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Assessment of Radiation Absorbed Dose and Cancer Risk in Head Computed Tomography Examinations

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تقييم الجرعة الممتصة من الإشعاع وخطر الإصابة بالسرطان في فحوصات الأشعة المقطعية على الرأس

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Abstract

Background:

The advanced development of computed tomography, which has become widely used, has increased interest and concerns about the risks of radiation dose to the patient. This research intended to calculate the effective doses received by adult patients undergoing head CT examinations and estimate the risk of developing cancer.

Materials and Methods:

A total of 278 patients of mixed gender, 134 males and 144 females, received head CT. Clinical parameters were obtained from archived CT image files. For this study, the volume computed tomography dose index (CTDIvol), dose length product (DLP), and effective dose (E) were used to express the CT dose. In addition, WAZA-ARI v2 was used to estimate the organ dose values, effective dose, and radiation risks.

Results:

Mean ±SD values CTDIvol were as follows: for head examination for males and females with contrast were 300.2±81.54 mGy and 165.33±46.38 mGy respectively, and non-contrast were 102.24± 33.18 mGy and 97.63 ± 26.78mGy respectively. For males and females, the mean±SD values DLP for the head with contrast were 4899.6 ± 1229.62 mGy.cm, and 2235.73± 604.93 mGy.cm, respectively, and non-contrast were 1307.16 ±431.39 and 1203.07± 336.43mGy.cm respectively.

The mean effective doses which had been received by the patients from a CT examination for the head, for males and females with contrast were 5.71 ± 2.02 mSv and 4.47 ± 1.21mSv respectively, and non-contrast were 2.35 ± 0.78 mSv and 2.41± 0.67 mSv, respectively.

The cancer risks probability per ED103 and ED60 for males were 6.4X10^5 and 3.1X10^5 respectively, while for females were7.3X10^5 and 3.9X10^5 respectively.

Conclusion:

CT scan of the head found, for males and females, that the radiation dose values for DLP, E, and CTDI increased with contrast examinations. The radiation dose values obtained in this research were slightly higher than the values observed in the literature.

Keywords:

Computed tomography effective dose, volume computerized tomography dose index, dose length product, Lifetime attributable risk of cancer, Waza-AriV2.

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INTRODUCTION

Computerized tomography (CT) scan has a wide field to be used as a diagnostic device. In general, a CT scan includes irradiating thin slices of the patient by X-rays. It is an imaging test that uses a computer to produce cross-sectional images put a series of X-ray images together to create detailed images of organs, bones, tissues, and blood vessels in the body. Representing the X-ray attenuation properties of the anatomical structures [1]. Recently the radiation dose from CT scans has been emphasized due to the attention that has been given in the scientific literature to associated risks that have raised serious patient safety and public health concerns [2]. CT is among the radiological diagnostic methods and is one of the tests that contribute the most to the population, so improving patient examination procedures is a priority for all diagnoses. It poses a greater risk to children who are more sensitive to radiation than adults [3]. The advanced development of computed tomography and the introduction of multislice scanners, which have become widely used, has increased interest and concerns about the risks of radiation dose to the patient [4]. The International Committee on Radiation Protection (ICRP) has established diagnostic reference levels (DRL). These are for use in medical diagnostics to manage CT dose assessment, estimate unusually high doses, and provide quantities for protocol comparison and optimization to avoid unnecessary doses [5]. The CT dose is based on the tube kilovolt peak (KVP) and milliamperes per second (mAs), representing the tube current and the slide-scan time. An increase in mAs leads to an increase in the dose, and KVP also increases the radiation dose because the rays carry more energy [6]. In general, organ doses and E provide the complete evaluation of X-ray exposure; an alternative method of dosimetry is based on transmitted energy which is considered a practical measure of patient dose. The values of transmitted energy allow for estimation of the dose that should be derived for exposure to both adults and pediatric patients [7]. ICRP developed the concept of E and provided a single measure of the dose to a reference person (of average age, gender, and nationality) that is proportional to the total 'radiation detriment' from stochastic effects associated with the exposure [8]. The equivalent dose or the absorbed dose to irradiated tissues is the proper quantity for planning the exposure of patients and that of risk assessments. E should be considered when determining the amount of medical exposure to assess patient exposure, comparing doses from different diagnostic procedures, various techniques for the same medical examination , and other hospitals and countries [9]. Therefore, this research aimed to calculate E received by adult patients undergoing head CT examinations, estimate the organ dose, and compare both doses with reference levels (international standards) to assess cancer risk.

Materials and Methods

The CT examination was carried out in the Radiology Department of Azadi Teaching Hospital. The CT scanner used was a Toshiba Aquilion 64 CT. CTDIvol, DLP, and E were used to express the CT dose for this study.

Data collection: All scans were performed according to standard protocols for the head using standard protocols on the device. A total of 278 patients of mixed gender, 134 males and 144

مـجلـة جـــامعة بـــابل للعلـــوم الصـــرفة والتطـــبيقية مـجلـة جـــامعة بـــابل للعلـــوم الصـــرفة والتطـــبيقية

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females, received head CT. Their ages ranged from 18 to 95 years; patients below 18 were excluded from the study. Clinical parameters were obtained from archived CT image files, which include age, gender, X-ray tube voltages (kV), mAs (from protocol), rotation time, and image number, which are shown in Table 1, as well as diagnostic reference dose values, including CTDIvol (mGy) and DLP (mGy cm).

Table 1: Clinical Parameters Used in this Study, Obtained from Archived CT Image Files

Examination	no (C) *	no	Age (years)	Tube output (kV)	mAs (C)*	mAs
Male	6	128	18-90	120	9002.67	3790.19
Female	12	132	18-95	120	6491.58	3591.06

*(C) with contrast

Organ doses calculation: for a head examination, a web-based computerized tomography dose calculation system (WAZA-ARI v2) was used to estimate the organ dose values, E, and radiation hazards [10].

Results and Discussion

Toshiba Aquilion 64 CT displays dose quantities on the operator's console, CTDIvol, and DLP. The mean ±SD age of the head CT examination patients was 52.74308 ± 21.27073 years (18 to 95 years). A constant voltage potential (120 kVp) was used for head CT examination with variable mAs; this variation in mAs could be attributed to the difference in patient size.

Computed tomography dose index: CTDIvol represents the normalized radiation dose delivered to the volume of tissue exposed for one 360-degree rotation of the X-ray beam and is defined as [11]:

$$\text{CTDIvol} = \text{CTDIw/Pitch} \quad \ldots\ldots\ldots\ldots 1$$

The pitch (*p*) is defined as the ratio of the table feed to NxT (the number of tomographic sections, each of nominal thickness *T* (mm) from a single rotation) and is dimensionless. The CTDIvol value cannot be interpreted as a patient dose; CTDIvol does *not* take into account the patient's physical characteristics, nor does it relate to dose measurements in acrylic dosimetry phantom. Mean CTDIvol values were as follows: for head examination for males and females with contrast were 300.2±81.54 mGy and 165.33±46.38 mGy respectively, and non-contrast were 102.24± 33.18 mGy and 97.63 ± 26.78mGy respectively, as shown in Table 3. This study demonstrates that the value of CTDI for female and male patients was higher than the reference value [12].

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Dose–length product: Toshiba Aquilion 64 CT also displays the DLP, which is defined as [11]:

DLP =scan length x (CTDIvol) ……..……………..2

L is the scan length (in cm). The DLP considers the scan length and number of sequences for the examination. There is a variation between DLP values caused by differences in mAs for males and females: the mean±SD values DLP of the head with contrast were 4899.6 ± 1229.62 mGy.cm and 2235.73± 604.93 mGy.cm respectively, and non-contrast were 1307.16 ±431.39 and 1203.07± 336.43mGy.cm respectively, as shown in Table 3. The results were higher for this study than the result published by Huda and Mettler [13].

Effective dose estimation: In a CT scan, the E received by a patient from a CT examination for each scan was calculated by multiplying the given DLP values with the k factor. The patient effective dose is defined as [14]:

E = DLP x K …………………………………….….3

Where K is an age-specific conversion factor, this study was focused on adults, so the k values for head for an adult were used in CT examinations as listed in Table 2.

Table 2: The Adult and Sex-Specific Effective Dose per Dose Length Product Conversion Factors [15]**.**

Examination	Head
k (mSvmGy-1cm-1) *	0.0019
male* **k (mSvmGy-1cm-1)**	0.0018
Female* **k (mSvmGy-1cm-1)**	0.002

*The adult conversion factors that used for the tube voltage of 120

The mean E which had been received by the male patients from a CT examination for the head, for males and females with contrast were 5.71 ± 2.02 mSv and 4.47 ± 1.21mSv respectively and non-contrast 2.35 ± 0.78 mSv and 2.41± 0.67 mSv, respectively as shown in Table 3.

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Table 3: Measured CTDIw, DLP and E for Head Examination

Examination	CTDIv (mGy) (C)*		CTDIv (mGy)		DLP (mGy.cm) (C)*		DLP (mGy.cm)		E (mSv) (C)*		E (mSv)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Male	300.2	81.54	102.24	33.18	4899.6	1229.62	1307.16	431.39	5.71239	2.020476	2.352897	0.77651
Female	165.33	46.38	97.63	26.78	2235.73	604.93	1203.07	336.43	4.471467	1.209863	2.406133	0.672858

*(C) with contrast

In this study, the mean E was comparable to other studies that used the same scanner type that was 3.5±1.4 mSv **(**Elmahdi et al.) [16]. However, Maharjanet et al. (2016) measured E for head protocol, which was1.7 ± 0.2 mSv [17]; this value was lower than the value found in the present study. Therefore, to reduce the E for head examination, scanning parameters should be revised to lesser scan length and fewer images per exam.

Estimations effective dose, equivalent dose, and organ doses in the adult male and female phantoms: The risk of exposure to a CT scan is directly proportional to the dose of the organ. The measured dose of the organs or tissues which were within the irradiated area was remarkably high. In the head examination, radiation-sensitive organs such as the lens of the eye and the brain will be exposed to higher doses than other organs such as the breast and gonads, which do not lie proximate to the examination field.

Waza-AriV2 software dosimetry was used to estimate organ-specific doses (as shown in Table 4); it is a system based on the Monte Carlo simulation methods that estimate organ doses from the parameters of exposure that are utilized in the CT equipment. Estimation of the radiation dose depended on the radiation transport attributable organ dose on the (female and male) adult phantom [18]. In the head scan, the salivary glands received the highest dose, 21.23 mGy for males and 23.28 mGy for females. This value is higher than the value reported by Yamashita et al., which was a direct measurement of organ dose for head CT examination by using OSL dosimetry because the area measured by dose calculation software was somewhat close to the thyroid gland. The eye lens and brain received a relatively high dose in both male and female phantoms in the brain study. The eye lens and brain in the male phantom received 20.44 and 19.83 mGy, respectively; the female phantom received 22.51 and 19.95 mGy, respectively. This value is lower than the estimated and measured values reported by Yamashita et al. [19].

Equivalent dose HT [mSv] of each organ is obtained by using the radiation weighting factor WR for X-ray of 1 and the absorbed dose of each organ DTR [mGy] as follows [20]:

$$HT = WR \times DTR = DTR \qquad \text{……………………………}4$$

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E is then calculated by summing the product of the tissue weighting factor W_T of each organ and [mSv] HT for all organs [21].

$$\mathbf{E}=\sum W_T H_T \ldots\ldots 5$$

Tissue weighting factor W_T of each organ is different between ICRP103 [22] and ICRP 60[23], so in WAZA-ARI, both ED103 and ED60 are displayed in the calculation result [24]. ED103 is slightly greater than ED60 for females and males. For females, both ED103 and ED60 are shown to be greater than males, as shown in Table 4. However, these values are less than the values obtained from equation 3 and are shown in Table 3.

Estimates of radiation risk: Estimation of cancer risk (R) from the exposure to ionizing radiation was estimated by multiplying E obtained by CT- Waza-AriV2 for the head with the risk coefficient ($Tr= 5.5*10^{-2}Sv^{-1}$) obtained from ICRP Publication103 (2007) (ICRP 2007) as the following equation [25]:

$$R=\Sigma Tr.E \ldots\ldots 6$$

The cancer risks probability per ED103 and ED60 for males were 6.4 per 10^5 and 3.1per 10^5 respectively, while for females were 7.3per 10^5 and 3.9 per10^5 respectively. They were less than those observed in other studies of CT procedures for 64 slices which were 13 per 10^5 [25]. However, females are more sensitive to radiation than males, so more outstanding care should be taken for female patients, especially young patients (ICRP, 2007). Therefore, cancer risk must take into account gender and age.

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Table 4: Organ Absorbed Doses mGy and E mSv Based on Tissue Weighting Factors from ICRP 60 (ED60) and ICRP 103 (E103) for Adult Male and Female for Head Examinations Estimate by Waza-AriV2 Software Dosimeter

Organ/Tissue	Male Organ Dose/mGy	Female Organ Dose/mGy
Gonad	less 0.01	LESS 0.01
Prostate/Uterus	less 0.01	LESS 0.01
Urinary bladder	less 0.01	LESS 0.01
Colon	0.01	LESS 0.01
Small intestine	less 0.01	LESS 0.01
Kidney	0.01	0.01
Pancreas	0.01	0.01
Gall bladder	0.01	0.01
Stomach	0.01	0.01
Spleen	0.02	0.02
Adrenals	0.01	0.01
Liver	0.02	0.03
Heart	0.12	0.15
Lungs	0.16	0.21
Breast	0.08	0.05
Esophagus	0.28	0.53
Thymus	0.21	0.24
Thyroid	1.44	2.94
Salivary glands	21.23	23.28
Oral cavity	15.4	16.97
Out of thorax	17.11	18.32
Lens	20.44	22.51
Brain	19.83	19.95
Lymphaden	1.67	1.71
Muscle	1.23	1.11
Skin	2.38	2.45
Bone	10.66	12.26
Active marrow	1.75	1.94
ED103	1.18mSv	1.34 mSv
ED60	0.57 mSv	0.7 mSv

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CONCLUSION

In this study, routine brain radiation doses were evaluated by CT. CT scan of the head found, for males and females, that the radiation dose values for DLP, E, and CTDI increased with contrast examinations. Also, organ dose and E were estimated using Monte Carlo simulation of a CT scanner based on computational human phantoms for adult males and females; this covers a total of 28 organs and tissues for tube potentials 120 kVp, for head examination. Therefore, using appropriate tools for E estimation and organs dose becomes a critical issue to provide health professionals with valuable information to assess the risks accompanying the CT examination and keep the patient's radiation dose as low as reasonably possible. The radiation dose values obtained in this research were slightly higher than the values observed in the literature. Radiation exposure from the CT scans would probably affect the exposed organ and increase the likelihood of cancer in the other radiosensitive organs, particularly for young people. Therefore, special consideration should be given to people who have a CT scan more than once or those who have a CT scan at a young age. It is necessary to determine the minimum level of exposure to scan the brain, thus reducing the dose and reducing the risk.

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Conflict of interests

There are no conflicts of interest.

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الخلاصة

مقدمة:

أدى التطور المتقدم في التصوير المقطعي ، الذي أصبح مستخدمًا على نطاق واسع ، إلى زيادة الاهتمام والمخاوف بشأن مخاطر جرعة الإشعاع بالنسبة للمريض. يهدف هذا البحث إلى حساب الجرعات الفعالة التي يتلقاها المرضى البالغون الذين يخضعون لفحص الرأس بالأشعة المقطعية ، وتقدير مخاطر الإصابة بالسرطان..

طرق العمل:

البيانات التي تم دراستها في هذا البحث هي ل(278) مريض. تم الحصول على المعلمات السريرية من ملفات الصور المقطعية المؤرشفة ، لهذه الدراسة والتي تمثل كل من مؤشر جرعة التصوير المقطعي المحسوب بالحجم (CTDI vol) وطول الجرعة ((DLP) و تم استخدام الجرعة الفعالة (E) للتعبير عن جرعة التصوير المقطعي المحسوب ,وتم الاستعانة ب (WAZA-ARI v2) لغرض تقدير قيم كل من جرعة العضو والجرعة الفعالة ومخاطر الإشعاع.

الاستنتاجات:

أن قيم جرع الإشعاع لفحوصات المقطعية للراس لكل من للذكور والإناث وهي تمثل كل منDLP و E و CTDI زادت مع فحوصات التي تم زرق المرضى بالصبغة وكذلك كانت قيم جرعة الإشعاع التي تم الحصول عليها في هذا البحث أعلى قليلاً من القيم التي لوحظت في الأدبيات.

الكلمات المفتاحية: الجرعة الفعالة للتصوير المقطعي المحسوب E, مؤشر جرعة التصوير المقطعي المحوسب الحجم (CTDIvol)، منتج طول الجرعة (DLP)، Waza-AriV2 .

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