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The Effect of Linear Energy Transfer, Particle and Energy Fluence on Renal Surface Area during Abdominal CT Scan

[1]Issahaku Shirazu, [2]Cyril Schandorf, [3]Y. B Mensah, [4]S. Y. Mensah, [1]Theophilus Sackey, [1]Ernest Kojo Eduful, [1]Mark Pokoo-Aikins, [1]Theresa Bebaaku Dery

[1]Ghana Atomic Energy Commission, Radiological and Medical Sciences Research Institute, Medical Radiation Physics Center, Accra, Ghana
[2]Graduate School of Nuclear and Allied Sciences, University of Ghana, Legon, Ghana
[3]University of Ghana Medical School, Department of Radiology, Korle-Bu Teaching Hospital, Accra Ghana
[4]University of Cape Coast, School of Agriculture and Physical Sciences Faculty of Physical Sciences, Department of Physics, Cape coast, Ghana.

ABSTRACT

The quantities that determine the relative image noise level by either increasing or reducing its value are photon quality (kVp) and photon quantity (mAs). This study is to determine the effect of LET, energy and particle fluence on the renal surface area during abdominal CT scan. The method involve extracting three exposure parameters from image data using MVL DICOM application software including: kVp, mA and scan time. The kVp or the photon peak energy which is applied in the A-P direction during abdominal CT scan was used to estimate linear energy transfer. While the particle fluence and the energy fluence were estimated from the effective mAs and the kVp on the total renal surface respectively. The effective mAs were estimated by dividing the mAs by the average pitch factor of approximately 0.813. In all the examinations, the average protocol setting in terms of exposure time and kilovolts peak were 500s and 120keV respectively. While the average protocol in all the centers recorded a mean effective milliamp second (mAs) of 59.27 mAs and tube current of 94.22A. The influence of these parameters on abdominal scan depends on the scan time, scan scope, the size of the renal surface area (RSA) which has varied values. The effects of effective mean mAs per unit mean renal surface area, described as mean effective particle fluence were 1.32mAs/cm2 and 1.50 mAs/cm2 for male and female respectively. The energy fluence, which is the photon energy per unit renal surface area estimated to have a mean value of 4.02 keVcm-2 and 4.51 keVcm-2 for male and female respectively. In addition, the maximum and minimum variations of all the measured parameters. The LET, which described the lost in photon energy as it traverses across the renal tissues in the A-P direction was estimated, with a mean value of 2.60 keV/µm and 2.67 keV/µm for male and female respectively. The maximum and minimum LET values were 4.49 keV/µm and 1.90 keV/µm for male and 5.26 keV/µm and 1.98 keV/µm for female respectively. The maximum measured values were below the critical LET values estimated to be between 15 to 20 keV/µm. These estimated risk parameters were used to predict the effect on abdominal and kidney tissues using the various modeled equations.
Keywords : Photon Quality, Photon Quantity, Image Noise, LET, Particle Fluence, Energy Fluence.

I. INTRODUCTION

The framework of the exposure parameters are based on the effects of the LET, during CT examinations. The definition described the probability of a photon loses all its energy as it transverse through a material. The lost energy is said to have been deposited in the material. It's of interest to know that, protons, neutrons, and **α** particles have much higher LET than gamma or x-rays. LET is expressed in keV per micron (keV/µm) as standard units. Other important parameters associated with low-dose radiation is the charge particle fluence, the energy fluence and the rate at which there affect human tissues or organs. The charge particle fluence refer to the number of particles per unit surface area with which the tissue or organ is irradiated. This process is *determine by the amount of* ***milliamp second (mAs)*** *on the organ surface area of the irradiated body [1]*. It controls the quantity or the amount of x-ray photons produced and describe the quantity of ions in the x-ray beam as the beam approach the irradiated organ surface.

The sum of a specific energy per unit surface area contained by the particles with which an organ is irradiated *is described as energy fluence [2]. This is determine by the* Kilovolt Peak ***(kVp)*** *of the incident beam on the irradiated organ surface area.* It determine the quality of the incident beam and controls the contrast or grey level in the image. The most important radiation exposure quantities that relate radiation dose to an organs from any given CT study depend on tube current scanning time in milliamp-seconds (**mAs**) and the tube voltage in kilovolt peaks (**kVp**). These quantities determine the relative image noise level by either increasing or reducing the **mAs** and **kVp.** However, reduction in relative noise in CT images will automatically give rise to an increase in radiation dose and vice visa. Hence, there will always be a tradeoff between minimal image noise and low doses of radiation to patients in medical imaging **[3]**. It is important to note that photons are energetic enough to overcome the binding energy of an orbiting electrons in an atoms. This energetic photon can knock off electron from its orbital shell, thereby creating ions. In human body exposure to photons, results in the creation of hydroxyl radicals in the body. These are due to the x-ray interactions with the body cells which consist of mainly water molecules. The nearby DNA will cause a base damage or strand breaks and the hydroxyl may even ionize DNA directly. It should be noted that, various systems within the cell may rapidly repair most of these radiation-induced damage. However, it is less easy to repaired double-strand breaks, which may lead to induction of cancer. These biological exposure to photon energy give rise to the determination of various fundamental dosimetric quantity in radiological imaging **[4]**. The effect of this quantities determine the dose to human body.

II. OBJECTIVES

The aim is to determine the effect of particle fluence, energy fluence and linear energy transfer with associated photon quality (**kVp**) and quantity (**mAs**) on renal surface area during abdominal CT scan.

III. LITERATURE REVIEW

In medical imaging, LET describe the number of ionisations of tissues or organs by ionizing radiation as it traverses through a human body. Estimates of critical values of LET, gives an indication below which radiation hormesis is likely to occur but above which it is unlikely to occur. The critical value of LET is estimated to be between 15 to 20 keV/μm, and hence radiation hormesis may occur with beta, gamma or x rays, but is unlikely to occur with alpha radiation [**5**]. It is expressed in keV per micron (keV/μm) as a standard universal units. Generally, the LET can be define mathematically in term of stopping potential as:

$$\boldsymbol{LET}\ (\tfrac{s}{\rho}) = 4\boldsymbol{\pi e^4 N z^2 Z}(\boldsymbol{ln}\frac{2m_0v^2}{I} - \boldsymbol{ln}(\mathbf{1} - \boldsymbol{\beta^2}) - \boldsymbol{\beta^2}) \quad (1)$$

However, **t**he approximate radiative mass stopping power for diagnostic energies is:

$$\boldsymbol{LET}\ \left(\frac{s}{\rho}\right) = \boldsymbol{\sigma_0}\frac{N_A}{A_r}\ \boldsymbol{Z^2}(\boldsymbol{T} + \mu_0)\boldsymbol{B} \quad (2)$$

where,

$\beta = \frac{v}{c}$, B=hν/T, v is the velocity of the beam particle, T is the kinetic energy, e is the charge of an electron, Z is the atomic number of the irradiated material, m_0 is the mass, z is the charge number of the beam particle, I is the average ionisation potential (11.5ZeV), σ_0 (0.58barns/nucleus), c, N, h and **π** have their usual meaning.

Clinically, in low-dose radiation, LET is expressed as the effect of radiant energy transferred per unit length of ionization track in an organ or tissue, expressed mathematically as:

$$L = \frac{d\varepsilon}{dl} \quad (3)$$

Where, dℇ is the photon energy transverses through a distance dl.
The effect of the application of a number of photons and varied energies incident on human body surface is described by the rate at which it affect the tissues being irradiated. These rates are described by two parameters term as the particle fluence rate and the energy fluence

rates. Furthermore, the rate at which particle fluence and energy fluence impacted on the abdominal tissues are estimated using the equations below:

The particle fluence within the total acquisition time (t):

$$\boldsymbol{\varphi} = \frac{\phi}{t} \qquad (4)$$

The energy fluence within the total acquisition time (t):

$$\psi = \frac{\psi}{t} \qquad (5)$$

The energy and particle fluence parameters are responsible for the effects that radiation causes in tissues. For instance the biological modifications that might lead to cancer are cause by the effect of these parameter.

These two quantitative parameters are define as:

Particle Fluence rate (φ) on the tissue or organ per unit time **[6]**: Mathematically as:

$$\boldsymbol{\varphi} = \frac{d\phi}{dt} \qquad (6)$$

Energy Fluence Rate (ψ) on the tissue or organ per unit time **[6]**: Mathematically as:

$$\psi = \frac{d\,\psi}{dt} \qquad (7)$$

The relationship between these parameters (Particle and energy fluence) and the acquisition exposure parameters (kVp and mAs) are shown in the equations below.

These quantities are express mathematically as in equation 8 (particle fluence) and equation 9 (energy fluence) **[7]**;

$$\phi = \frac{dN}{da} \qquad (8)$$

$$\psi = \frac{d\varepsilon}{da} \qquad (9)$$

where,

dN is the number of particles, ***da*** is the cross-sectional area and ***dℰ*** is the Photon energy.

In terms of the renal surface, the ***dl*** in equation **3** represent the distance transverse in the A-P direction and the ***da*** is the renal surface area as described below.

$$\boldsymbol{L} = \frac{\boldsymbol{kVp}}{\boldsymbol{A-P}}$$ For Linear Energy Transfer

$$\phi = \frac{\boldsymbol{mAs}}{\boldsymbol{RSA}}$$ For particle fluence

$$\boldsymbol{\psi} = \frac{\boldsymbol{kVp}}{\boldsymbol{RSA}}$$ For energy fluence

where all the parameters have their usual meaning [**8**].

IV. METHODOLOGY

The estimated pre-set parameters were photon quality (**kVp**) and quantity (**mAs**) to estimate LET, particle and energy fluence in relation to the effect on the abdomen and on renal surface area. On the control console these are variable parameters together with tube current, acquisition time and many other parameters to be selected before image acquisition, a typical CT control console is shown below.

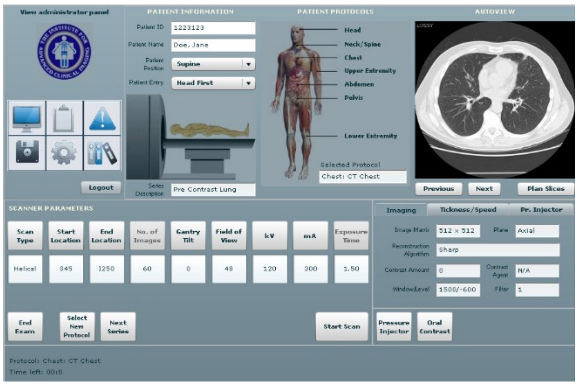


Fig 1 Input CT console

The selection of these parameters depends on several factors, this include; patients age, weight, size, gender, body region and type of procedure. In addition this determine a trade-off between a balance of image quality produce and the dose received for purposes of patient radiation protection. Furthermore, the automatic control unit automatically adjust these parameters based on the attenuation of the patients' body tissues and record these values on the image data. The extraction of these data were mainly for radiation protection and not the exact dose to patients. These data was extracted from the image data using MVL DICOM application software. The displayed of these extracted parameters are shown in ***Figure 3.18***

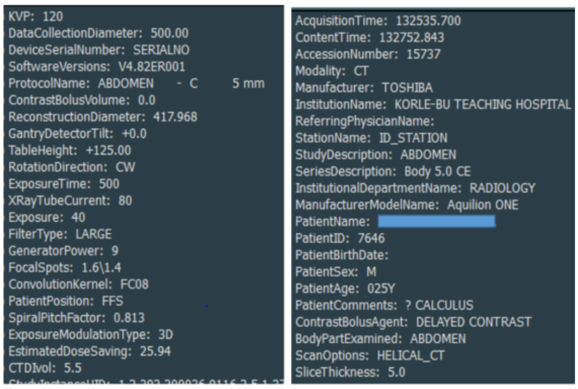


Figure 2. Acquisition parameters from image data

After extracting the image data three exposure parameters were estimated using the photon peak energy in the A-P direction to estimate linear energy transfer. While the particle fluence and the energy fluence were estimated from the effective mAs and the kVp on the total renal surface. The effective mAs were estimated by dividing the mAs by the average pitch factor of approximately 0.813. The relationship between these parameters (Particle and energy fluence) and the acquisition exposure parameters (kVp and mAs) are shown in the equations below.

$$\boldsymbol{L} = \frac{\boldsymbol{kVp}}{\boldsymbol{A-P}} \quad \text{For Linear Energy Transfer}$$

$$\phi = \frac{\boldsymbol{mAs}}{\boldsymbol{RSA}} \quad \text{For particle fluence}$$

$$\boldsymbol{\psi} = \frac{\boldsymbol{kVp}}{\boldsymbol{RSA}} \quad \text{For energy fluence}$$

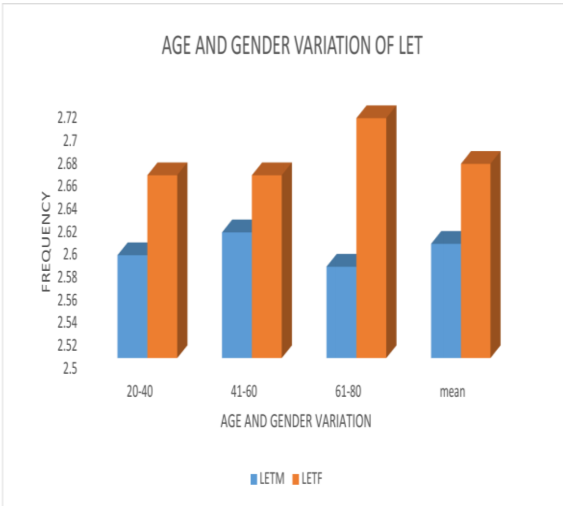
where all the parameters have their usual meaning as stated in chapter two section 2.3.

V. RESULTS

The measured parameters are shown in table 1.

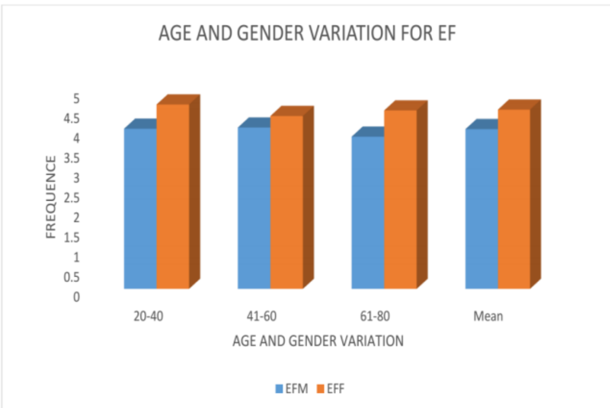
Table 1. Estimated exposure parameters

STATISTICS	**LET$_M$**	**LET$_M$/t**	**PF$_M$**	**PF$_M$/t**	**EF$_M$**	**EF$_M$/t**
MALE	**keV/cm^2**	**keV/cm^2/s**	**mAs/cm^2**	**mAs/cm^2/s**	**keV/cm^2**	**keV/cm^2/s**
20-40						
MEAN	2.59	0.0052	1.34	0.0027	4.03	0.0081
MAX	3.76	0.0075	2.61	0.0052	7.83	0.0157
MIN	2.12	0.0042	0.90	0.0018	2.69	0.0054
MAX/MIN	1.78	1.7766	2.92	2.9151	2.91	2.9153
41-60						
MEAN	2.61	0.0052	1.35	0.0027	4.06	0.0081
MAX	4.49	0.0090	4.17	0.0083	12.51	0.0250
MIN	1.90	0.0038	0.69	0.0014	2.07	0.0041
MAX/MIN	2.37	2.3705	6.04	6.0406	6.04	6.0406
61-80						
MEAN	2.58	0.0052	1.28	0.0026	3.83	0.0077
MAX	2.86	0.0057	1.58	0.0032	4.74	0.0095
MIN	1.93	0.0039	0.97	0.0019	2.91	0.0058
MAX/MIN	1.49	1.4861	1.63	1.6285	1.63	1.6288
20-80						
MEAN	**2.60**	**0.0052**	**1.32**	**0.0036**	**4.02**	**0.0080**
MAX	4.49	0.0090	5.13	0.0103	12.51	0.0250
MIN	1.90	0.0038	0.85	0.0017	2.07	0.0041
MAX/MIN	2.37	2.3705	6.04	6.0406	6.04	6.0406
FEMALE						
20-40						
MEAN	2.66	0.0053	1.55	0.0031	4.64	0.0093
MAX	5.26	0.0105	6.16	0.0123	18.48	0.0370
MIN	1.98	0.0040	0.88	0.0018	2.65	0.0053
MAX/MIN	2.66	2.6550	6.99	6.9847	6.99	6.9860
41-60						
MEAN	2.66	0.0053	1.45	0.0029	4.35	0.0087
MAX	3.18	0.0064	2.16	0.0043	6.47	0.0130
MIN	2.27	0.0045	0.86	0.0017	2.59	0.0052
MAX/MIN	1.40	1.4000	2.50	2.5020	2.50	2.5027
61-80						
MEAN	2.71	0.0054	1.50	0.0030	4.49	0.0090
MAX	3.05	0.0061	1.85	0.0037	5.55	0.0111
MIN	2.35	0.0047	1.19	0.0024	3.57	0.0071
MAX/MIN	1.30	1.2945	1.55	1.5540	1.55	1.5539
20-80						
MEAN	**2.67**	**0.0053**	**1.50**	**0.0034**	**4.51**	**0.0090**
MAX	5.26	0.0105	7.56	0.0152	18.48	0.0370
MIN	1.98	0.0040	1.09	0.0022	2.59	0.0052



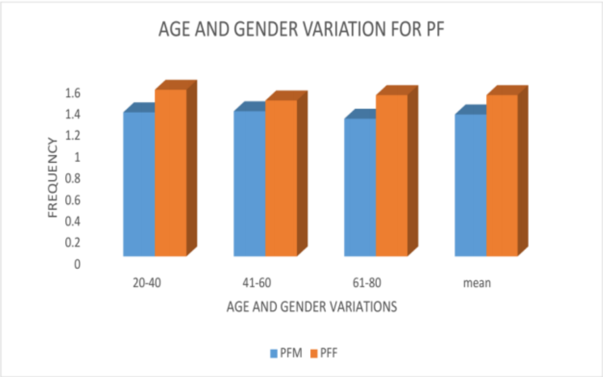
LET/M Male Linear Energy Transfer LET/F Female Linear Energy Transfer

Figure 3



EF/M Male Energy Fluence EF/F Female Energy Fluence

Figure 4



FP/M Male Particle Fluence FP/F Female Particle Fluence

Figure 5

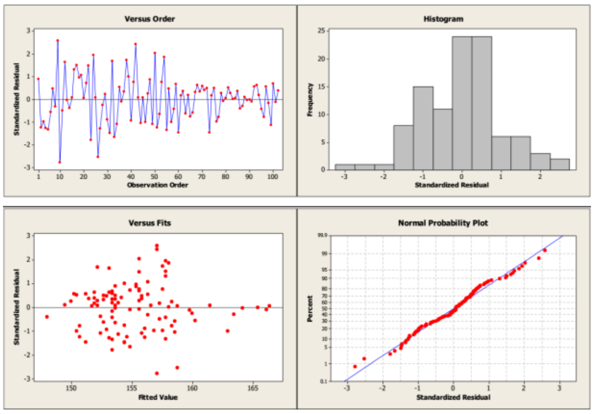


Figure 7

MODELED EQUATION OF E, PF and EF

E = 14.5 - 5254.59 PF + 1751.44 EF

Summary of Model

S = 7.5

R-Sq = 96.05%

R-Sq(adj) = 97.97%

R-Sq(pred) = 97.93%

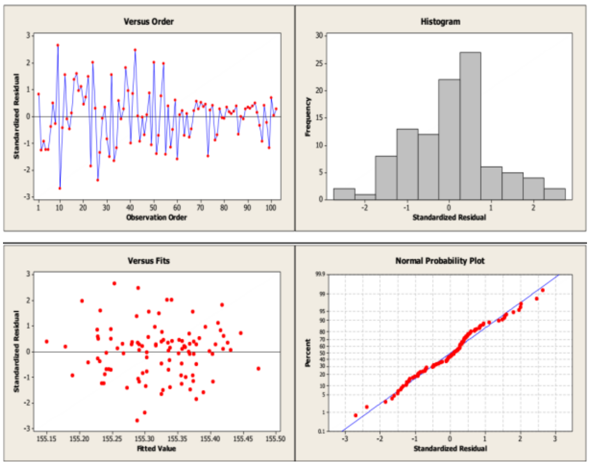


Figure 6

MODELED EQUATION OF RD, PF and EF

RD = 0.075 - 125.85 PF + 41.95 EF

Summary of Model

S = 0.028

R-Sq = 95.49%

R-Sq(adj) = 96.49%

R-Sq(pred) = 96.96%

MODELED EQUATION OF LET and RD

LET = 2.8 - 2.16 RD

Summary of Model

S = 0.35

R-Sq = 94.94%

R-Sq(adj) = 95.45%

R-Sq(pred) = 94.42%

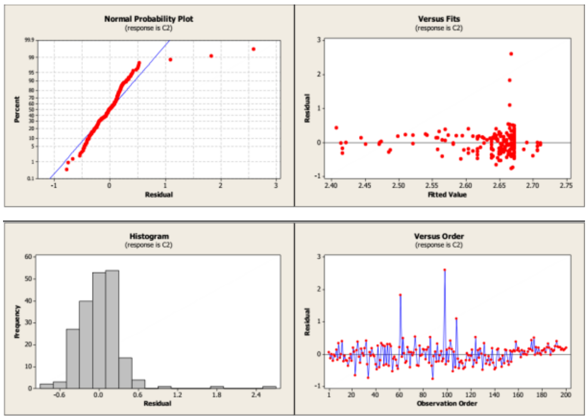


Figure 8

VI. DISCUSSIONS AND ANALYSIS

The two common pre-set parameters during CT scan are kV, mA and scan time with many other parameters. The kV and the product of mA and the scan time are used to estimate LET, particle and energy fluence. In addition, the rate of these parameters on the renal surface area were estimated. This enable the prediction of prognostic consequences of these parameters. In all the examinations, the average protocol setting in terms of exposure time and kilovolts peak were 500s and 120keV respectively. While the average protocol in all the centers recorded a mean effective milliamp second (mAs) of 59.27 mAs and tube current of 94.22A. These parameters play an important role in the determination of the level of exposure in term of particle and energy fluence in the abdominal CT examinations to the kidney and other abdominal tissues. The influence of these parameters on abdominal scan depends on the scan time, scan scope, the size of the renal surface area (RSA) which has varied values. The effects of mean effective mAs per unit mean renal surface area, described as mean effective particle fluence were **1.32**mAs/cm^2 and **1.50** mAs/cm^2 for male and female respectively. The energy fluence, which is the photon energy per unit renal surface area estimated to have a mean value of **4.02 keVcm^{-2}** and **4.51 keVcm^{-2}** for male and female respectively. In addition, the maximum and minimum variations of all the measured parameters.

The LET, which described the lost in photon energy as it traverses across the kidney in the A-P direction was estimated, with a mean value of **2.60** keV/µm and **2.67** keV/µm for male and female respectively. The maximum and minimum LET values were **4.49** keV/µm and **1.90** keV/µm for male and **5.26** keV/µm and **1.98** keV/µm for female respectively. The maximum measured values were below the critical LET values estimated to be between 15 to 20 keV/µm. The average estimated rate of this parameters on the abdominal tissues. These estimated risk parameters were used to predict the effect on abdominal and kidney tissues using the modeled equations. Summary of these parameters are shown in table 2.

TABLE 2 LET, PF AND EF

STATISTICS	LET_M	LET_M/t	PF_M	PF_M/t	EF_M	EF_M/t
	keV/cm^2	**keV/cm^2/s**	**mAs/cm^2**	**mAs/cm^2/s**	**keV/cm^2**	**keV/cm^2/s**
MALE						
MEAN	**2.60**	**0.0052**	**1.32**	**0.0036**	**4.02**	**0.0080**
MAX	4.49	0.0090	5.13	0.0103	12.51	0.0250
MIN	1.90	0.0038	0.85	0.0017	2.07	0.0041
MAX/MIN	2.37	2.37	6.04	6.04	6.04	6.04
FEMALE						
MEAN	**2.67**	**0.0053**	**1.50**	**0.0034**	**4.51**	**0.0090**
MAX	5.26	0.0105	7.56	0.0152	18.48	0.0370
MIN	1.98	0.0040	1.09	0.0022	2.59	0.0052
MAX/MIN	2.66	2.66	6.96	6.96	7.14	7.14

The three important exposure parameter, LET, particle fluence and energy fluence which are determine based on the milliamp second and the kilovolt peak influence patient dose based on LNT model [9]. Therefore optimization procedures based on these parameters is essential as it may contribute significantly to the dose received by patients. The higher the kVp, the higher the energy fluence and the lesser the noise in the image due to better image contrast. In the case of the mAs the higher the particle fluence the more ionisation in the irradiated material. It is important to note that ionizing radiation, such as x-rays, is uniquely energetic enough to overcome the binding energy of the electrons orbiting an atoms and molecules. This energetic photon can knock off electrons in its orbital shell, thereby creating ions. In abdominal and renal tissues exposure to x-rays, results in a creation of hydroxyl radicals from x-ray interactions with water molecules in the abdomen tissues, these free radicals in turn interact with nearby DNA to cause strand breaks or base damage or may ionize DNA directly [**10**]. This radiation induce damage may rapidly repaired by various systems within the cell, but DNA double-strand breaks are less easily repaired. However, this disrepair can lead to induction of point mutations, chromosomal translocations, and gene fusions, all of which are linked to the induction of cancer. These biological exposure to photon energy give rise to the determination of various fundamental dosimetric quantity (in this case LET, particle and energy fluence) in radiological imaging.

The result of these three exposure parameters on the abdomen are the deposition of dose to the renal and other abdominal tissue based on the extrapolation by the LNT model may lead to cancer. Furthermore, optimization refers to the process of keeping the exposure of patients to the minimum necessary to achieve the required diagnostic objective. Patient dosimetry and DRLs are recognized as important tools for optimization of patient radiation protection. Unfortunately, values of these DRLs are not available for Comparison in Ghana. BSS set requirements and recommendations for implementation of the principle of optimization of radiation protection of patients in medical facilities using ionizing radiation. Recommendations from IAEA using BSS and other related international bodies such as ICRP, EC and AAPM set out basic essential practice principles that assist clinicians in clinical practice. Hence, values of this study were compare with those from these international organizations for purposes of optimization and not exact dose values to various tissues. The results shows that abdominal CT imaging in Ghana are generally within the accepted range of values. The modeled equations should be used to estimate dose to renal surface and other abdominal tissues before imaging.

Table 3. Exposure and Dose Parameters

PARAMETERS	MALE	FEMALE	MEAN
LET_M (keV/cm^2)	2.60	2.67	**2.63**
LET_M/t (keV/cm^2/s)	0.0052	0.0053	**0.0053**
PF_M (mAs/cm^2)	1.32	1.50	**1.41**
PF_M/t (mAs/cm^2)	0.0036	0.0034	**0.0035**
EF_M (keV/cm^2)	4.02	4.51	**4.26**
EF_M/t (keV/cm^2/s)	0.0080	0.0090	**0.0085**

The proposed payment system combines the Iris recognition with the visual cryptography by which customer data privacy can be obtained and prevents theft through phishing attack [8]. This method provides best for legitimate user identification. This method can also be implemented in computers using external iris recognition devices.

VII. ACKNOWLEDGEMENTS

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