-specific dose for the different types of computed tomography examination

Types of computed tomography examination	Description	Body mass index (kgm^{-2})	Effective dose (mSv)	Patient-specific dose (mSv/kgm^{-2})
Abdomen	Mean±SD	22.28±0.79	9.69±0.55	0.468±0.042
	Range	10.80-31.20	2.90-19.00	0.118-1.481
Cranial	Mean±SD	24.29±0.64	3.48±0.23	0.149±0.011
	Range	13.38-42.60	0.78-14.00	0.024-0.623
Craniocervical	Mean±SD	25.15±1.26	7.43±0.29	0.302±0.022
	Range	20.81-33.65	6.50-8.80	0.220-0.420
Abdominal pelvis	Mean±SD	26.17±3.01	10.00±0.89	0.394±0.040
	Range	20.50-36.99	7.40-13.00	0.271-0.488
Thoracic	Mean±SD	21.32±1.10	6.24±0.23	0.304±0.017
	Range	15.15-31.60	4.80-7.80	0.171-0.429
Thoracoabdominal	Mean±SD	16.99±2.47	14.25±0.85	0.927±0.0.211
	Range	9.64-20.48	12.00-16.00	0.64-1.56
Cervical spine	Mean±SD	22.19±2.08	4.85±2.14	0.243±0.116
	Range	17.92-25.95	1.90-11.00	0.074-0.156
Pelvis	Mean±SD	20.75±1.21	3.30±0.63	0.155±0.022
	Range	18.37-25.59	1.40-5.70	0.076-0.223

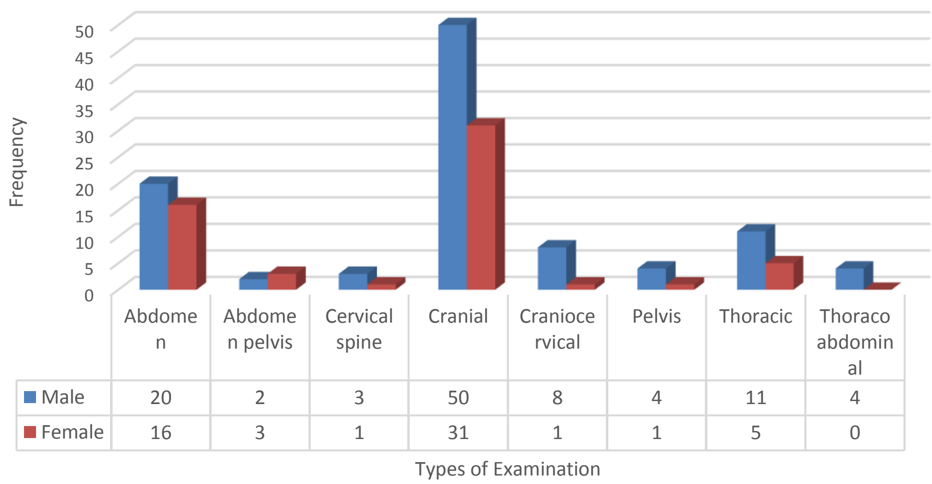

Figure 2. Types of computed tomography examination based on gender distribution

The cranial CT examinations were the most frequent tests (50.625%). On the other hand, the cervical spine and thoracoabdominal CT scans were the least frequent examinations (2.500% each). Figure 2 illustrates the types of CT examination based on gender distribution.

Variation in patient-specific dose between study types

It was found that the mean PSD varied widely between and within the study types (Table 1). The mean PSD tended to be higher in the thoracoabdominal CT examination (0.927±0.211 mSv/kgm^{-2}) in a range of 0.64-1.56 mSv/kgm^{-2}, compared to those in other examinations. The widest range in PSD (0.118-1.481 mSv/kgm^{-2}) was recorded for the abdominal CT examination. The mean PSD differed for all types of examinations. Accordingly, there was a variation in PSD within and between the CT examination types since there was no consistent pattern in patient-specific radiation dose within and between the types of examinations.

Estimation of cancer risk

The LAR of cancer incidence for all cancer types widely varied depending on gender, age, and CT examination type. For females, the highest LAR of cancer incidence was observed in a single patient who underwent cervical spine examination with a value of 1.5550% (1 in 64), followed by that of cranial examination with a mean value of 0.4680% (1 in 214) in a range of 0.0614-1.8166% and a single patient undergoing abdomen/pelvis examination with a LAR cancer incidence of 0.1648% (1 in 607).

Regarding the males, the highest mean LAR of cancer incidence was obtained for thoracoabdominal examination with a value of 0.7456% (1 in 134) in a range of 0.1473-1.3271%. On the other hand, the lowest mean LAR of cancer incidence was observed for cranial examination with a mean value of 0.230% in a range of 0.0414-1.0852%.

Discussion

The age group of 56-65 years had the highest frequency of CT examination (19.375%). This could be attributed to the fact that the center under investigation was a trauma center mostly having patients who are victims of automobile accidents. The age group of 56-65 are agile and are engaged in many activities that make them susceptible to accidents. People aged above 65 years are considered to be weak and health-wise and hardly survive fatal accidents. Because many of them might have ailments, such as hypertension, diabetes, and heart-related problems. Therefore, a few number that survive visit the center.

In the current study, only seven patients were within the age group of 0-15 years (pediatrics). This may be due to the advice of the radiologists and medical physicists recommending other diagnostic examination procedures for pediatrics, since the best available risk estimates suggest that pediatric CT will result in significantly increased lifetime radiation risk, compared to the adult CT [14].

In the present study, the cranial CT examinations were the most frequent tests (22.50%), while the cervical spine (2.50%) and thoracoabdominal CT (2.50%) examinations were the least frequent ones. This may be related to the fact that ultrasound imaging cannot be used to image the head, and that conventional X-ray cannot give cross-sectional images. Furthermore, the CT scan of the head is very important for the management of cerebrovascular accidents, meningitis, and road traffic accidents [13].

Based on the results, 48.13%, 17.50%, 24.38%, and 9.99% of the patients were normal, underweight, overweight, and obese, respectively, based on the standard weight status categories associated with BMI [15]. The pattern was attributed to the distribution of patients that visited the center during the study period.

We noted variations in effective dose even within study types. Some of these variations may be clinically indicated to accommodate the patients of different size or the specifics of the clinical question that was addressed [9]. Ideally, each patient should have his/her specific dose depending on the age, weight, and height [12]. In the current study, each patient had a different patient-specific radiation dose, even for the same type of examination or age.

In this regard, some patients had the same BMI; however, their effective doses differed. On the other hand, some patients had the same effective doses irrespective of their BMI. This shows that the radiographers and the radiologist did not consider the BMI of patients before the selection of the technique factors on the control console of the CT machine.

The goal of using height and weight (i.e., BMI) as predictors was to obtain a minimally confounded estimate of the effect of patient dimensions on effective dose in CT protocols [16]. The defect of this approach is that the diagnostic information is compromised due to the use of lower dose with respect to patient size and that a sharp image would be acquired at a higher dose that is not necessary, thereby exposing the patients to radiation risk.

The LAR of cancer incidence was estimated in percentage. The known fact is that for the same type of examination, cancer risk depends on effective dose, age, and gender [5]. As indicated in tables 2 and 3, the estimated LARs of cancer incidence were considerably higher in females than in males, except in pelvis and thoracic examinations. In this respect, the females and males had the LARs of cancer incidence of 0.1648% (1 in 607) and 0.5466% (1 in 183) for pelvis examination, and 0.3952% (1 in 253) and 0.4205% (1 in 238) for thoracic examination, respectively.

Inconsistent with the normal trend, our results demonstrated that the risk was higher in females than in males (Table 4).

Table 2. Mean effective dose and estimated lifetime attributable risk of cancer incidence for male patients

Types of Examination	Frequency	Description	Effective dose (mSv)	LAR of cancer incidence (%)
Abdomen	20	Mean±SD	9.95±0.88	0.4400±0.25
		Range	2.90-19.00	0.0505-0.9285
Abdomen pelvis	2	Mean±SD	9.90±0.10	0.2892±0.02
		Range	9.80-10.00	0.2754-0.3030
Cervical spine	3	Mean±SD	2.80±0.85	0.3356±0.14
		Range	1.90-4.50	0.1990-0.4709
Cranial	50	Mean±SD	3.48±0.31	0.2300±0.20
		Range	0.92-14.00	0.0414-1.0852
Craniocervical	8	Mean±SD	6.50±0.27	0.4431±0.21
		Range	6.50-8.40	0.1525-0.7379
Pelvis	4	Mean±SD	3.40±0.88	0.5466±0.45
		Range	1.40-5.70	0.0650-1.1163
Thoracic	11	Mean±SD	6.42±0.28	0.4205±0.33
		Range	5.10-7.80	0.1027-1.1907
Thoracoabdominal	4	Mean±SD	14.25±0.85	0.7456±0.48
		Range	12.00-16.00	0.1473-1.3271

LAR: lifetime attributable risk

Table 3. Mean effective dose and estimated lifetime attributable risk of cancer incidence for female patients

Types of examination	Frequency	Description	Effective dose (mSv)	LAR of cancer incidence (%)
Abdomen	16	Mean±SD	9.36±0.57	0.4655±0.27
		Range	5.30-14.00	0.0471-0.9810
Abdomen pelvis	3	Mean±SD	10.07±1.62	0.4376±0.18
		Range	7.40-13.00	0.2250-0.5505
Cervical spine	1	Mean±SD	11.00	1.5550
		Range	-	-
Cranial	31	Mean±SD	3.49±0.33	0.4680±0.42
		Range	0.78-8.40	0.0614-1.8166
Craniocervical	1	Mean±SD	8.80	0.5428
		Range		-
Pelvis	1	Mean±SD	2.90	0.1648
		Range	-	-
Thoracic	5	Mean±SD	5.86±0.41	0.3952±0.33
		Range	4.80-7.00	0.1332-0.9506
Thoracoabdominal	-	Mean±SD	-	-
		Range	-	-

Table 4. Mean effective dose and lifetime attributable risk for male and female patients

	Frequency	Description	Effective dose (mSv)	LAR incidence of cancer (%)
Male	102	Mean±SD	5.18±3.91	0.3454±0.28
		Range	0.72-19.00	0.0401-1.3271
Female	58	Mean±SD	6.49±4.92	0.4743±0.38
		Range	0.78-31.00	0.0471-1.8166

Table 5. Mean age, effective dose, and lifetime attributable risk for all patients

Description	Effective dose (mSv)	Age (year)	LAR cancer incidence (%)
Mean±SD	6.06±4.30	49.17±19.80	0.3921±0.32
Range	0.72-31.00	2-94	0.0401-1.8166

In this respect, the females had a mean cancer incidence LAR of 0.3454% (1 in 290) in a range of 0.0401-1.3271% (1 in 2494 to 1 in 75). On the other hand, the mean of this variable in the males was obtained as 0.4743% (1 in 211) in a range of 0.0471-1.8166 % (1 in 2123 to 1 in 55). Regarding all patients, the mean LAR of cancer incidence was estimated as 0.3921% (1 in 255) in a range of 0.0401-1.8166 (1 in 2494 to 1 in 55).

This study showed that CT scan was associated with a non-negligible LAR of cancer incidence. Since risk is a function of effective dose in a proportionate order, an attempt to reduce effective dose received by patient will mitigate the risk. Consequently, it is necessary to make doses delivered to patients as low as reasonably achievable so as to reduce the risk without compromising the image quality.

Conclusion

As the findings of the present study revealed, the dose (effective dose) indicated variations within and across the investigated CT examinations. Even after the normalization of effective dose with BMI, a considerable variation was observed with the abdominal and pelvis examinations as the tests with the highest (22.5%) and lowest (5.6 %) coefficients of variation. Based on the findings, it is necessary to perform monitoring actions so as to reduce the patients' dose in the center. This can be achieved by organizing conferences and workshops for radiographers, setting guidelines for different exposures, and establishing diagnostic reference levels with which centers can compare their doses.

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