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Original article

## Eye lens and thyroid gland radiation exposure for patients undergoing brain computed tomography examination

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## ABSTRACT

This study aims to estimate the effective radiation dose and organ dose from head CT procedures. It was conducted in three main private hospitals in Khartoum State-Sudan, using Toshiba machines with 64 slices. The total number of patients included in this study was 142 patients (82 males and 60 females). The effective dose and organ dose were calculated by CT Expo software. The effective dose slightly varied among patients according to gender and age. The effective dose for female patients (5.99 mSv) was higher than that for male patients (5.84 mSv), and the pediatric dose (5.46 mSv) was lower than the adults' dose (5.94 mSv).

The dose for eye lens was found lower for male patients (89.117 mSv) than the dose for female patients (94.62) mSv). According to patients' age: the dose received by the lens of the eye was much lower in pediatric (79.93 mSv) than the adults (92.41 mSv). The dose for thyroid in female patients (33.52 mSv) was higher than the male patients (28 mSv). The pediatric dose (28.34 mSv) was lower than the adults' dose (30.64 mSv).

Departmental imaging protocol and lack of training among hospital staff are expected to be responsible for these variations. Therefore, this study recommends that the CT technologists be trained on suitable strategies to achieve dose optimization. Moreover, patients' doses must be monitored regularly.

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## 1. Introduction

Computed tomography (CT) is the primary source of medical exposure from diagnostic imaging procedures. CT procedures' frequency is 5% of medical exposure and contributes up to 70% of the collective dose from medical investigations (Zontar et al., 2015). CT scans have the benefits of better image resolutions when compared to conventional x-ray procedures. The image resolution (details) in

CT depends on the focal spot size, Source skin distance (SSD), the pixel size, the field of view (FOV), pitch, slice thickness, and the number of the detectors. Nevertheless, patients are exposed to high doses approaching 400 times the doses from conventional x-rays (IAEA, 2001). The potential hazards, such as inducing cancers associated with radiation exposure, necessitate extensive and accurate calculations of doses. The effective dose from CT is the leading radiation source to the public, contributing more than 70% of the radiation dose from diagnostic medical applications (Hart et al., 2010). In repetitive brain CT scans, the eye lens dose may exceed 600 mSv for 14 procedures during patients' management (Roslee et al., 2020; Hinzpeter et al., 2017). Furthermore, during CT angiography procedures, the effective dose per procedure may exceed 100 mSv with 30 time's effective dose variation among the patient's populations (Sulieman et al., 2020). Therefore, rigorous Risk-benefit ratio assessments are vital elements to justify such procedures. More attention is needed when radiosensitive organs lie within the irradiated field. Sensitivity due to gender

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and age are also influential elements to be considered. Head CT is a standard procedure to detect tumors in the head and brain, vascular disorders such as aneurysm, bleeding, stroke, and abnormalities of the paranasal sinuses (Alkhorayef et al., 2019). Thyroid cancer is the leading endocrine cancer with an incidence rate of 14.4 in 100,000 population and increasing by 3.6% per year on average due to exposure to ionizing radiation and other risk factors (Kim et al., 2020). A cataract is the leading cause of vision impairment globally, and ionizing radiation is connected with cortical and posterior subcapsular cataract (cloudiness) (Shiels & Hejtmancik, 2019, Blakely et al., 2010). Eyes and the thyroid gland would receive relatively high doses if the radiation dose were not optimized. Radiation-induced cataractogenesis is a documented harmful effect when the lens is exposed to ionizing radiation. (Thome et al., 2018). Tipnis et al., 2015 estimated patients the mean and standard deviation (SD) of thyroid dose from CT procedure to be  $50 \pm 23$  mGy with young patients  $\leq 20$  years old have high cancer risk up to six times compared to older patients (Tipnis et al., 2015). The establishment of diagnostic reference level (DRL) is a necessary step towards patient dose optimization to guarantee that the patient radiation doses are as low as reasonably achievable (ALARA) consistent with the clinical indication. In Sudan, national DRL has not been adopted yet, but many authors reported local and multi-center DRL values for CT examinations (Suliman et al., 2020; Manssor et al., 2015; Suliman et al., 2015). In addition to that, some patients may receive a high dose of unjustified CT examinations (Kanzaria et al., 2015). Thus, the evaluation of radiation-induced cancer and cataract during head and neck CT examinations is crucial. This study aims to estimate the effective dose and equivalent dose received by the thyroid and lens of the eyes during brain CT scan using CT. Expo Software.

## 2. Material and methods

This study was conducted in three main private hospitals in Khartoum-Sudan: Royal Care International Hospital (RCIH), Alzaytona Specialized Hospital (ZSH), and Alamal National Hospital (ANH). The committee of ethics and research approved the study before the data collection. Data were collected from 142 patients (82 (57.7%) males and 60 (42.3%) females) who underwent head CT examinations using Toshiba Aquilion CT-scanner 64 slices (Toshiba, Japan). The CT protocols were as follows:

In RCIH, the tube potential was 120 kVp, tube current-time product ranged between 150 and 225 mAs, slice thickness ranged from 3 to 5 mm, collimation from 19 to 32 mm, and scan length from 11 to 23 cm. The patients' populations consisted of pediatric (age range: 3.0–13.0 years), and adults age range: 21.0–95.0 years). In ANH, the kVp was 120 kV, mAs was 225 mA, slice thickness ranged from 3 to 5 mm, collimation was 32 mm, and scan length from 14 to 24 cm.

In ZSH, the kVp was 120 kV, mAs was 225 mA, slice thickness was 5 mm, and collimation was 32 mm, and the scan length ranged from 14 to 24 cm. The machines are capable within 13 cm of anatomy in a single rotation with dose saving software (SureExposure). Technologists minimize the scan length to cover the necessary field size using gantry angulation to avoid the orbits. Patient radiation dose is a function of the field of view; thus, careful adjustment of the field size will significantly reduce the dose length product (DLP). Image acquisition protocol is based on departmental protocol and patients' diagnosis requirements.

The data consists of: Patients' information (Gender, Age), dose parameters tube current  $\times$  time (mAs), peak tube potential (kVp),  $CTDI_{vol}$  (mGy), DLP (mGy.cm), collimation, number of slices, slice thickness (mm) and pitch.

### 2.1. CT dose measurements

CT Expo software (v2.5) (Hanover, Germany) was used to calculate common CT dose descriptors including CT dose index ( $CTDI_w$ ) and CT volume dose index ( $CTDI_{vol}$  (mGy), CT dose-length product (DLP (mGy.cm) and effective dose (E (mSv) according to the CT modality (number of detectors) and manufacturer. The effective and the organ doses (mSv) for the lens of eye and thyroid were calculated and assessed in accordance with new recommendations of the international commission for radiological protection ICRP 103 (ICRP, 2007). The software calculations based on mathematical phantom calculations of standard man characteristics (height (1.7 m) and weight (70 kg) for male (ADAM), and (height (1.6 m), and weight (60 kg) for female (EVA) (Zankl et al., 1991). Exposure parameters and CT modality and scanning mode whether helical or axial were used to generate CT effective and organ dose per procedure.

## 3. Results

The current study results concern 142 patients who underwent CT brain procedures at three radiology departments to estimate the effective dose and equivalent dose received by the lens of the eyes and the thyroid gland during brain CT scan using CT Expo Software. Table 1 shows the statistical parameters of the CT brain for all patients per CT procedure. In Table 1, data are presented as mean, median, standard deviation, minimum, maximum, and third quartile for the dose parameters. Comparable tube potential (kVp) ( $119.9 \pm 1.8$ ) was used for all departments. The tube current (mA) and scan length (mm) variation resulted in a wide variation in patient doses in terms of  $CTDI_{vol}$  (mGy) and DLP (mGy.cm). Table 2 presents the dose received by the sensitive organs investigated: the eye lens and thyroid gland are shown as mean  $\pm$  standard deviation (SD). The mean and SD dose of the eye lens and thyroid gland (mSv) were  $91.44 \pm 48.28$  and  $30.47 \pm 36.89$ , respectively. The dose to the eye lens was higher than that of the thyroid gland. This is basically because the eye lens sometimes lies within the primary beam. The wide variation between the minimum and maximum doses of the eye lens and the thyroid gland was up to 40 times. Table 3 shows the organ effective and equivalent doses for the lens of eyes and thyroid according to the gender. The equivalent dose of the eye lens and thyroid gland for both genders suggests the absence of variation according to patients' gender. Table 4 shows the effective and equivalent dose for the eye lens and thyroid gland according to the patients' variation in the effective and organ doses (mSv) per procedure for pediatric and adult patients is less than 10%.

## 4. Discussion

Head CT scanning is usually associated, with high doses of radiation with the effective dose ranged from 1.2 to 8.8 mSv per procedure (Mettler et al., 2020). CT procedures expose critical organs such as the eyes and thyroid gland to relatively high doses as well. Exposing the eyes to ionizing radiation during head CT results in harmful effects on the lens. The most common effect is clouding or opacification of the lens, known as a cataract. Cataract obstructs the passage of light and thus limits vision. Radiation-induced cataractogenesis might appear within a year or two post-exposure if the dose received by the eyes was high. Yuan et al., studied the effect of head CT on the lens and found a significant association between head CT and cataract formation (Yuan et al., 2013). Eye lens Cataracts are a multifactorial disease associated with age, female sex, genetic predisposition, smoking, diabetes mellitus, drug intake, and exposure to ionizing and non-ionizing

**Table 1**  
Statistical parameters of radiation dose for all patients.

Exposure parameter	Mean	Median	SD	Min	3d Quartile	Max
Tube potential (kVp)	120.0	120	0.0	0.0	120	120
Tube current-time product (mAs)	220.62	225	23.65	100	225	300
CTDI <sub>vol</sub> (mGy)	94.16	81.46	70.39	22.4	84.77	264
DLP (mGy.cm)	1675	1546.9	844.12	451.2	1724.74	5652.8
ED (mSv)	5.90	4.77	3.96	1.2	6.02	24.7

**Table 2**  
Organ dose equivalent (mSv) of lens of eyes and thyroid gland for all patients.

Organ dose equivalent (mSv)	Mean	Median	SD	Min	3d Quartile	Max
Eye lens	91.44	84.82	48.28	11	88.91	429.4
Thyroid gland	30.47	14.95	36.89	10	36.7	194.6

**Table 3**  
Organ equivalent and effective doses (mSv) for lens of eyes and thyroid gland according to gender.

Gender	Organ dose equivalent (mSv)	Mean	Median	SD	Min	3d Quartile	Max
Male	Effective dose	5.84	4.48	4.70	1.2	5.38	24.7
	Eye	89.117	84.80	41.13	11	89.50	364.5
	Thyroid gland	28	14	41.53	1	25.96	194
Female	Effective dose	5.99	5.21	2.67	1.9	7.86	15.7
	Eye lens	94.62	85.48	56.83	23.6	88.23	429.4
	Thyroid gland	33.52	22.80	29.45	3	48.57	113.2

**Table 4**  
Effective and equivalent doses (mSv) for lens of eyes and thyroid according to patient's age.

Patient group	Radiation dose (mSv)	Mean	Median	SD	Min	3d Quartile	Max
Adult	Effective dose	5.94	4.83	4.01	1.2	6	24.7
	Eye lens	92.41	84.97	49.08	11	88.95	429.4
	Thyroid gland	30.64	14.95	37.65	1	36.70	194
Pediatric	Effective dose	5.46	4.41	3.36	1.4	7.45	12.5
	Eye lens	79.93	82	37.33	23.4	88.90	165
	Thyroid gland	28.34	14.60	24.51	5.6	48.80	93

radiation. To some extent, cataract induced by ionizing radiation exposure can be differentiated from other sources. Eye lens opacities induced by ionizing radiation exposure, in general, can be detected and posterior subcapsular (PSC). Eye lens cataracts related to the age cataracts are frequently initiated in the lens nucleus, while cataracts in the eye lens cortex are routinely detected in patients with diabetes mellitus (IAEA, 2020).

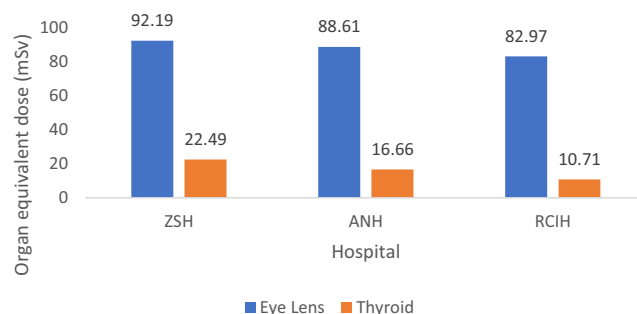
The development of tumors in the thyroid gland post-radiation exposure has been documented. The primary risk factor for radiation-induced thyroid cancer is the dose delivered to the thyroid gland: the risk is higher with a mean dose exceeding 50–100 mSv, and the age at exposure: children being at higher risks than adults. (Iglesias et al., 2017). One-third of radiation-induced thyroid tumors are malignant. Papillary thyroid carcinoma (PTC), which is the most common radiation-induced thyroid gland cancer, was reported more than five years after the exposure (Schneider et al., 1993).

For the age, the median for all patients was 49 years, and the patients' ages ranged between 3 and 95 years. kVp and mA were 120.0 (constant potential) and 220.62 ± 23.65, the CTDI<sub>vol</sub>, DLP, and effective dose 94.16 ± 70.39 mGy, 1765 ± 844.12 mGy.cm, and 5.90 ± 3.96 mSv respectively.

From Table 2, the eyes lens, the equivalent dose was 91.44 ± 48.28 mSv, and the mean dose was 91.41 mSv per procedure. Suzuki (Suzuki et al., 2010) and Alkhorayef (Alkhorayef et al., 2017) reported the eye lens doses ranging from 50.9 –113.3, and mean 41.2 mSv, respectively. Our values are relatively high compared

to theirs, especially the dose per procedure, which requires thorough investigation. The CT radiation dose is highly variable, and there may be a significant difference in the dose levels reported in numerous centers over the world. This variation is anticipated because of the various imaging protocols and the intrinsic differences between models and CT scanner manufacturers (Suliaman et al., 2020; Alkhorayef et al., 2017). Fig. 1 shows the comparison between the equivalent dose to the lens and thyroid in the three hospitals.

The thyroid dose during brain CT was 30.47 ± 36.89 mSv. Tipnis et al. (2015) reported that thyroid doses of 50 ± 23 mSv ranged



**Fig. 1.** Comparison between equivalent dose to the lens and thyroid in the three hospitals.

from 16 to 127 mSv, which is higher than our study, although our dose range for thyroid was wider: 1.0–194.6 mSv.

From Table 3, the effective dose for male patients was  $5.84 \pm 4.70$  mSv, and for female patients,  $5.99 \pm 2.67$  mSv. They compared this with values reported by Woo et al. (2012), where the effective dose for male 9.7 mSv and female 8.4 mSv, our values are much lower for both genders. Yilmaz (Yilmaz et al., 2013) reported that the effective dose ranged between 1.2 and 4.7 mSv, which is lower than our study, ranging from 1.2 to 24.7 mSv. The organ doses for eyes and thyroid according to gender, given as mean  $\pm$  SD were: the equivalent dose for eyes was  $89.12 \pm 41.13$  mSv and  $94.62 \pm 56.83$  mSv for male and female, respectively. And for thyroid,  $28 \pm 41.53$  mSv and  $33.52 \pm 29.45$  mSv for male and female, respectively. According to age, the organ doses received by an adult and pediatric patients were: the effective dose was  $5.94 \pm 4.01$  mSv and  $5.46 \pm 3.36$  mSv for adults and pediatric, respectively. The equivalent dose for eye lens was  $92.41 \pm 49.08$  mSv and  $79.93 \pm 37.33$  mSv for adults and pediatric, respectively. As for the thyroid, the equivalent dose was  $30.64 \pm 37.65$  mSv and  $28.34 \pm 24.51$  mSv for adults and pediatrics, respectively. Poon and Badawy 2019, reported wide eye lens dose variation due to variation in image acquisition technique, which ranged from 2.0 to 130 mGy per CT brain procedure between studies (2–130 mGy), primarily owing to discrepancies in scanning technique. Thus tilting CT gantry with help in dose reduction significantly by avoiding direct exposure of the eye lens. In addition to that, the use of dose reduction techniques such as tube modulation, Bismuth shielding, and tube current optimization is useful in dose reduction up to 30% (Poon and Badawy 2019). For pediatric patients, Ploussi et al., 2018, evaluated eye lens and thyroid dose during pediatric CT brain procedures. The eye lens and thyroid doses per procedure were ranged from 10.5 to 34.2 mGy and 1.7 to 2.4 mGy, in that order (Ploussi et al., 2018). Fig. 2 shows a comparison of eye lens doses with previously published studies (Ploussi et al., 2018; Suzuki et al., 2010; Heaney and Norvill, 2006; Abdeen et al., 2010).

Huda et al., 2013, reported that the mean and range of thyroid gland doses (mGy) during the CT procedure was 55 (29–80) per CT neck procedure. The cancer risk per procedure for young females (aged 20 y) is  $\approx 0.1\%$ , and the risk gradually decreases with age. Patients' size, gender, and thyroid location affect the dose per procedure. Frank et al. reported a lower thyroid dose (18.7 mGy) per CT chest procedure using tube current modulation with dose reduction by a factor of 2 compared to conventional CT technique (Franck et al., 2018). A reduction of the mean patients' thyroid dose up to 62% during CT examination without deterioration in the image quality using radiation shielding was 62 reported by Abuzaid et al., 2017. Thus using dose reduction technique and radiation shielding is recommended to reduce the thyroid dose and the

radiogenic risk without affecting the image quality. These doses, although sometimes less than reported values are yet to be optimized due to the radio-sensitivity of the organs investigated. The main element in the elevated dose reported is the CT personnel. Intensive training and education on adjusting scan parameters based on the nature of the test and required image quality, the time of scanning, is the key towards dose optimization.

## 5. Conclusion

Estimation of effective and organ radiation doses from brain CT procedures was conducted in three main hospitals in Khartoum state-Sudan. The study was performed using Toshiba machines with 6 slices on the total number of 142 patients. The effective dose slightly varied for patients according to gender and age, where female patients' doses were higher than male patients, and pediatrics received much lower doses than adults. The results were comparable to the literature, but dose reduction is still needed. The elevated doses reported in our studies can be attributed to personnel's insufficient training, especially technologists who usually perform such procedures without follow-up from senior staff. Further studies are recommended to investigate the potential for using radioprotective materials to protect superficial radiosensitive organs.

## CRediT authorship contribution statement

**Hiba Omer:** Conceptualization, Data curation, Writing - original draft, Writing - review & editing. **Suhaib Alameen:** Conceptualization, Data curation, Formal analysis, Methodology, Writing - original draft. **Waleed E. Mahmoud:** Conceptualization, Data curation, Formal analysis, Methodology, Writing - original draft. **Abdelmoneim Sulieman:** Formal analysis, Writing - review & editing. **Omaira Nasir:** Methodology, Writing - review & editing. **Fouad Abolaban:** Methodology, Writing - review & editing.

## Declaration of Competing Interest

The researchers acknowledge that the project was fully funded by the authors and that there are no conflicts of interest.

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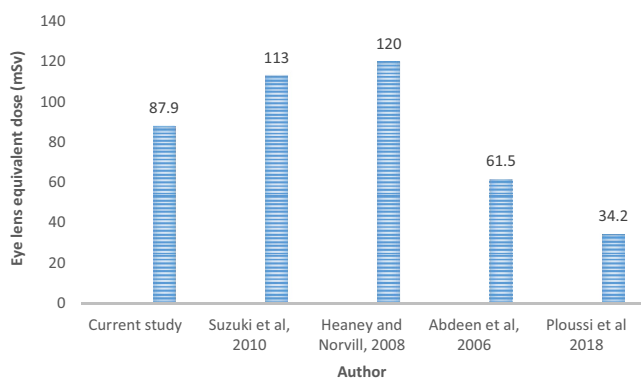


Fig. 2. Eye lens equivalent dose during CT procedures in comparison with previous studies.



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