Original

Patient's Radiation Risk in Perspective: Insight from Brain Computed Tomography Scan Examination using a 64 Slice CT Machine

[1]Robinson ED, [2]Ononugbo CP, [3]Oliver GL

[1]*Department of Radiology, Rivers State University Teaching Hospital, Nigeria*
[2]*Department of Physics, University of Port Harcourt, Port Harcourt, Nigeria*
[3]*Department of Physics, Faculty of Natural and Applied Sciences, Ignatius Ajuru University of Education, Port Harcourt. Nigeria*

Corresponding author: Ebbi Donald Robinson, *Department of Radiology, Rivers State University Teaching Hospital, Nigeria; ebbi.robinson@ust.edu.ng; +2348037099667*

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Abstract
Background: Computed Tomography (CT) uses Ionizing radiation which can cause damage. The study evaluated patient's radiation risk with an insight to brain CT scan using 64 slice CT machine.
Method: The study was an empirical study conducted at the Rivers State University Teaching Hospital with patients referred for brain CT scan using a 64 Slice GE Optima Helical CT system, from June 2022 to December 2022. Participants were counseled, informed consent and ethical approval obtained before the study. The examination was performed in accordance with standard protocols for brain CT scan. Radiation dose was measured with a coded themoluminiscent dosimeter chip. The effective doses were estimated by multiplying the absorbed dose by the weighting factor. The cancer and hereditary risk per procedure were estimated by multiplying the effective dose with the cancer and hereditary risk factor coefficients of $5.5x10^{-2}$ Sv^{-1} and $0.2X10^{-2}$ Sv^{-1} respectively. Statistical Package for the Social Sciences (SPSS) windows version 22.30 statistical software (SPSS Inc, Chicago, Illinois, USA) was used to analyse the data and the results presented in tables, charts and graphs.
Result: Males undertake CT brain in younger age; however, the absorbed radiation dose with its consequent effective dose was higher in females and low radiation dose could inadvertently necessitate cancer.
Conclusion: The prevalence of obesity was found to be high. Therefore, there is a need for proper health education and promotion to reduce it and its possible attending consequences.

Keywords: Computed Tomography, radiation risk, themoluminiscent dosimeter, absorbed radiation dose, effective dose, Cancer risk, hereditary risk, Cancer risk coefficients.

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Introduction

Computed tomography (CT) is a medical imaging device used in hospitals to demonstrate the internal structures of the body in a pictorial format with the aim of establishing evidence of any damage or disease conditions within the body.[1-5] The exposure to ionizing radiation following diagnostic CT investigations has been documented to have some stochastic ionizing radiation effect.[1-3]

CT scan of the brain has greatly changed the landscape of neuro-radiological diagnostic yield in the past 50 years, from the time of invention to the first time it was used to evaluate a suspected brain tumour.[6-9] Notwithstanding the benefits, the risk associated with the use of this ionizing radiation based modality is now a thing of concern.[10] Thus, the 2016 United Nations environment Annual Report,[11] has stated that the medical use of ionizing radiation is one the greatest sources of ionizing radiation exposure to among humans, increasing the population radiation burden.[11-12] Research has shown prevailing evidence that support the fact that there is an increased malignancy risk in humans because of exposure to ionizing radiation.[13] Due to the harmful concerns associated with the use of ionizing radiation it was classified as a Group 1 Carcinogen ("carcinogenic to humans").[2,14]

Although there is no documented clinical trials regarding the risk of cancer from medical radiation exposure in adults, the long term effect from 'survivors of the 1945 Hiroshima and Nagasaki atomic bomb blasts showed an associated risk of exposure to ionizing radiation'.[15,16] Thus, it has been identified as a cancer risk factor,[17] and due to its potential to induce cancer, it has been classified as a universal carcinogen of concern.[2,17,18,19]

Diagnostic Ionizing radiation use is supposed to be justified, optimized with a dose limit that is as low as possible to achieve the desired result. Unfortunately, the knowledge of physician concerning the risk of ionizing radiation is relatively low.[20,21] Thus, the study is aimed at evaluating 'Patient's radiation risk with an insight to brain CT scan examination using a 64 slice CT machine'. The study will further address pertinent concerns centered on patient's safety by suggesting radiation exposure reference levels, thereby contributing to the advancements in the field of medical imaging by promoting responsible and evidence-based healthcare decisions without compromising diagnostic precision.

Method

A 64 Slice GE Optima Helical CT system, manufactured in USA in 2012 with recent calibration was the machine used. The age, height and weight of the patients were obtained and documented prior to the investigation. The examination was done with the patient well positioned in accordance with standard protocols for brain CT scan. Radiation dose to the brain was measured with a coded themoluminiscent dosimeter (TLD) chips (TLD LiF-100) which has been previously annealed to wipe out previous data. The TLD chip was placed on the glabella been the centering point and held in position with a transparent (radiolucent) adhesive tape before the exposures.

The sample population was ninety – two (92) being the number of brain CT examination performed within 6 months duration in a radiodiagnostic facility in Port Harcourt. To eliminate bias, a randomized sampling method was adopted with a sample size of 25 which was derived from the sample population.

After the completion of the examination, the TLD was immediately removed and labeled appropriately against the patient's initials and carefully sealed in tiny transparent cellophane bag with the name of the patient abbreviated in letters to maintain confidentiality. The transparent cellophane bag was later inserted into a black bag to prevent spurious exposures from background radiation. The TLD's were then sent for reading at the radiation dosimetric laboratory of the Regional Centre for Energy Research and Training (CERT).

Body mass index (BMI) of participants was obtained from the participant's weight and height. by dividing the weight (kg) by square of the height (m^2).

The effective doses were estimated by multiplying the absorbed dose by the weighting factor. A tissue weighting factor of 0.01 for the brain was used to convert the absorbed dose to effective dose in Sievert (Sv) as recommended by the International Commission on Radiological Protection.[22,23]

$$E = HTw_T \quad (1)$$

The Radiation Cancer risk was estimated following each procedure. The cancer risk (R_{CR}) per procedure was obtained by multiplying the effective dose (E_{eff}) with the risk coefficients (F_{CR}) $F_{CR} = 5.5X10^{-2}\ Sv^{-1}$ obtained from ICRP 103[22, 23] as stated in equation 2 below.

$$R_{CR} = F_{CR}\ x\ E_{eff} \quad (2)$$

Hereditary risk being the radiation risk of genetic effects (R_{GE}) was evaluated by multiplying the mean dose by the risk factor coefficients $F_{GE} = 0.2X10^{-2}\ Sv^{-1}$ obtained from ICRP 103 publication[22,23] as shown in equation 3.

$$R_{GR} = F_{GE}\ x\ E_{eff} \quad (3)$$

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Results

The age distributions of the participants show an age range of 39.00 to 74.00 years with a mean age of 62.80±8.58 years (table 1). The absorbed radiation dose ranges from 116.40 mSv to 253.00 mSv with a mean absorbed radiation dose of 177.04±33.98 mSv as also shown on table 1. The effective dose ranges from 1.16 mSv to 2.53 mSv with a mean effective dose of 1.77±0.348 mSv with an associated estimated maximum cancer risk of 13.92$\times 10^{-5}$ (being approximately 14 persons per 100,000 people) and mean hereditary risk of 3.5408$\times 10^{-6}$ (table 1).

The cancer risk of participant's ranges from 6.38$\times 10^{-5}$ to 13.92$\times 10^{-5}$ with a mean cancer risk of 9.737$\times 10^{-5}$ whereas, the hereditary risk of the participants ranges from 2.32$\times 10^{-6}$ to 5.06$\times 10^{-6}$ (table 1).

According to table 3, the age of the males' ranges from 39.00 to 69.00 years with a mean age of 61.00±9.12 years while the females were aged 50.00 to 74.00 years with a mean age of 64.46±8.05years. BMI of the males' ranges from 20.37 to 33.80 with a mean BMI of 26.02±4.39 while that of the females ranges from 20.37 to 36.70, with mean females BMI of 26.88±5.16 (table 2). The mean absorbed radiation doses were 181.82±38.08 mSv and 171.88±29.69 mSv for females and males respectively. The mean absorbed doses received by females were higher than that of males. These findings may be attributed to the BMI of the participants which has the same gender distribution as that of the absorbed dose.

The scatter plot of patients BMI against age shows a non-patterned distribution of variables which suggests a non-linear relationship between BMI and age. The Linear regression analysis done yielded a linear equation where y is patient BMI and x is age (in years) (Figure 1) as shown in equation 4.

$$y=0.4126X \qquad r2= 0.796 \qquad (4)$$

The scatter plot of patients absorbed radiation dose against age as demonstrated on figure 2 shows a non-patterned distribution of variables which depicts a non-linear relationship between absorbed radiation dose and age. Linear regression analysis done yielded a linear equation where y is patient absorbed radiation dose (in mSv) and x is age (in years) as shown in equation 5 (Figure 2).

$$y=2.7609x \qquad r2 = -0.672 \qquad (5)$$

The relationship between patients' absorbed radiation dose with BMI also demonstrated a non-patterned distribution of variables which is depicts a non-linear relationship absorbed radiation dose and age (figure 3). Linear regression analysis yielded a linear equation where y is patient absorbed radiation dose (in mSv) and x is BMI (Figure 3).

$$y=6.432x \qquad r2=1.334 \qquad (6)$$

The mean effective dose among females was 1.82±0.38 mSv while that among the males was 1.72±0.30 mSv as shown on table 3. The cancer risk for males 9.4592 $\times 10^{-5}$ range from 6.38 $\times 10^{-5}$ to 13.40$\times 10^{-5}$, whereas among the female participants the mean cancer risk was 9.997$\times 10^{-5}$ and ranges from 8.03$\times 10^{-5}$ to 13.90$\times 10^{-5}$ (table 4). The hereditary risk of the male ranges from 2.32$\times 10^{-6}$ to 4.86$\times 10^{-6}$ with a mean risk of 3.4383 $\times 10^{-6}$while that of females was 2.92$\times 10^{-6}$ to 5.06$\times 10^{-6}$ with a mean hereditary risk of 3.6354$\times 10^{-6}$ (table 3).

Table 5 shows correlation between radiation dose with age, BMI, and Cancer Risk as well as hereditary risk of participants which shows an association between absorbed radiation dose and cancer risk. However, a negative association was observed between cancer risk and BMI which was similar to that between hereditary risk and age (table 4).

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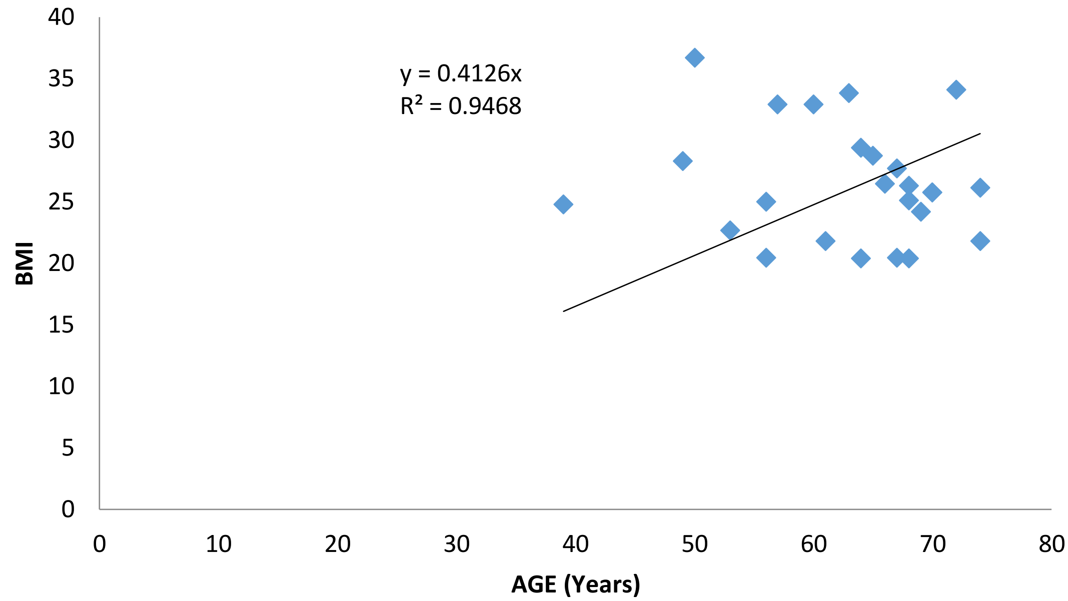

Figure 1: Scatter plot of patients age with BMI

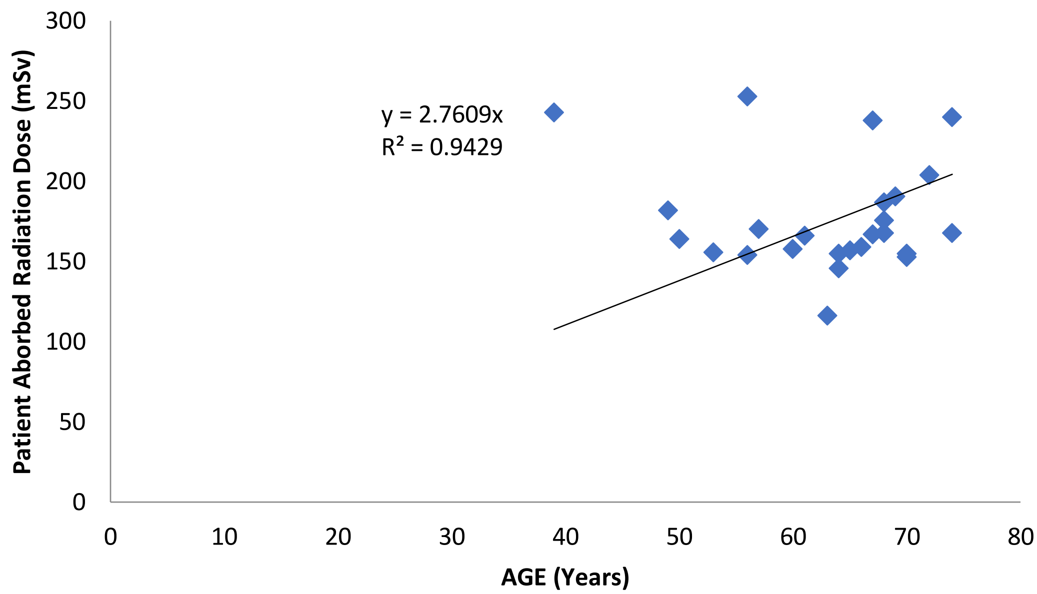

Figure 2: Scatter plot of patients absorbed radiation dose with age

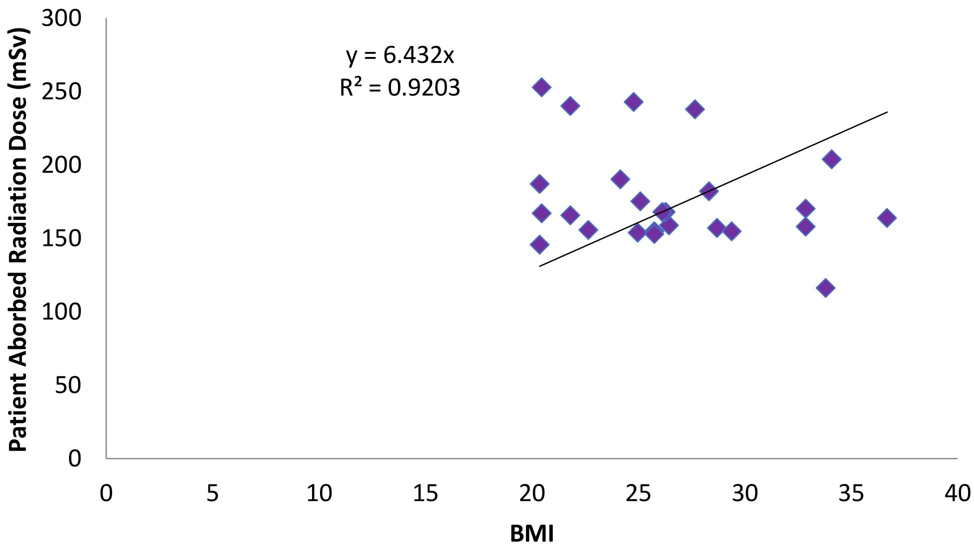

Figure 3: Scatter plot of patients absorbed radiation dose with BMI

Table 1: Radiation dose to the patients with associated estimated risk

S/N	Patients Sample	Age (year)	Patient Radiation Dose (mSv)	Effective Dose (mSv)	C.Risk $\times 10^{-5}$	H. RISK $\times 10^{-6}$
1.	P1	49.00	182.00	1.82	10.10	3.64
2.	P2	50.00	164.00	1.64	9.02	3.28
3.	P3	57.00	170.40	1.70	9.35	3.41
4.	P4	56.00	253.00	2.53	13.92	5.06
5.	P5	74.00	240.20	2.40	13.20	4.81
6.	P6	66.00	159.00	1.59	8.75	3.18
7.	P7	67.00	167.00	1.67	9.19	3.34
8.	P8	68.00	168.00	1.68	9.24	3.36
9.	P9	39.00	243.00	2.43	13.37	4.86
10.	P10	61.00	166.00	1.66	9.13	3.32
11.	P11	63.00	116.40	1.16	6.38	2.32
12.	P12	60.00	158.00	1.58	8.69	3.16
13.	P13	67.00	238.00	2.38	13.09	4.76
14.	P14	64.00	146.00	1.46	8.03	2.92
15.	P15	65.00	157.00	1.57	8.64	3.14
16.	P16	53.00	156.00	1.56	8.58	3.12
17.	P17	64.00	155.00	1.55	8.53	3.10
18.	P18	56.00	154.00	1.54	8.47	3.08
19.	P19	68.00	175.60	1.76	9.68	3.52
20.	P20	68.00	187.00	1.87	10.29	3.74
21.	P21	69.00	190.50	1.91	10.51	3.82

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22.	P22	70.00	155.00	1.55	8.53	3.10
23.	P23	70.00	153.00	1.53	8.42	3.06
24.	P24	72.00	204.00	2.04	11.22	4.08
25.	P25	74.00	168.00	1.68	9.24	3.36

	Cancer Risk	Hereditary Risk
Mean	9.737×10^{-5}	3.5408x10-6
Std. Deviation	1.8704×10^{-5}	0.6801x10-6
Minimum	6.3800×10^{-5}	2.3200x10-6
Maximum	13.9150×10^{-5}	5.0600x10-6

C.Risk: Cancer risk; H. RISk: Hereditary risk

Table 2: Gender distributions of absorbed doses of patients

	MALE			FEMALE		
S/No	Age (year)	BMI (kg/m²)	Radiation Dose (mSv)	Age (year)	BMI (kg/m²)	Radiation Dose (mSv)
1	49	28.31	182.0	67	27.68	238.0
2	67	20.45	167.0	64	20.37	146.0
3	68	26.28	168.0	65	28.71	157.0
4	39	24.78	243.0	53	22.64	156.0
5	61	21.8	166.0	70	25.76	155.0
6	63	33.8	116.4	70	25.76	153.0
7	60	32.87	158.0	72	34.08	204.0
8	64	29.38	155.0	74	26.13	168.0
9	56	24.98	154.0	50	36.7	164.0
10	68	25.1	175.6	57	32.87	170.4
11	68	20.37	187.0	56	20.45	253.0
12	69	24.16	190.5	74	21.8	240.2
13	-	-	-	66	26.44	159.0
	61.00±9.12	26.02±4.39	171.88±29.69	64.46±8.05	26.88±5.16	181.82±38.08

Table 3: Gender distributions of effective doses of patients with associated cancer risk

MALES				FEMALES		
S/No	Effective Dose (mSv)	C.Risk $\times 10^{-5}$	H.Risk $\times 10^{-6}$	Effective dose (mSv)	C.Risk $\times 10^{-5}$	H.Risk $\times 10^{-6}$
1	1.82	10.0	3.64	2.38	13.1	4.76
2	1.67	9.19	3.34	1.46	8.03	2.92
3	1.68	9.24	3.36	1.57	8.64	3.14
4	2.43	13.4	4.86	1.56	8.58	3.12
5	1.66	9.13	3.32	1.55	8.53	3.10
6	1.16	6.38	2.32	1.53	8.42	3.06
7	1.58	8.69	3.16	2.04	11.2	4.08
8	1.55	8.53	3.10	1.68	9.24	3.36
9	1.54	8.47	3.08	1.64	9.02	3.28
10	1.76	9.68	3.52	1.7	9.35	3.40
11	1.87	10.3	3.74	2.53	13.9	5.06
12	1.91	10.5	3.82	2.4	13.2	4.80

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13	-	-	-	1.59	8.75	3.18

C.Risk: Cancer Risk

Table 4: Correlation between radiation dose with age, BMI, and Cancer Risk of participants

		AGE	BMI	Absorbed Dose	Cancer risk	Hereditary risk
AGE	Pearson Correlation	1	-.146	-.125	-.124	-.124
	Sig. (2-tailed)		.485	.552	.555	.555
BMI	Pearson Correlation	-.146	1	-.276	-.277	-.277
	Sig. (2-tailed)	.485		.182	.180	.180
Absorbed Dose	Pearson Correlation	-.125	-.276	1	1.000**	1.000**
	Sig. (2-tailed)	.552	.182		.000	.000
Cancer Risk	Pearson Correlation	-.124	-.277	1.000**	1	-
	Sig. (2-tailed)	.555	.180	.000		-
Hereditary Risk	Pearson Correlation	-.124	-.277	1.000**	-	1
	Sig. (2-tailed)	.555	.180	.000	-	

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Discussion

The age distribution of the participants shows that males undertake brain CT scan at a younger age when compared to females, whereas the females have a slightly higher BMI when compared to males.

The absorbed radiation doses range from 116.40 mSv to 253.00 mSv with a mean patient absorbed radiation dose of 177.04±33.98 mSv. The mean absorbed radiation doses were 181.82±38.08 mSv and 171.88±29.69 mSv for females and males respectively. The mean absorbed doses received by females were higher than that of males. Consequent upon that, the mean effective dose among females were also higher than that observed among the males. These findings may be attributed to the slightly higher BMI of the females compared to males. This finding is in consonance with a study to evaluate 'Patient Body Mass Index and Physician Radiation Dose during Coronary Angiography' by Madder et al.[24] Their study revealed a significant increase in the Dose Area Product and investigating physician absorbed radiation dose with increasing patient BMI. In a study with 550 adult patients (age $\geq$ 15 years) to determine body-mass index-based effective dose determination in commonly performed computed tomography examinations in adults by Deevband et al.[25] demonstrated that higher BMI contributes to an increase in patients absorbed radiation dose. Although their study was not specific for brain CT scan, further studies is recommended to establish the findings.

The increase female dosage observed in the index study was also in consonance with the study by Mkimel et al.[26] Their study 'Assessment of the Radiation Dose during 16 Slices CT Examinations' documented an effective dose of 0.71 mSv and 0.76 mSv for males and females respectively during a head CT scan.[26] Notwithstanding the mean values obtained in the index study were higher than the values obtained in the study by Mkimel et al.[26] The higher female to male values were evident. The male to female discrepancy which could be attributed to BMI needs further evaluation with a higher sample population and multicentre studies to clarity.

The mean effective dose obtained from of the index study was higher that documented by Robinson et al.[27] where a similar 64 slice CT was used. In their study,[27] the effective dose was 0.26±0.16 mSv wherein 60 patients participated in the study. The difference may be due to disparity in the study populations.

The scatter plot of brain absorbed dose against age showed a non-patterned distribution of variable which signifies non-linear relationship between the absorbed dose and age. This opines that there is no relationship between the patients absorbed radiation dose and age. The scatter plot of patients BMI against age, absorbed radiation dose against age, and absorbed radiation dose with BMI showed a non-patterned distribution of variables which suggests a non-linear association

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between the variables. In other to ascertain this observation further study with a larger population of study is required.

The Lifetime Attributable cancer risk was approximately 3 to 10 per 100,000 CT scan procedures. Conversely in a similar study by Semghoul et al,[28] in Morocco documented the participant cancer risk per CT procedure to be 4 to 13 per 100,000 CT scan procedures. The cancer risk from the study[28] was higher than the documented in the index study. The reason for the variance may be due to the radiation exposure factors used, as the higher the radiation dose the higher the cancer risk.[18-21] Secondly, the reason may also be attributed to geography differences, and the availability of diagnostic reference range for that population. Thirdly the sample population may have also contributed to the variation observed as the sample population in the index study was higher than the number of patients that participated in the study.[28]

A study by Tahmasebzadeh et al,[29] to evaluate the Lifetime attributable cancer risk related to prevalent CT scan procedures in pediatric medical imaging centers showed a LAR following a chest CT scan of 68.23 per 100,000 for patients of <1-year-old and abdomen-pelvic CT scans of 57.30 per 100,000 for patients within the age group 10- to 15-years. The values obtained from their study[29] were higher than that obtained from Semghoul et al,[28] Kadowaki et al,[30] and the index study. Although the model and number of CT scanner slices used in their study[29] could not be ascertain, the fact that the study population was only children (pediatric) could have contributed to the variations observed.

Radiation dose and cancer risk in retrospectively and prospectively ECG-gated coronary angiography using 64-slice multidetector CT was evaluated by Huang et al.,[31] documented an absorbed radiation doses of up to 27.7mSv and a lifetime cancer risk incidence of up to 0.37% for 50-year-old subjects for those associated with retrospectively ECG-gated coronary CTA. The difference observed could be because the by Huang et al.,[31] was a multinational study cutting across England, USA and Hong Kong as against a single centre study.

Einstein et al,[32] estimated the Radiation Dose and Cancer Risk during Tomography Coronary Angiography using 16-Slice Computed tomography machine using 50 patients. The study revealed that the lifetime attributable cancer risk was approximately 1 in 1,600 [32] which could be literally approximately to be 62.5 per 100,000 persons, values which were higher than that of the index study.

Another study aimed to estimate organ doses of the uterus and prostate and evaluate the lifetime attributable risk (LAR) of cancer incidence and mortality with 665 patients by Shubayr & Alashban[33] revealed a LAR of cancer from CT scan of the uterus and prostate as 0.36 ± 0.22 and 0.48 ± 0.18 cases per 100,000 persons respectively. The values from this study were far lower than that observed by Semghoul et al,[28] and the index study. Notwithstanding, the available date does not indicate the type of CT scanner used for the study, whereas the population of study by Shubayr & Alashban[33] was ten times that of the index study. Their study[33] also documented that the LAR of prostate and uterus cancer occurrence obtained was due to low radiation doses used during the study. This suggests that the exposure factors used during their study[33] may be lower than that used in the index study resulting to the lower LAR.

The hereditary risk observed in the index study was approximately 4 per million procedures.

This was slightly lower than that documented by Semghoul et al,[28] being 5 per million CT procedures. The variation in both studies may be due to the higher radiation exposure factors, geography differences, availability of diagnostic reference ranges and the sample population.

The correlation between radiation dose with age, BMI, and Cancer Risk as well as hereditary risk of participants showed an association between absorbed radiation dose and cancer risk. This was in consonance with the study by Cao et al.[34] The result from the study[34] showed a positive correlation between ionizing radiation dose from CT and cancer risk with a consequent highlight on the need for the awareness of the potential cancer risk of CT scans. However, contrary to this view, Garg et al,[35] evaluated the lifetime attributable risk (LAR) of cancer from low- and standard-dose chest CT scans which was done on COVID-19 patents and documented that there is no succinct consensus on lifetime attributable risk (LAR) estimates and the cancer risk associated with CT scan.

The correlation between radiation doses to the brain with age, BMI, and Cancer risk of participants showed that there is no correlation between age and cancer risk or BMI. The association cancer risk and BMI showed a weak negative association which was similar to that observed between hereditary risk and age. Conversely the study by de Basea et al,[36] documented that the lifetime attributable cancer risks does not reveal a consistent dependence on age at exposure, which was

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evident in their study[36] with different risk patterns among the exposure age groups. There is need for further studies to ascertain this opinion due to paucity of data.

Implications of the findings of this study
The findings from the study show that the use of ionizing radiation has an associated risk, and this should necessitate improvement in existing regulations and policies concerning the use of radiation in medical diagnosis.

Limitations of the Study
The study was subject to limitations such as long machine down time, high cost of investigation, challenges of power supply and high cost of machine maintenance.

Conclusion

According to the study, males undertake CT brain earlier in age than females however the absorbed radiation dose with its consequent the effective doses was higher among the females compared to that received by males. The study has provided information concerning lifetime cancer risk associated with brain computed tomography to be within 6 and 14 persons per 100,000 procedures.

The study also concludes that, there was a lifetime cancer risk associated with the use of this ionizing radiation-based imaging modality with approximately 10 per 10^5 population undergoing CT scan procedures could develop cancer in their lifetime. Furthermore, the study also concludes that the hereditary risk for the future generations of the sampled patients was found to 4 per 10^6 populations. Therefore, irrespective of how low the radiation exposure could be, it could inadvertently necessitate malignant lesions.

Declarations

Ethical Consideration: Ethical clearance for the study was obtained from the Rivers State University Teaching Hospital Health Research Ethics Committee in a correspondence letter dated 12th April 2022 with reference RSUTH/REC/2022/163.

Authors' Contribution: All the authors participated and were involved in the conceptualization of the study, collation of data, analysis and review of the study as well as the writing, and proof reading of the manuscript.
The manuscript has been read and approved by all the authors and all the authors were involved in the conceptualization, collation of data, analysis and review of the study.

Conflict of interest: There are no financial and non-financial competing interest associated with this study.

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Abbreviations and Symbols

Computed tomography	CT
Lifetime attributable risk	LAR
Sievert	Sv
Themoluminiscent dosimeter	TLD
Centre for Energy Research and Training	CERT
Cancer risk	C.Risk
Hereditary risk	H. RISk
Effective dose	E_{eff}
Body mass index	BMI
International Commission on Radiological Protection	ICRP

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