ESTIMATION OF RADIATION DOSE AND ASSOCIATED CANCER RISKS FROM COMPUTED TOMOGRAPHIC SCANS

A dissertation submitted to the Department Of Physics, Bangladesh University of Engineering & Technology, Dhaka, in partial fulfillment of requirement for the degree of MASTER OF PHILOSOPHY in Physics

Submitted by

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Session: April/2012

DEPARTMENT OF PHYSICS

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

DHAKA-1000, BANGLADESH

March, 2018

BANGLADESH UNIVERSITY OF ENGINEERING & TECHNOLOGY (BUET), DHAKA
DEPARTMENT OF PHYSICS

CERTIFICATION OF THESIS

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Dedicated

To

My Beloved Parents

ACKNOWLEDGEMENTS

All the admiration to the most Compassionate, most Merciful and Almighty ALLAH Subhanahu wa ta'ala who has enabled me to submit this humble work leading to the M. Phil degree.

I would like to express my profound respect and the heartfelt gratitude to my honorable supervisor Dr. Afia Begum, Professor, Department of Physics, Bangladesh University of Engineering and Technology (BUET) for her scholastic and indispensable guidance, constructive criticism and valuable suggestion and active encouragement throughout the entire course of this research work.

Then I would like to express my profound respect and the hearty gratitude to Dr. Aleya Begum, Ex-member, Bangladesh Atomic Energy Commission (BAEC), Dhaka, Bangladesh, for her kind permission to carry on this work in Health Physics Division, Atomic Energy Center and making available the support and endowment of all possible facilities of her establishment. Without her commitment, sparring and constant disposal, the thesis would not have gone as far as it did.

I convey my cordial thanks and gratitude to Dr. A. K. M. Moinul Haque Meaze, Professor, Dept. of Physics, Chittagong University, Md. Rezaul Karim Khan, Senior Scientific Officer, Md. Ashraful Hoque, Chief Engineer and Mst. Janntul Ferdous, Principal Scientific Officer and other staffs for their constant encouragement, generous support and constant co-operation in performing the experimental procedures in HPD, BAEC.

I express my heartfelt gratitude to Dr. Md. Forhad Mina, Professor and Head, Department of Physics, BUET for his keen interest and constant inspiration. I am further grateful to Prof. Dr. Md. Abu Hashan Bhuiyan, Prof. Dr. Jiban Podder, Prof. Dr. Md. Feroz Alam Khan, Prof. Dr. A. K. M. Akther Hossain, Profs. Md. Mostak Hossain, Prof. Fahima Khanam, Prof. Dr. Rafi Uddin, Prof. Dr. Nasreen Akter, Dr. Mohammed Abdul Basith, Dr. Mohammad Abu Sayem Karal and all others teachers of the Department.

I express my profound gratitude to my beloved parents and my brother Jahangir Kabir for their inspiration, encouragement and endless love to complete my study. I wish to thank Mr. Sourav and Mr. Monower and other staffs of the Department of Physics, BUET, for their co-operation during this research work.

Shaiful Kabir

ABSTRACT

Absorbed dose of 100 patients during CT imaging procedure in a renowned hospital of Dhaka city were measured using Thermoluminescence (TL) chips. For dose measurement at the scanned region TL chips were sealed in a uniform manner with 10 rows and 5 columns between two polythene sheets. Fifty TL chips were used for each CT scan at the scanned region. These TL chips were readout using the Harshaw TLD Reader (model 3500) of Health Physics Division, Atomic Energy Center, BAEC, Dhaka. The patients were selected randomly based on three different CT types e.g. CT abdomen, CT chest and CT head. Applied voltage, applied current, exposure time, scanning length, dose length product (DLP), age and sex of the patient were recorded for each CT scan. The maximum value of absorbed dose was obtained 79.05 mSv for CT head scanning and the minimum value of it was obtained 1.27 mSv for CT abdomen scanning. The effective dose was calculated by multiplying DLP value obtained from the dose report with the conversion coefficient provided by European Guidelines for multi-slice computed tomography (MSCT). The maximum and minimum value of effective dose was obtained 45.93 mSv for CT abdomen and 1.24 mSv for CT head scanning respectively. The lifetime attributable risk (LAR) of cancer was also estimated using web based calculator X-rayrisk.com. It was observed that the LAR of cancer increases with the decrease of patient age and the increase of the effective dose. Therefore, pediatric patients are in higher radiation risk than adult patients. So it is very important in radiology departments to monitor and control the dose of the patients during CT imaging procedures and the dose should always be as low as reasonably achievable.

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1.1 General

Radiation is, in general, the mechanism to the emission and propagation of energy through space or a material medium. It may be particle or wave form. In case of particle radiation energy propagates by travelling corpuscles that have a definite rest mass, definite momentum and definite position at any instant. On the other hand, electromagnetic radiation constitutes the mode of energy propagation for such phenomena as light waves, heat waves, radio waves, microwaves, ultraviolet rays, X-ray and γ rays. Electromagnetic radiations have definite frequency [1]. In the electromagnetic spectrum low frequency waves such as radio waves and microwaves lie at one end and high frequency waves such as X-rays and gamma rays at the other end. The low frequency waves cannot ionize the atom or molecules called non-ionizing radiation and high frequency waves are called ionizing radiation.

Ionizing radiation is found at the shorter wavelength, high frequency as well as high energy end of the electromagnetic spectrum. There are three main kinds of ionizing radiation:

(i) Alpha particle, which contain two protons and two neutrons;
(ii) Beta particles, which are essentially electrons; and
(iii) Gamma rays and X-rays, which are photons.

Recently, the application of ionizing radiation is increasing dramatically in the medical sector. Ionizing radiation, such as X-rays, is uniquely energetic enough to overcome the binding energy of the electron orbiting atoms and molecules; thus, these radiations can knock electrons out of their orbits, thereby creating ions. In biological material, exposed to X-ray, the most common scenario is the creation of hydroxyl radicals from X-ray interaction with water molecules; these radicals in turn interact with nearby DNA to cause strand breaks or base damage. X-ray can also ionize DNA directly. Most radiation-induced damage is rapidly repaired by various systems within the cell, but DNA double-strand breaks are less easily repaired and occasional misrepair can lead to induction of point mutations, chromosomal translocations and gene fusions, all of which are linked to the induction of cancer [2]. There are two types of risks associated with radiation, deterministic and stochastic. Deterministic risks are those with a predictable effect directly related to the quantity of radiation exposure, such as radiation burns. Stochastic risks are those associated with the effects of chance mutations which occur at random but are based on the level of radiation exposure. With increasing exposure the probability of these mutations is increased, possibly resulting in radiation-induced cancers [3, 4]. Radiation exposure due to medical imaging is typically associated with stochastic carcinogenic risks, particularly the development of leukemia, thyroid and some solid organ cancers, as well as long-term risks of cataracts, sterility and birth defects [4, 5].

Stochastic effects can also be caused by many other factors, not only by radiation. Since everybody is exposed to natural radiation and to other factors, stochastic effects can arise in all of us regardless of the type of work (working with radiation or not). Whether or not an individual develops the effect is simply a question of chance. Since there is no evidence of a lower threshold for the appearance of stochastic effects, the practical course is to ensure that all radiation exposures follow a principle known as ALARA (As Low As Reasonable Achievable) [6].

The most important risk from exposure to radiation is cancer. Much of our knowledge about the risks from radiation is based on studies of more than 100,000 survivors of the atomic bombs at Hiroshima and Nagasaki, Japan, at the end of World War II. Other studies of radiation industry workers and studies of people receiving large doses of medical radiation also have been an important source of knowledge. Scientists obtained many things from these studies. The most important things [7] are found such as:

- The higher the radiation dose, the greater the chance of developing cancer.
- Cancers caused by radiation do not appear until years after the radiation exposure.
- Some people are more likely to develop cancer from radiation exposure than others.

Although such levels of exposure rarely happen, a person who is exposed to a large amount of radiation all at one time could become sick or even die within hours or days. This level of exposure would be rare and can happen only in extreme situations, such as a serious nuclear accident or a nuclear attack [7]. Though, the excessive level of radiation is harmful for human body, it has been using in medical sector such as X-ray, Computed Tomography (CT) and cancer treatment.

Computed Tomography (CT) scanner was invented by Sir Hounsfield in 1972. The invention of Computed Tomography is considered to be the greatest innovation in the field of radiology since the discovery of X-rays. Now a day"s Computed Tomography (CT) has become an invaluable diagnostic tool in radiology department. It delivers non-superimposed, cross-sectional images of the body, which can show smaller contrast differences than conventional X-ray images. This allows better visualization of specific differently structured soft-tissue regions. This cross-sectional imaging technique provided diagnostic radiology with better insight into the pathogenesis of the body [8]. In CT scans several X-ray beams are sent simultaneously from different angles in the human body instead of a single X-ray beam. CT can produce a much better quality organ image than that produced by an ordinary X-ray. As a result the use of CT imaging has been increased rapidly throughout the world [9].

Today, approximately 85.3 million CT scans are performed annually in the United States alone, where it was about 62 million in 2006, which indicates that the CT technology has evolved rapidly [10]. In perspectives of Bangladesh there is no any accurate statistics.

The first spiral CT scanner was "Siemens SOMATOM Plus" system [8]. Depending on the data projection, scanning configuration, scanning motions and detector arrangement CT evolution may be acquired in one of several possible geometries in terms of generation described below:

(i) First Generation (Parallel-Beam Geometry): Parallel-beam geometry is technically the simplest technically and the easiest with which to understand the important CT principles. Multiple measurements of X-ray transmission are obtained using a single highly collimated X-ray pencil beam and detector. The beam is translated in a linear motion across the patient to obtain a projection profile. The source and detector are then rotated about the patient isocenter by approximately 1 degree and another projection profile is obtained. This translate-rotate scanning motion is repeated until the source and detector have been rotated by 180 degrees. The highly collimated beam provides excellent rejection of radiation scattered in the patient; however, the complex scanning motion results in long (approximately 5 minutes) scan times. This geometry was used by Hounsfield in his original experiment in 1980, but is not used in modern scanners [11].

(ii) Second Generation (Fan Beam, Multiple Detectors): Scan times were reduced to approximately 30 s with the use of a fan beam of X-rays and a linear detector array. A translate-rotate scanning motion was still employed; however, a larger rotate increment could be used, which resulted in shorter scan times. The reconstruction algorithms are slightly more complicated than those for first-generation algorithms because they must handle fan-beam projection data.

(iii) Third Generation (Fan Beam, Rotating Detectors): A fan beam of X-rays is rotated 360 degrees around the isocenter. No translation motion is used; however, the fan beam must be wide enough to completely contain the patient. A curved detector array consisting of several hundred independent detectors is mechanically coupled to the X-ray source and both rotate together. As a result, these rotate only motions acquire projection data for a single image in as little as 1s. Third-generation designs have the advantage that thin tungsten septa can be placed between each detector in the array and focused on the X-ray source to reject scattered radiation.

(iv) Fourth Generation (Fan Beam, Fixed Detectors): In a fourth-generation scanner, the X-ray source and fan beam rotate about the isocenter, while the detector array remains stationary. The detectors are calibrated twice during each rotation of the X-ray source, providing a self-calibrating system. Third-generation systems are calibrated only once every few hours. Two detector geometries are currently used for fourth-generation systems: (i) a rotating X-ray source inside a fixed detector array and (ii) a rotating X-ray source outside a rotating detector array.

(v) Fifth Generation (Scanning Electron Beam): Fifth-generation scanners are unique in that the X-ray source becomes an integral part of the system design. The detector array remains stationary, while a high-energy electron beams are electronically swept along a semicircular tungsten strip anode and X-rays are produced at the point where the electron beam hits the anode, resulting in a source of X-rays that rotates about the patient with no moving parts. Projection data can be acquired in approximately 50 ms, which is fast enough to image the beating heart without significant motion [11].

1.2 Objectives of the Present Study

Organ doses from CT scanning are considerably larger than those from corresponding conventional radiography. For example, a conventional anterior–posterior abdominal X-ray examination results in a dose to the stomach of approximately 0.25 mGy, which is at least 50 times smaller than the corresponding stomach dose from an abdominal CT scan [12]. Although CT scans are very useful clinically, CT procedure has an inherent potential to cancer in a patient. This is because CT is a source of ionizing radiation. Therefore, it is important to estimate the effect of CT technology on public health in terms its medical benefit. Although the immediate benefit to the individual patient can be substantial, the relatively high radiation dose associated with CT compared with conventional radiography has raised health concerns [12-18]. Due to these concerns people that are likely to have repeated exposure to radiation are typically monitored and restricted to ensure that they are not over-exposed to high levels. The radiation doses to particular organs from any given CT study depend on a number of factors. The most important are the number of scans, the tube current, scanning time in milliampere-second (mAs), the size of patient, scan range, the scan pitch (the degree of overlap between adjacent CR slices), the tube voltage in the kilovolt peaks (kVp) and the specific design of the scanner being used [19]. Reducing peak kilovotage (kVp) can be an effective means of reducing the radiation dose imparted during an examination [20]. Decreases in kVp can result in nonlinear and exponential increases in image noise. Many of these factors are under the control of the radiologist or radiology technician. Ideally, they should be tailored to the type of study being performed and to the size of the particular patient, a practice that is increasing but is by no means universal [21]. It is always the case that the relative noise in CT images will increase as the radiation dose decreases, which means that there will always be a tradeoff between the need for low-noise images and the desirability of using low doses of radiation [22].

Recently, a new CT machine (GE-Light Speed VCT) has been installed in a renowned hospital of Dhaka city. The fore said several factors for this machine have not yet been investigated till now. Therefore, this research work has been undertaken.

The main objectives of the present research are to

- ❖ measure the absorbed dose of the patients at the scanned region for different type CT imaging procedure and compare the dose with the guidance level.
- ❖ determine the effective dose per scan for different type CT imaging procedure.
- ❖ estimate the lifetime attributable risk of cancer for different type CT imaging procedure.
- ❖ make a suggestion to minimize the dose as low as reasonably achievable (ALARA).

2.1 Literature Review

Scientist all over the world investigated the radiation dose of patient for computed tomography (CT) scan of different organs of human body using different types of dosimeters. A very few works has been done in our country in this field. So, it is important to know about radiation dose during CT scan in Bangladesh. Some of the previous works which are most relevant to the present study will be reviewed in the subsequent pages.

Rashid M. H. et al. [23] measured radiation exposure and the associated lifetime attributable risk of cancer for common CT imaging procedures at a hospital in Dhaka city using thermoluminescence (TL) dosimeters. It was found that the minimum dose was for CT head examination. The largest radiation contribution to the sample population was from „CT abdomen and pelvis.‟ The LAR of cancer was also estimated using risk calculator Xrayrisk.com, which uses the Linear Nothreshold Model (LNT). The maximum and minimum value of LAR was found for „CT urography‟ and „CT brain‟ respectively and also the LAR decreases with patient age.

Islam M. R. [24] had determined patient dose during common computed tomography imaging procedure at a hospital in the Dhaka city using thermoluminescence (TL) dosimeters. The effective dose of twenty six patients was calculated for different types of CT imaging. The maximum and minimum value of effective dose was obtained 50.26 mSv for CT abdomen and 1.99 mSv for CT head scan respectively. The lifetime attributable risk (LAR) of cancer was also estimated. It was also observed that LAR increases with decreasing age and increasing effective dose.

Huda W. and Vance A. [25] have determined typical organ doses and the corresponding effective doses to adult and pediatric patients undergoing a single CT examination. Heads, chests and abdomens of patients ranging from neonates to oversized adults (120 kg) were modeled as uniform cylinders of water. Monte Carlo dosimetry data were used to obtain average doses in the directly irradiated region. Dosimetry data were used to compute the total energy imparted, which was converted into the corresponding effective dose using patient size dependent effective dose per unit energy imparted coefficients. Representative patient doses were obtained for scanning protocols that take into account the size of the patient being scanned by typical MDCT scanners. Representative organ absorbed doses in CT are substantially lower than threshold doses for the induction of deterministic effects and effective doses are comparable to annual doses from natural background radiation.

Huda W. [26] has investigated radiation doses and risks in chest Computed Tomography examinations. Patient dose calculations were based on the characteristics of 16-slice CT scanner from 4 imaging equipment vendors. The dose–length product (DLP) was used to quantify the amount of radiation used to perform chest CT examinations. Values of DLP were converted into a corresponding effective dose (E) using age-dependent E/DLP conversion coefficients applicable to chest CT examinations. Calculations of effective doses were performed for a typical chest CT examination, as well as for a low-dose protocol for patients with cystic fibrosis. Effective doses were used to estimate nominal cancer risks. It was concluded that patients undergoing chest CT examinations should have a benefit that exceeds the (small) radiation risk.

Ware D. E. et al. [27] have determined the radiation effective dose to adult and pediatric patients undergoing abdominal computed tomographic examinations. CT technique factors (tube voltage, current, scanning time ect.) were obtained for three groups of randomly selected patients undergoing abdominal CT examinations: 31 children aged 10 years or younger; 32 young adults" aged 11–18 years; and 36 adults older than 18 years. The radiographic techniques, together with the measured cross sections of patients, were used to estimate the total energy imparted to each patient. Each value of energy imparted was subsequently converted into the corresponding effective dose to the patient, taking into account the mass of the patient. Values of energy imparted to patients undergoing abdominal CT examinations were a factor of three times higher in adults than in children, but the corresponding patient effective doses were 50% higher in children than in adults.

Miglioretti D. L. et al. [28] have estimated the radiation exposure as well as cancer associated with CT scan in pediatrics. Radiation doses were calculated for 744 CT scans performed between 2001 and 2011.The use of CT scan doubled for children younger than 5 years of age and tripled for children 5 to 14 years of age between 1996 and 2005, remained stable between 2006 and 2007 and then began to decline. Projected lifetime attributable risks of cancer were higher for younger patients and girls than for older patients and boys and they were also higher for patients who underwent CT scans of the abdomen or spine than for patients who underwent other types of CT scans. The increased use of CT in pediatrics, combined with the wide variability in radiation doses has resulted in many children receiving a high-dose examination.

Qu X. M. et al. [29] had investigated dose reduction of cone beam CT (CBCT) scanning for the entire oral and maxillofacial regions with thyroid collars. An anthropomorphic adult human male phantom (ART-210; Radiology Support Devices, Inc., Long Beach, CA) was used. The absorbed doses were measured using thermoluminescent dosimeter (TLD). The scans were carried out with and without thyroid collars. Effective organ dose and total effective dose were derived using International Commission on Radiological Protection 2007 recommendations. Thyroid collars can effectively reduce the radiation dose to the thyroid and oesophagus if used appropriately.

Huda W. et al. [30] have calculated effective radiation dose at head and abdomen CT in pediatric and adult patients. Cylindrical water-equivalent phantoms were modeled for patients aged newborn to adult and the energy imparted per unit axial exposure was computed. To determine the energy imparted to the simulated patients of different ages undergoing head and abdomen CT examinations, X-ray technique factors were combined with measured CT axial exposures. Body region specific ratios were calculated for effective dose per unit energy imparted and these ratios were corrected for patient mass to obtain the effective dose to simulated patients. With use of standard techniques, the energy imparted to simulated patients at CT always increased with patient size, but the effective dose was higher in children than in adults. At CT in the head and abdomen, effective doses were highest in newborns.

Osei E. K. and Darko J. [31] surveyed organ equivalent and effective doses from radiological examinations. Organ and effective doses were estimated for 94 patients who underwent CT examinations and for 338 patients who had conventional radiography examinations. The OrgDose (Organ effective doses, version 2) program was used for the estimation of effective doses. The entrance surface doses had a wide range even for the same examination: 0.44–10.31 mGy (abdomen) and 0.66–16.08 mGy (lumbar spine) and the corresponding effective dose ranges 0.025–0.77 mSv and 0.025–0.95 mSv respectively. Effective dose for adult abdomen-pelvis CT examinations ranges 5.4–19.8 mSv with a mean of 13.6 mSv and for pediatrics ranges 2.1–5.5 mSv with a mean of 2.7 mSv. The mean effective dose for adult chest and head CT examinations were 7.9 and 1.8 mSv respectively and for pediatrics were 1.7 and 1.1 mSv. It is very important in the diagnostic radiology departments to monitor and control doses to patients during imaging procedures. The doses delivered to patients in any medical imaging procedure should always be optimized for the given purpose.

Salibi P. N. et al. [32] had studied on the lifetime attributable risk of cancer from CT among patients surviving severe traumatic brain injury. A retrospective cross-sectional study was conducted with prospectively collected data on patients 16 years old and older admitted with a Glasgow coma scale score of 8 or less to a single level 1 trauma center from 2007 to 2010. The effective dose of each CT examination the patients underwent was predicted with literature-accepted effective dose values of standard helical CT protocols. The lifetime attributable risk of cancer and related mortality incurred as a result of CT were estimated with the cumulative effective dose incurred from the time of injury to a 1-year follow-up evaluation. Radiation exposure from the use of CT in the evaluation and management of severe traumatic brain injury causes negligible increases in lifetime attributable risk of cancer and cancer-related mortality.

Hirata M. et al. [33] measured radiation dose in cerebral perfusion studies with a multi detector row computed tomography (MDCT) scanner on various voltage and current settings using a human head phantom. Radiation doses were measured using a total of 41 thermoluminescent dosimeters (TLDs) placed in the human head phantom. Thirty-six TLDs were inside and three were on the surface of the slice of the X-ray beam center and two were placed on the surface 3 cm caudal assuming the lens position. Average radiation doses of surface, inside and lens increased in proportion to the increases of tube voltage and tube current. In cerebral CT perfusion study, radiation dose can vary considerably.

Bindman R. S. et al. [34] had measured lifetime attributable risks of cancer during CT examination. They conducted a retrospective cross-sectional study describing radiation dose associated with the 11 most common types of diagnostic CT studies performed on 1119 consecutive adult patients at 4 San Francisco Bay Area institutions in California in 2008. They estimated lifetime attributable risks of cancer by study type from these measured doses. Radiation doses varied significantly between the different types of CT studies. An estimated LAR of cancer for routine head CT of women was 1 in 8100 and of men 1 in 11080.

Bindman R. S. et al. [35] calculated the effective dose and lifetime attributable risk (LAR) of cancer associated with CT examinations. The 11 CT types examined included 3 head and neck studies, 4 chest studies and 4 abdomen and pelvis studies. The mean effective dose varied widely in between study types. The mean effective dose for abdomen, chest and head CT scanning were obtained 15 mSv, 8 mSv and 2 mSv respectively. This study provides evidence that radiation exposure from commonly performed CT examinations is both higher and more variable than previously recognized, contributing to a substantially increased risk of cancer, particularly among younger women.

The development of computed tomography (CT) in the early 1970s revolutionizes medical radiology. Physicians were able to obtain high-quality tomographic (cross-sectional) images of internal structures of the body [11]. CT provides high quality X-ray imaging with substantial benefits in healthcare, although patient doses are relatively high, often exceeding 10 mSv effective dose per examination [36]. In computed tomography (CT) imaging, only a relatively small percentage of the incident energy fluence on the patient is transmitted to the radiation detector and subsequently used to create the image [37]. Most of the incident photons are either absorbed by the patient or scattered out of the imaged section and thus do not contribute to image formation. For a given X-ray beam, the relative proportions of the transmitted, scattered and absorbed photons will depend on the patient shape, size, and composition [38]. The energy absorbed by the patient will be a measure of the stochastic patient risk [39] and the energy fluence transmitted will determine the amount of noise (quantummottle) in the resultant image. Changes in patient size from the newborn to oversized adult are very large and play an important role in determining both patient doses and the resultant CT image quality [40]. Clinical application of the technique has continued to increase such that CT examinations now account for approximately 40% of the annual collective dose from medical X-rays in the UK whilst representing only 5% of their total number [41].

3. 1 Computed Tomographic System

The fundamental task of CT system is to make extremely large number of (approximately 500,000) highly accurate measurements of X-ray transmission through the patient in precisely controlled geometry. A fundamental system of scanner generally consists of a gantry, a patient table, a control console and a computer as shown in Figure 3.1.

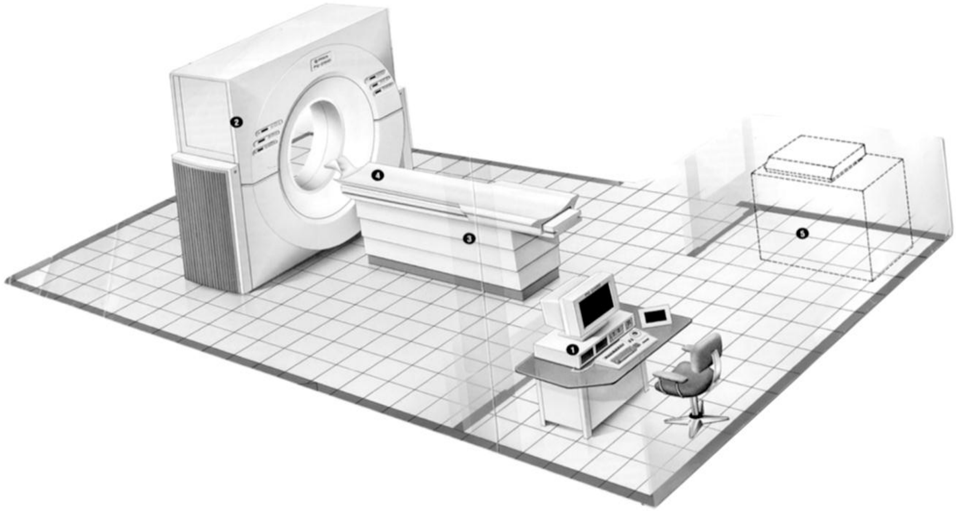


Figure 3.1: Schematic diagram of a typical CT scanning system

Gantry

The gantry contains the X-ray source, X-ray detectors and the data–acquisition system (DAS). The X-ray tube and detector are mounted onto a rotating gantry and rotate around the patient shown in Figure 3.2.

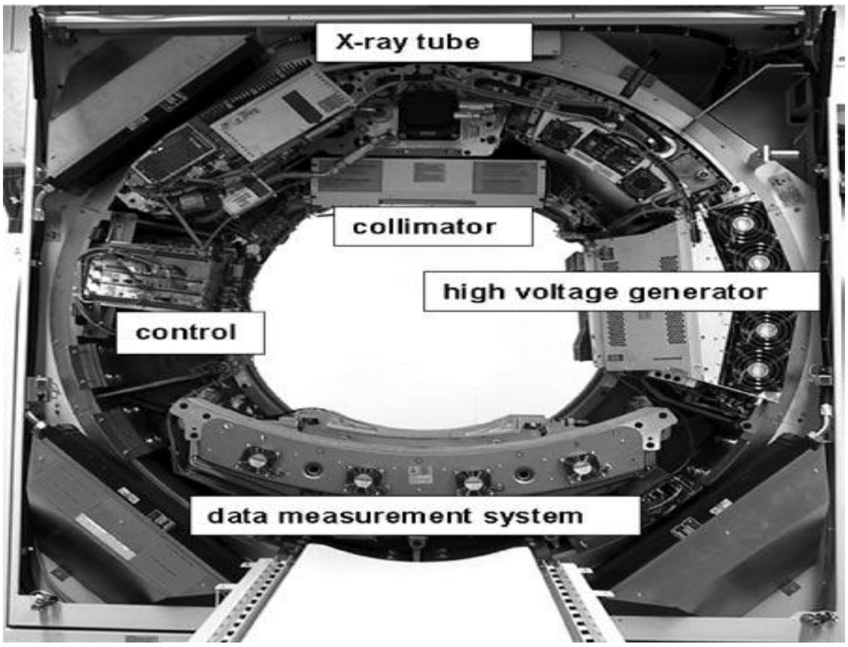


Figure 3.2: Major Internal Components of CT gantry

In a multi-detector CT (MDCT) system, the detector comprises several rows and more detector elements that cover a scan field of view of usually 50 cm. The X-ray attenuation of the object is measured by the individual detector elements

All measurement values acquired at the same angular position of the measurement system form a “projection” or “view.” Typically, 1,000 projections are measured during each 360° rotation [42].

X-ray Source

Almost all of CT scanners use bremsstrahlung X-ray tubes (Figure 3.3) as the source of radiation. These tubes are produced X-ray by accelerating a beam of electrons onto a target anode. The anode area from which X-ray are emitted, projected along the direction of the beam is called the focal spot. Most systems have two possible focal spot sizes, approximately 0.5×2.5 mm and 1.0 × 2.5 mm. A collimator is used to control the width of the imaged slice. The power required to maintain these tubes are typically 120 kV at 200 mA to 500 mA and frequency operating between 5 and 50 kHz [11].

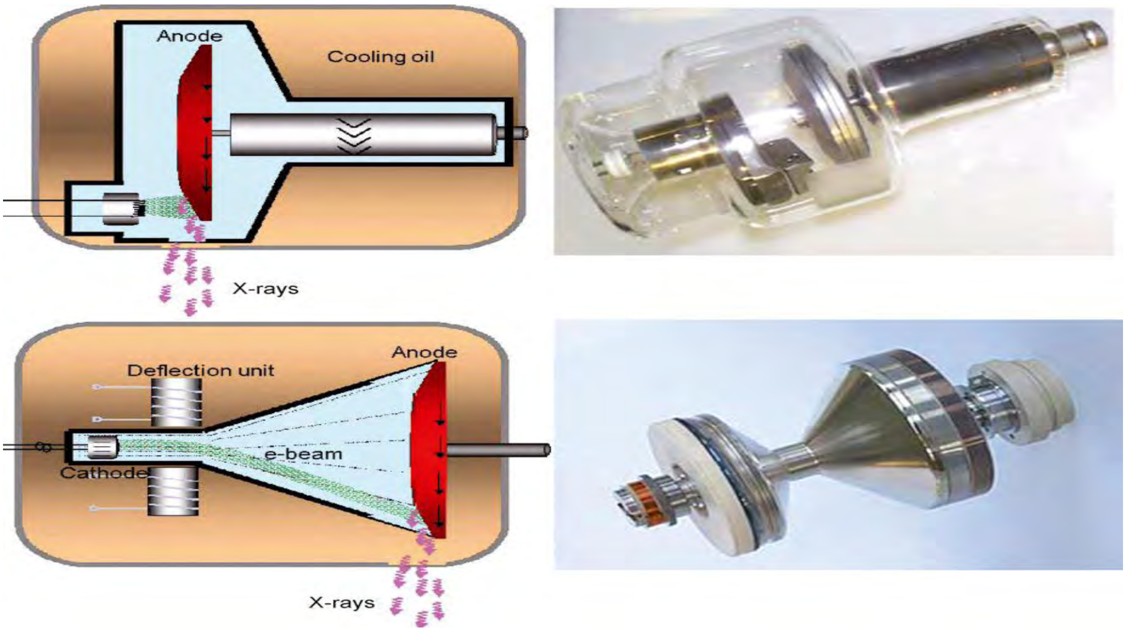


Figure 3.3: Conventional X-ray tube

The intensity of the X-ray beam is attenuated by absorption and scattering processes as it passes through the patient. The degree of attenuation depends on the energy spectrum of the X-ray as well as on the average atomic number and mass density of the patient tissues.

X-ray Detector

X-ray detectors used in CT system must have a high overall efficiency to minimize the patient radiation dose have a large dynamic range and be very stable with time and be insensitive to temperature variation within the gantry. The detector efficiency depends on three factors which are geometric efficiency, quantum efficiency and conversion efficiency. Geometric efficiency means the area of the detectors sensitivity as a fraction of the total exposed area. Quantum efficiency refers to the fraction of incident X-ray on the detector that are absorbed and contributed to the measured signal. On the other hand, conversion efficiency refers to the ability to accurately convert the absorbed X-ray signal into an electrical signal. The product of these three efficiencies is called overall efficiency of the detector and its value generally lies between 0.45 and 0.85. If the efficiency is less than 1, it is called non-ideal detector system. Modern commercial systems use one of two detector types namely: (i) solid-state detector and (ii) gas ionization detector.

(i) Solid-state Detectors: Solid-state detectors consist of an array of scintillating crystals and photodiodes as illustrated in Figure 3.4.

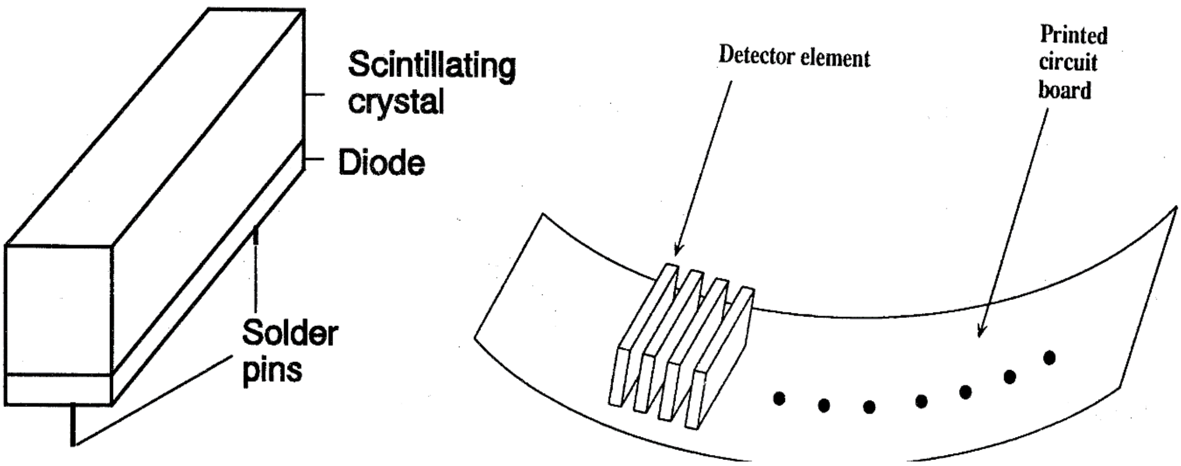


Figure 3.4: A solid-state detector consists of a scintillating crystal and photodiode combination

The scintillators normally a ceramic material made of rare earth oxides. Solid-state detectors generally have very high quantum and conversion efficiencies and a large dynamic range.

(ii) Gas Ionization Detector: Gas ionization detectors consist of an array of chambers (Figure 3.5) containing compressed gas (usually xenon at up to 30 atm pressure).

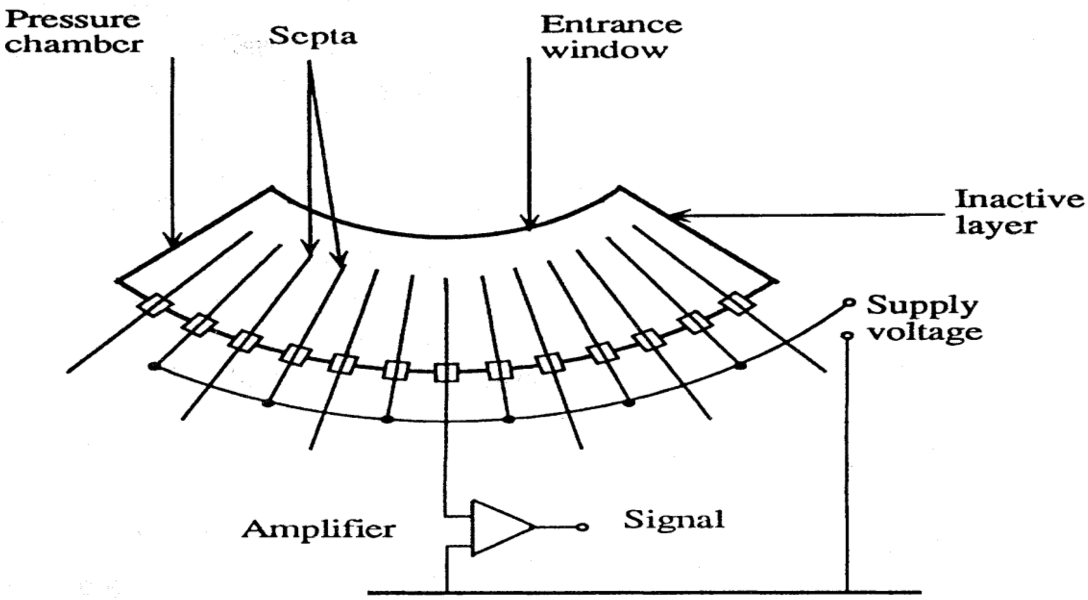


Figure 3.5: Gas ionization detector arrays consist of high-pressure gas in multiple chambers separated by thin septa

A high voltage is applied to tungsten septa between chambers to collect ions produced by the radiation. Gas ionization detectors have excellent stability and a large dynamic range but have lower quantum efficiency than solid-state detectors.

3.2 Scanning System of CT

Helical Scan

Helical CT is often referred to as "volume scanning". This implies a clear differentiation from conventional CT and the tomographic technique used there. Helical CT uses a different scanning principle. Unlike in sequential CT, the patient on the table is moved continuously through the scan field in the z direction while the gantry performs multiple 360° rotations in the same direction shown in Figure 3.6.

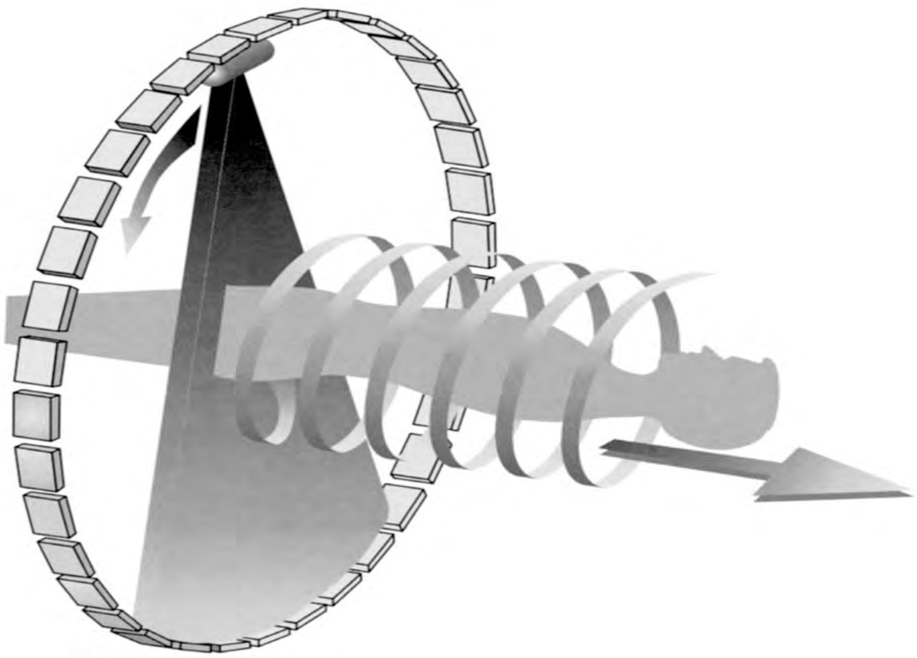


Figure 3.6: Helical scanning around the patient

The table movement in the z direction during the acquisition will naturally generate inconsistent sets of data, causing every image reconstructed directly from a volume data set to be degraded by artifacts [8].

Axial Scan

Computerized axial tomography (CAT) scan can reveal some soft-tissue and other structures that cannot be seen in conventional X-rays. Using the same dosage of radiation as that of an ordinary X-ray machine, an entire slice of the body can be made visible with about 100 times more clarity with the CAT scan. The "cuts"(tomograms) for the CAT scan are usually made 5 or 10 mm apart. The CAT machine rotates 180 degrees around the patient's body; hence, the term "axial." The machine sends out a thin X-ray beam at 160 different points shown in Figure 3.7.

Figure 3.7: Axial scanning image

Crystals positioned at the opposite points of the beam pick up and record the absorption rates of the varying thicknesses of tissue and bone. The data are then relayed to a computer that turns the information into a 2-dimensional cross-sectional image [43].

There are many methods currently in use for quantifying ionizing radiations. In the present study, to measure the radiation dose thermoluminescent (TL) dosimeter has been used during CT scan. After completing the scan TL chips were read out by Harshaw TLD Reader (model 3500) in the "Health Physics Division" of Atomic Energy Centre, Dhaka. Finally, the effective dose as well as the LAR of cancer due to CT imaging procedure for an individual patient was estimated.

4.1 Thermoluminescence Dosimetric System

Thermoluminescence dosimetric system consists of Lithium Fluoride (LiF) TLDs, a TLD annealing oven and a TLD reader.

4.1.1 Lithium Fluoride (LiF) TLDs

Thermoluminescence of lithium fluoride has attracted immense attention because of its complexity and also usefulness as a dosimetric material [44]. In the present study, LiF with impurity doping in the form of chips having commercial names of TLD-100 (natural isotopes with ratio of 7.5% Li and 92.5% F and of size 1/8 inch ×1/8 inch × 0.035 inch and weighting about 24 mg) has been used as TLD and the chips are supplied by the Harshaw Chemical Company, Cleveland, Ohio, USA. The effective atomic number of dosimetric LiF (effective Z=8.18) is close to that for soft tissue (effective Z=7.4) and for air (effective Z= 7.65). Hence for identical exposures to radiation, the amount of energy absorbed by LiF is very close to that absorbed by an equal mass of soft tissue or air. For this reason, LiF is widely used for the measurement of radiation doses within staff member, patients, personnel dosimetry and other dosimetric measurements.

4.1.2 TLD Annealing Oven

For each TL substance used in dosimetric applications, it is very important to anneal the TL substance for restoring its basic condition after an irradiation. The annealing of a TL material has two purposes: the first is to empty the traps of the phosphor completely after the irradiation and readout cycle; the second is to stabilize the electron traps in order to obtain the same glow curves after repeated irradiations and thermal treatment. For any TL material, the annealing procedure is similar, in some cases such as LiF, it is very difficult because if the procedure is not strictly the same, one can obtain significantly different results from repeated irradiations to the same exposure. All TL phosphors display some changes in their TL characteristics depending on the thermal treatment which they receive. A thermal annealing is almost required, to ensure complete readout of stored signal and repeated use of the phosphor without significant change in its thermoluminescent sensitivity. Therefore, all dosimeters should be identically annealed, as far as practically possible, to standardize their sensitivities and background, before making radiation measurement. Before irradiation, all TLDs were annealed in a TLD oven. In this study, to anneal the TLDs Victoreen Model 2600-62 annealing oven has been used as shown in Figure 4.1. This oven anneal the TLDs (LiF;Mg, Ti-TLD-100) one hour at 400^0 C and two hours at 100^0 C. After completion the annealing cycle, TL materials were cooled down to room temperature in the oven for whole night by switching off the oven. The TL sensitivity, stability, precision and minimum detectable absorbed dose can be affected by storage and handling of the dosimeter. The most important effects produced by storage and handling of dosimeters can be divided into those due to (1) environmental factor such as temperature, humidity, ultraviolet (UV), visible radiation and other agents and (2) physical handling factors such as sieving, dispensing, cleaning, picking up, etc. Many phosphors respond to normal ambient levels of UV and visible radiation. The effects are two types: the production of a light-induced TL signal and the photo-transfer and subsequent retrapping of trapped charge carriers.

In some phosphors the latter effect can result in increased fading of the dosimetry traps, while in others a transfer of electrons to the dosimetry traps results in an apparent increase in the subsequently recorded TL signal.

Figure 4.1: Victoreen Model 2600-62 TLD annealing Oven

After proper annealing, all TL dosimeters were processed and prepared for experimental work and then stored and handled carefully to protect them from a number of potentially adverse environmental conditions. Moreover, all TL dosimeters were cleaned with acetone in an ultrasonic bath from time to time.

4.1.3 TLD Reader

The Harshaw TLD Reader (Model 3500) provides cost-effective measurements of the radiation dose absorbed by individual TLD elements: ribbon (chips), rods, micro-cubes or powders. This instrument includes a sample drawer for a single element TLD dosimeter, a linear, programmable heating system and a cooled photomultiplier tube with associated electronics to measure the TL light output.

The WinREMS Software, which runs under Windows on a separate computer, provides the user interface, the reader control and the application software. After completing the scanning procedure of a patient, TL chips were read out by using the Harshaw TLD Reader (model 3500) shown in Figure 4.2.

Figure 4.2: Harshaw TLD reader (Model 3500) set up for dose measurement

The absorbed dose by each TL chip is obtained after completing read out procedure. The average absorbed dose is calculated by considering the TL chips of scanning region.

Specifications of Harshaw TLD Reader (Model 3500) [45]

(1) Warm up time: 30 minutes
(2) Test light stability: short term-less than 0.5 percent variation, based on 1 standard deviation of 10 consecutive readings performed at a constant temperature.
(3) Long term (0.5 to 110 hours) – 2 percent maximum deviation.
(4) TTP Reproducibility: ±1^{o}C

Linearity: Less than 1 percent deviation.

(5) TTP Capabilities:

Preheat temperature: Room Temperature to 400^0 C

Preheat time**:** 0 to 999 sec.

Acquire temperature: Room temperature to 400^0 C

Acquire time: 3-1/3 to 6000 sec.

Acquire rate: 1 to 50^oC/sec.

Anneal temperature: Room temperature to 400^0 C

Anneal time: 0 to 999 sec.

(6) Measurement range:

10 micro Gy to 1 Gy: Linear

10 Gy to 20 Gy : Supraliminal.

(7) Minimum Detectability:

Less than 10 micro Gy

4.2 Arrangement and Placement of TL Chips during CT Scan

To measure the radiation dose absorbed by the patient during CT scan TLD -100 chips were used. These TL chips were sealed in a uniform manner with 10 rows and 5 columns between two polythene sheets. Arrangement of TL chips between two polythene sheets is shown in Figure 4.3.

Figure. 4.3: Arrangement of TL chips between two polythene sheets

The dimension of TLD containing sheet was 36 cm × 45 cm. The sheet was placed on the patient table, just under the patient‟s body before starting an imaging procedure.

Figure 4.4 shows the placement of the polythene sheet containing TL chips before scanning procedure.

Figure 4.4: Placement of the TLD containing sheet on patient‟s bed just before starting of the scanning procedure

4.3 Types of CT Scan

In the present study CT scanning of abdomen, chest and head has been selected.

CT Scan of Abdomen

For abdomen CT scanning procedure 52 patients were selected. Among them 30 patients were male and 22 patients were female. The patient information such as age, sex, tube voltage, tube current and scanning time etc. were noted. In CT abdomen procedure, the tube voltage was 120 kV whereas tube current was varied from 420 mA to 700 mA and CT system was helical. Variation of the tube current during scan is due to variation of the weight of the patient. For each patient 50 TLD chips were used during each scan.

CT Scan of Chest

Twenty four patients were selected for chest CT scanning procedure. Among them 10 patients were male and 14 patients were female. Patient information such as age, sex, tube voltage, tube current and scanning time etc. were noted during each scan. In the chest CT scanning, the tube voltage was 120 kV and the tube current was varied for 200 mA to 700 mA. For each patient 50 TLD chips were used during each the CT scans. The scanning system is helical during the CT chest examination.

CT Scan of Head

Absorbed does measured for twenty four patients who undergo CT head examination. Among them 16 patients were male and 8 patients were female. The patient information such as age, sex, tube voltage, tube current and scanning time etc. were noted during the scan. In CT head procedure, the tube voltage was 120 kV and the tube current was varied from 320 mA to 700 mA depending upon the weight of the patient.

For each patient, 50 TLD chips were used during each scanning procedure. The scanning system is axial during head CT scanning. Figure 4.5 shows the CT machine which has been used.

Figure 4.5: Photograph of CT machine (GE-Lightspeed VCT)

4.4 Operating System of the CT Machine

The operating system of CT provides a dose report for a procedure, which is based on Monte Carlo Simulation Method [46]. This dose report for each scan was collected. Volumetric CT Dose Index (CTDIvol) and DLP were provided in this report. The CT protocol used for each individual patient was noted. Tube voltage, tube current, tube coverage, rotating speed of tube, motion of patient"s bed, pitch etc. are the variables of the CT protocol. For each patient the protocol applied was chosen based on the patient"s age, weight and scanning type. During the scanning period CT protocols used by operator and some additional information about patient (i.e, sex, age, etc.) was collected.

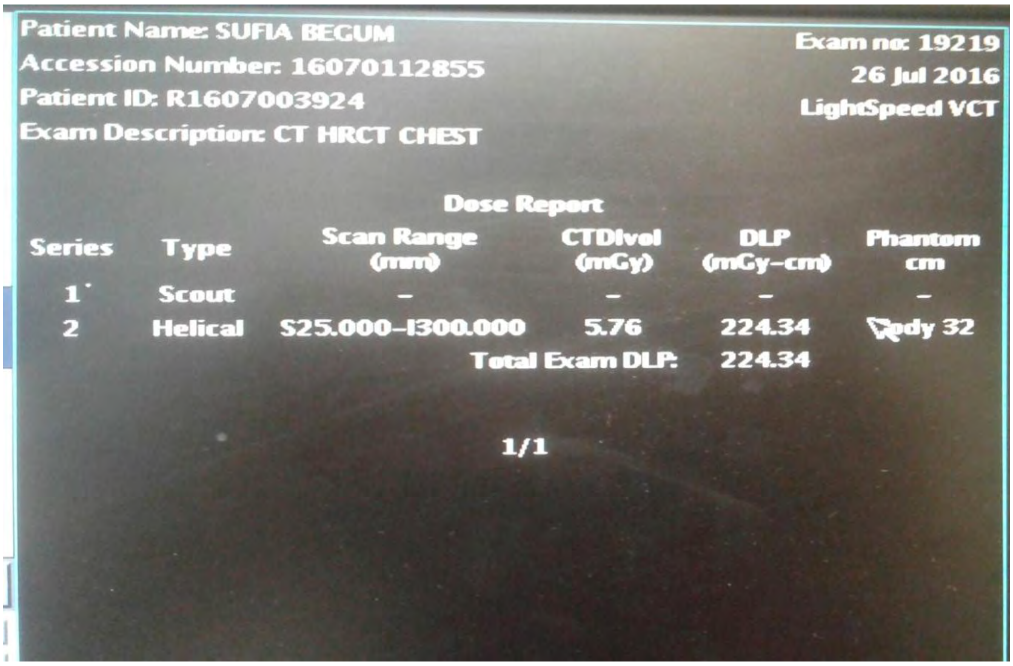


Figure 4.6: A dose report provided by the CT system

After completing the scanning procedure, a dose report is found for each patient as shown in Figure 4.6 which contains scanning length in millimeter scale, Volumetric CT Dose Index ($CTDI_{vol}$) in mGy unit and Dose Length Product (DLP) in mGy.cm unit.

4.5 Effective Dose Calculation

The CT Dose Index (CTDI) is estimates the average radiation output of a given scanner for a given scan protocol, at the central region of the scanning region consisting of multiple contiguous CT scans. Now, the average CTDI across the field of view is

$$CTDI_W = \frac{1}{3}\,CTDI_{100,center} + \frac{2}{3}\,CTDI_{100,periphery} \quad \text{......................... (4.1)}$$

It is also called the weighted CTDI and is calculated from the measured values of $CTDI_{100,center}$ and $CTDI_{100,periphery}$, where CTDI"s, for a scan length of 100 cm, at the central and peripheral regions, respectively, of a cylindrical acrylic phantom. $CTDI_{vol}$ is the pitch-corrected $CTDI_w$ for multi-slice non-contiguous scans and is displayed, for a specific scan protocol, on the console of a CT scanner. The energy delivered by a given scan protocol can be estimated by the Dose Length Product, DLP,

$$DLP = CTDI_{vol} \times \text{scan length } L = CTDI_w \times \frac{L}{p} \quad \text{..............................(4.2)}$$

Which is also displayed on the console. Here, *p* represents pitch

Effective dose measures the sensitivity of the tissue of the body part to be scanned for a patient of a given age. Effective dose is the product of the DLP and the conversion coefficient i.e.

Effective Dose = DLP × Conversion coefficient .... (4.3)

The conversion coefficient is available in European Guideline of CT [47] shown in appendix A (Table-A.1).

Dose Length Product (DLP) is the most significant parameter in CT scan. It is nothing but the product of scanning length and Volumetric CT Dose Index ($CTDI_{vol}$) and it is obtained from dose report.

DLP = (Measured $CTDI_{vol}$) × (Scanning length) .... (4.4)

4.6 Estimation of Cancer Risk

As a consequence of recent media coverage featuring the additional risk of cancer from CT scans, people have become more concerned about it. The lifetime attributable risk (LAR) is an estimate of cancer mortality caused by radiation exposure from CT scans, based on the Linear Nonthreshold Model (LNT) [48]. This model is used in radiation protection to estimate the long-term, biological damage caused by ionizing radiation. It assumed that the damage is directly proportional to the dose of radiation, According to this model, all dose levels radiation is always considered harmful with no safety threshold. The website X-rayrisk.com, in addition to being an educational site, contains a web-based calculator that allows one to estimate the LAR of cancer based on the information (namely, the body-region scanned, age, gender, average dose, etc.) supplied to the site for a given patient.

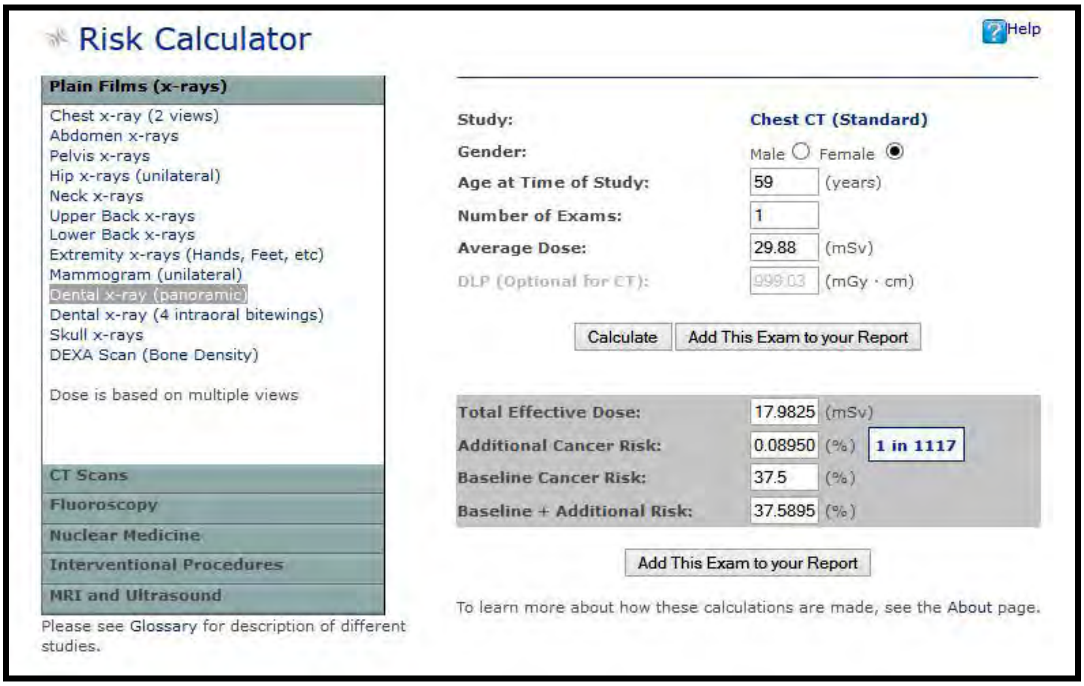


Figure 4.7: A view of the risk calculator in X-rayrisk.com.

This web- based calculator was used for risk estimation of individual diagnostic tests, associated with respective patients. It is very easy and simple to estimate life time attributed risk of cancer due to ionizing radiation using the risk calculator of X-rayrisk.com [49]. Figure 4.7 shows the view of the risk calculator.

This study was performed in a renowned hospital in Dhaka city. Patient‟s dose during CT imaging procedure by a modern multi-detector computed tomography (MDCT) scanner was measured. TL dosimetry system was used to measure the absorbed dose of patients. Using conversion coefficient of European Guideline for multi-detector CT (MDCT) [47], effective dose was calculated and a risk calculator [49] was used to measure the lifetime attributable risk (LAR) of cancer for individual patient.

5.1 Results and Discussion

Three different types of CT imaging procedures of one hundred patients were included in the present study. Figure 5.1 shows the age distribution of one hundred patients, among them fifty six were male and forty four were female patients. The three different types of CT imaging procedure are CT abdomen, CT chest and CT head.

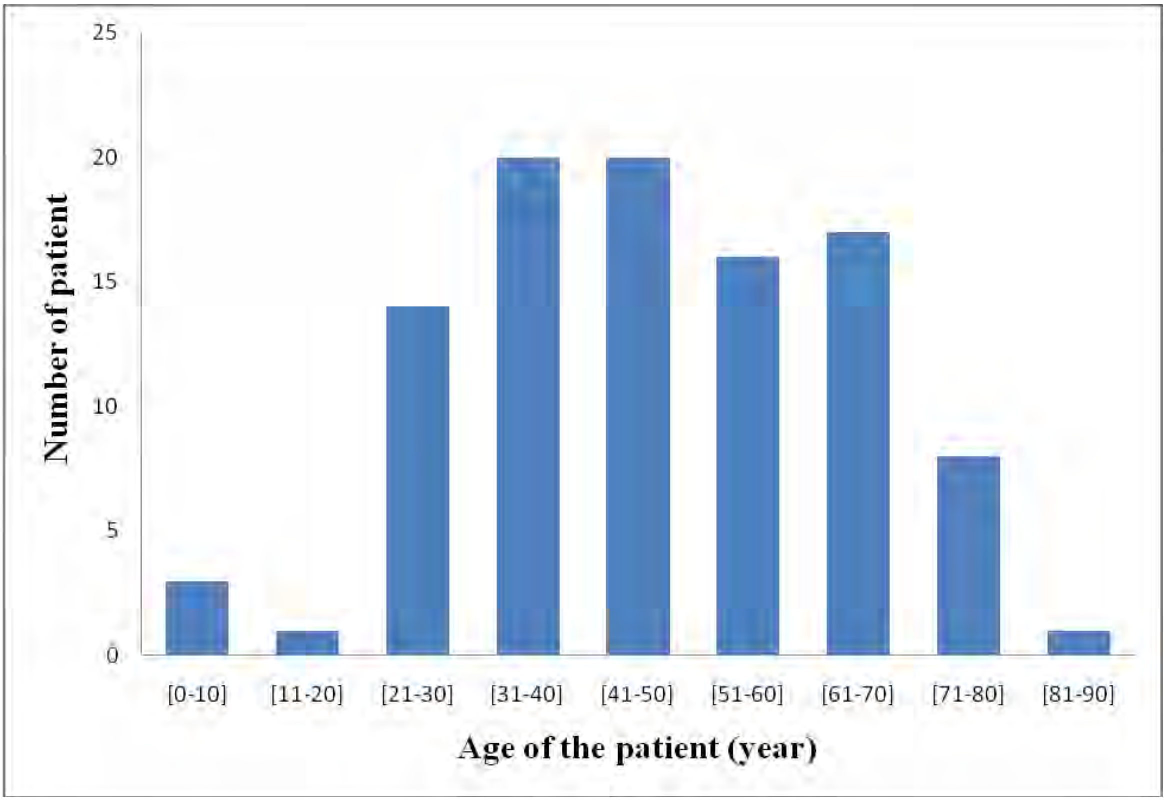


Figure 5.1: Age distribution of the patients undergoing CT imaging

Table 5.1: Absorbed dose per scan of the male patients during different type CT scan

SL no	Scanning region	Scanning system	Patient age (year)	Scanning length (cm)	Scanning duration (sec)	Tube current (mA)	Dose per scan (mSv)
01	Abdomen	Helical	1.5	23.5	2.72	420	4.09
02			3	23.5	8.8	420	21.81
03			24	27.0	3.05	700	21.19
04			26	42.6	5.68	700	14.64
05			27	50.95	16	420	23.45
06			31	40.1	15.7	420	23.1
07			33	40	4.22	500	29.8
08			33	38.5	3.77	500	10.07
09			34	46.5	5.00	700	6.67
10			35	28.05	3.36	700	10.76
11			37	77.75	6.44	500	18.18
12			39	49.0	9.26	700	18.42
13			40	45	4.68	500	9.68
14			42	44.7	20.3	420	28.46
15			43	44.1	5.82	500	41.3
16			43	23.9	19.77	500	15.37
17			44	43.0	15.5	420	23.86
18			46	48.65	5.32	500	13.58
19			48	26.1	12.8	420	20.00
20			50	47.5	4.9	500	9.15
21			52	50.2	10.2	500	6.33
22			53	40.0	14.5	420	21.5
23			55	34.0	14.58	700	1.27

SL no	Scanning region	Scanning system	Patient age (year)	Scanning length (cm)	Scanning duration (sec)	Tube current (mA)	Dose per scan (mSv)
24	Abdomen	Helical	56	37.7	17.2	420	29.07
25			57	23.6	10.2	420	22.84
26			64	27.7	15.00	420	20.41
27			71	26	4.22	700	9.44
28			72	46.75	4.77	500	25.66
29			72	15.1	2.82	500	12.85
30			79	40.0	4.22	700	20.75
31	Chest	Helical	35	10.8	27.1	200	15.02
32			50	29	3.63	500	14.65
33			54	26.9	3.36	650	13.49
34			61	27.7	3.72	650	16.17
35			62	23.3	3.95	650	24.56
36			63	13.3	6.69	280	23.26
37			65	29.6	7.2	420	14.7
38			65	24.3	4.04	650	13.24
39			67	32.8	3.63	650	10.72
40			70	32.2	10.49	650	8.08
41	Head	Axial	6	13.2	17	370	58.92
42			21	8.55	17	370	55.16
43			27	10.3	18	370	58.59
44			34	9.15	12.09	350	56.54

SL no	Scanning region	Scanning system	Patient age (year)	Scanning length (cm)	Scanning duration (sec)	Tube current (mA)	Dose per scan (mSv)
45	Head	Axial	35	5.45	18	370	63.05
46			35	12.2	9.00	350	42.66
47			39	7.35	18	370	79.05
48			46	7.7	20	370	17.54
49			48	6.1	36	200	38.49
50			52	5.83	18	370	60.5
51			55	6.16	18	370	69.37
52			60	5	16	370	59.84
53			65	5.06	18	370	75.2
54			66	6.8	48	200	64.15
55			68	9.5	16	370	56.05
56			77	3.61	18	370	66.04

Table 5.2: Absorbed dose per scan of the female patients during different type CT scan

SL no	Scanning region	Scanning system	Patient age (year)	Scanning length (cm)	Scanning duration (sec)	Tube current (mA)	Dose per scan (mSv)
01	Abdomen	Helical	23	43.2	13.89	500	15.46
02			24	27.1	14.7	420	23.35
03			27	46.0	5.32	500	17.56
04			28	12.7	10	420	20.7
05			29	40.5	5.18	500	14.12
06			30	40.0	14.5	420	20.51
07			36	28.8	11.6	420	18.8
08			39	25.2	5.18	700	28.42
09			40	30.8	15.8	420	24.79
10			40	41	4.32	700	6.15
11			42	26.5	11.1	420	18.99
12			47	30.2	14.5	420	17.49
13			48	35.8	4.85	700	18.6
14			50	28.1	14.5	420	23.84
15			53	43.5	4.5	500	22.63
16			54	39.4	4.22	700	27.9
17			56	74.4	4.07	700	10.16
18			60	39.9	5.95	700	7.87
19			61	42.3	5.18	500	14.99
20			65	40	17.26	700	13.26
21			75	34.8	4.86	700	7.36
22			84	35.2	23.16	500	8.6

SL no	Scanning region	Scanning system	Patient age (year)	Scanning length (cm)	Scanning duration (sec)	Tube current (mA)	Dose per scan (mSv)
23	Chest	Helical	20	58.1	4.07	650	5.33
24			42	58.5	4.07	700	18.6
25			42	12.3	20.3	350	60.36
26			44	38.5	3.64	700	19.72
27			44	23.8	3.91	650	23.64
28			50	41	4.32	650	68.7
29			55	33.5	3.63	650	9.6
30			55	29.6	7.18	650	35.01
31			56	68.4	5.46	650	16.7
32			59	32.5	3.54	700	18.35
33			60	27.4	3.5	650	9.38
34			67	47	4.86	500	19.31
35			68	22.9	2.9	700	17.02
36			70	27.2	3.41	650	11.92
37	Head	Axial	29	8	17	370	58.30
38			30	9.3	16	370	61.85
39			30	11.3	16	370	50.02
40			32	12.5	17	370	64.24
41			40	7.71	16	370	63.52
42			70	10.88	15	370	59.24
43			75	9.18	8	350	33.8
44			77	5.21	18	370	61.12

Table 5.1 and Table 5.2 show the absorbed dose per scan of the male and female patients during different type of CT imaging procedure respectively. From these Tables it has been observed that the maximum value of absorbed dose per scan was about 79.05 mSv in CT head scanning of a male patient of 39 years old. On the other hand, the minimum absorbed dose value was about 1.27 mSv in CT abdomen scanning of a male patient of 55 years.

Table 5.3: Effective dose and LAR of cancer of the male patient for different type CT scan

SL no	Scanning region	Age of the patient (year)	DLP (mGy.cm)	Effective dose (mSv)	LAR in %
01	Abdomen	1.5	75.88	2.27	0.08
02		3	335.19	10.06	0.4
03		24	481.11	7.22	0.22
04		26	411.40	6.17	0.14
05		27	804.05	12.06	0.22
06		31	757.11	11.36	0.2
07		33	798.56	11.98	0.24
08		33	1454.42	21.82	3.98
09		34	158.22	2.37	0.05
10		35	324.07	4.86	0.08
11		37	1078.2	16.17	0.13
12		39	2107.03	31.6	1.13
13		40	204.17	3.06	0.06
14		42	1353.69	20.31	0.18
15		43	2337.38	35.06	0.25
16		43	3061.95	45.93	2.36
17		44	701.23	10.52	0.14

SL no	Scanning region	Age of the patient (year)	DLP (mGy.cm)	Effective dose (mSv)	LAR in %
18	Abdomen	46	401.75	6.03	0.08
19		48	617.21	9.26	0.11
20		50	249.82	3.75	0.05
21		52	991.67	14.87	0.76
22		53	660.75	9.91	0.1
23		55	1004.06	15.06	0.14
24		56	114.50	16.718	0.12
25		57	478.8	7.18	0.09
26		64	723.64	10.85	0.07
27		71	787.58	11.814	0.43
28		72	967.63	14.51	0.07
29		72	1459.59	21.89	1.06
30		79	544.65	8.17	0.05
31	Chest	35	246.23	3.45	0.11
32		50	336.28	4.71	0.07
33		54	339.77	4.76	0.06
34		61	425.24	5.95	0.06
35		62	353.72	4.95	0.09
36		63	815.7	11.42	0.74
37		65	362.88	5.08	0.04
38		65	466.38	6.53	0.05
39		67	233.31	3.27	0.03
40		70	664.37	9.3	0.21

SL No	Scanning region	Age of the patient (year)	DLP (mGy.cm)	Effective dose (mSv)	LAR in %
41	Head	6	969.24	3.87	3.99
42		21	1166.96	2.45	0.62
43		27	1153.51	2.42	0.56
44		34	3861.44	8.11	7.10
45		35	1190.45	2.5	0.48
46		35	772.44	1.6	0.33
47		39	1375.18	2.89	0.54
48		46	1447.93	3.04	1.58
49		48	1505.31	3.16	0.62
50		52	1116.56	2.34	0.29
51		55	1291.02	2.71	0.31
52		60	1207.78	2.54	0.23
53		65	1391.6	2.92	0.25
54		66	3575.92	7.51	3.34
55		68	1171.29	2.46	0.17
56		77	1284.87	2.7	0.18

Table 5.4: Effective dose and LAR of cancer of the female patient for different type CT scan

SL no	Scanning region	Age of the patient (year)	DLP (mGy.cm)	Effective dose (mSv)	LAR in %
01	Abdomen	23	1751.09	26.27	2.35
02		24	683.73	10.26	0.38
03		27	626.04	9.39	0.26
04		28	434.54	6.52	0.29
05		29	3030.28	45.45	4.87
06		30	582.67	8.74	0.27
07		36	548.15	8.22	0.2
08		39	848.91	12.73	0.28
09		40	136.63	2.05	0.06
10		40	1092.53	16.39	0.24
11		42	508.02	7.62	0.17
12		47	379.57	5.69	0.13
13		48	434.91	6.52	0.13
14		50	608.48	9.13	0.16
15		53	570.28	8.55	0.14
16		54	719.87	10.8	0.16
17		56	872.7	13.09	0.11
18		60	245.35	3.68	0.04
19		61	2751.59	41.27	1.74
20		65	2920	43.8	3.44
21		75	252.09	3.78	0.02

SL no	Scanning region	Age of the patient (year)	DLP (mGy.cm)	Effective dose (mSv)	LAR in %
22	Abdomen	84	1627.23	24.41	0.66
23	Chest	20	1164.31	16.3	3.6
24		42	823.91	11.53	0.17
25		42	817.44	11.44	0.54
26		44	2519.88	35.28	2.62
27		44	247.36	3.46	0.19
28		50	528.52	7.4	0.46
29		55	829.14	11.6	0.49
30		55	959.92	13.43	0.6
31		56	683.7	9.6	0.09
32		59	729.09	10.21	0.09
33		60	221.46	3.1	0.05
34		67	691.95	9.69	0.07
35		68	443.06	6.2	0.06
36		70	835.73	11.7	0.12
37	Head	29	1031.27	2.17	0.80
38		30	963.31	2.02	0.83
39		30	886	1.86	0.67
40		32	1174.03	2.47	0.8
41		40	3404.4	7.14	5.43

SL	Scanning region	Age of the patient (year)	DLP (mGy.cm)	Effective dose (mSv)	LAR in %
42	Head	70	1026.25	2.16	0.20
43		75	592.69	1.24	0.09
44		77	1297.18	2.72	0.17

Table 5.3 and Table 5.4 show the effective dose and LAR of cancer for male and female patients respectively. The maximum value of lifetime attributable risk (LAR) of cancer was found 7.1 % in CT head scanning.

Figure 5.2 shows the average measured dose per scan at the scanned region. The average dose was obtained 17.6 mSv, 20.56 mSv and 57.22 mSv for CT abdomen, CT chest and CT head scanning respectively. Leswick D. A. et al. [50], obtained the average dose 15.5 mSv, 11.3 mSv and 2.7 mSv for CT abdomen, CT chest and CT head scanning respectively. The average dose per scan in CT head imaging was the maximum among the three types of CT imaging procedure and it was 57.22 mSv.

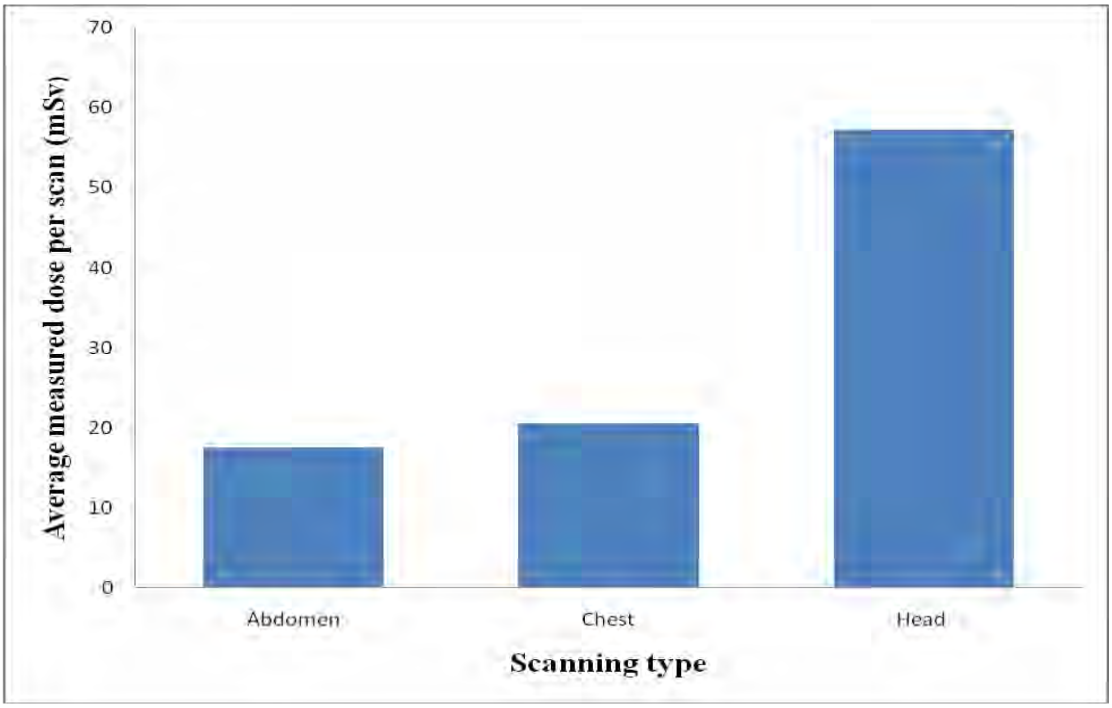


Figure 5.2: Average measured dose per scan and per test at the scanned region

According to American Nuclear Society [51] the average dose per person from all natural sources is about 0.62 mSv per year. International Standards allow exposure to 100 mSv every 5 years or 20 mSv per year with a maximum of 50 mSv in any given year. According to NSRC rule 1997 [52] the dose guidance level for CT head is 50 mSv in a single year and for CT abdomen is 25 mSv in a single year. But in the present study, the value of average measured dose per scan for head CT scanning exceeded these standard values where for abdomen it was within guidance level. The reasons appear to be the following: (a) very often more scans are performed for a procedure than is actually adequate for diagnosis, and/or (b) often the right protocol was not applied for a procedure, and/or (c) patient-size or age was not always considered for choosing the protocol. All these happen due to lack of knowledge and proper training of the operators.

Figure 5.3 shows a comparison of DLP value of diagnostic reference levels [53] for multi-detector CT scanner with the obtained DLP values of the present study. The obtained values were higher than the standard values for every type of CT scanning both for male and female patients. If DLP value increase effective dose will increase.

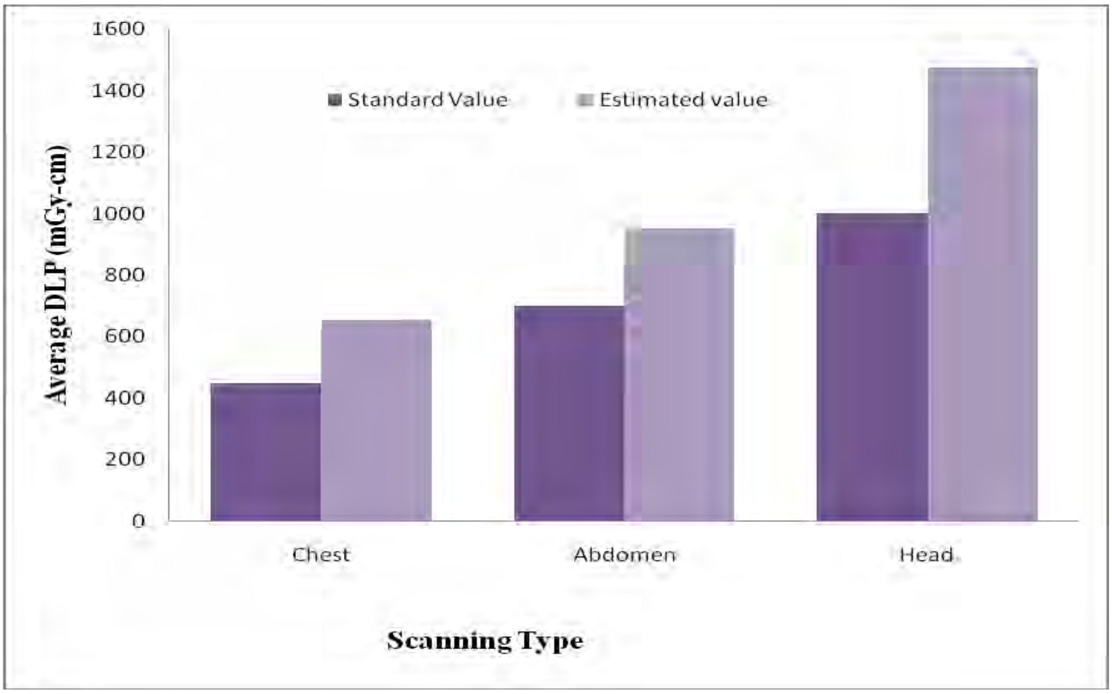


Figure 5.3 : A comparison of DLP with the standard value [52]

Figure 5.4 shows the effective dose per test per scan, which is a better measure of the health effect of CT procedures. The average value of effective dose was obtained 13.78 mSv for CT abdomen, 9.18 mSv for CT chest and 3.13 mSv for CT head respectively.

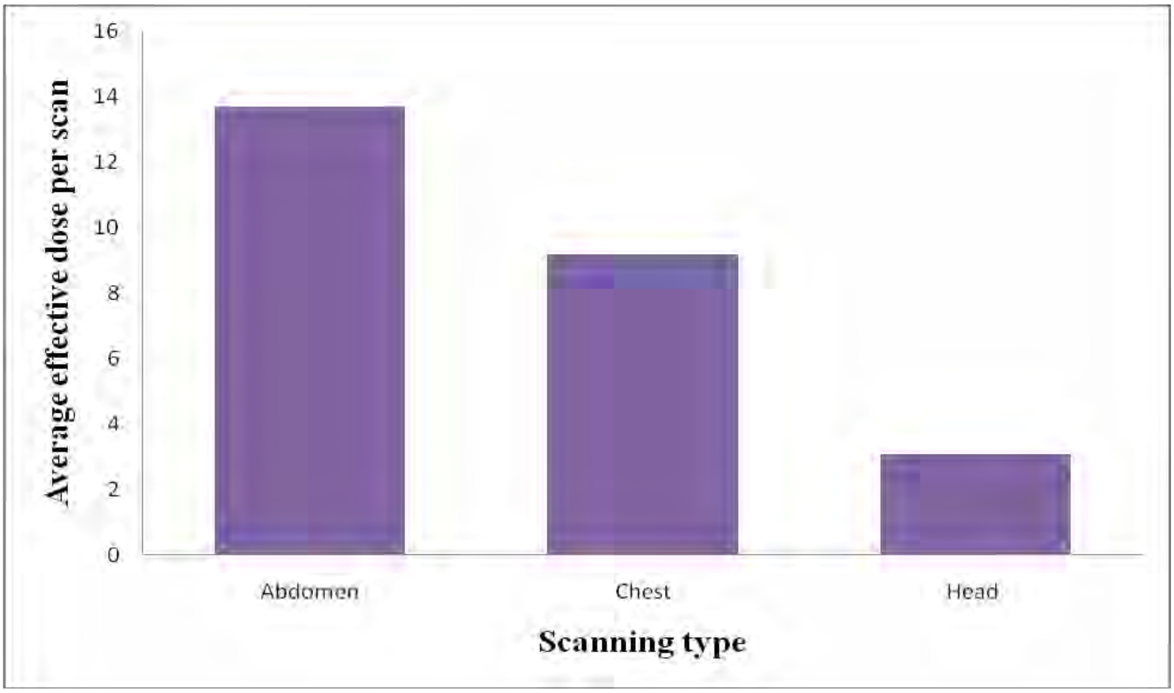


Figure 5.4: Average effective dose per scan and per test for different types of CT imaging procedure

E. K. et al. [31] had measured the average effective dose for abdomen, chest and head CT examinations were 13.6 mSv, 7.9 mSv and 1.8 mSv respectively.

In another investigation of Smith-Bindman R. et al. [35] the average effective dose for abdomen, chest and head CT scanning were 15 mSv, 8 mSv and 2 mSv respectively.

Table 5.5 shows the comparison of lifetime attributable risk (LAR) of cancer due to three types of CT imaging procedure for male and female patients.

For head CT scan the average value of LAR of cancer for female patient is 1 in 332 and for male patient it is 1 in 248. Smith-Bindman R. et al. [34] obtained the estimated LAR of cancer for routine head CT of women was 1 in 8100 and of men 1 in 11080. So, it could be say that, the cancer risk is higher for the patient who has undergone CT imaging procedure during this study.

Table 5.5: Comparison of estimated average LAR of cancer due to CT imaging procedure for male and female patients

CT Type	Male		Female	
	Average LAR of cancer		Average LAR of cancer	
	(1 in)	(%)	(1 in)	(%)
Abdomen	822	0.43	661	0.73
Chest	723	0.15	1447	0.5
Head	248	1.29	332	1.12

Figure. 5.5 shows the estimated average lifetime attributable risk (LAR) of cancer is not same for all types of CT imaging procedure.

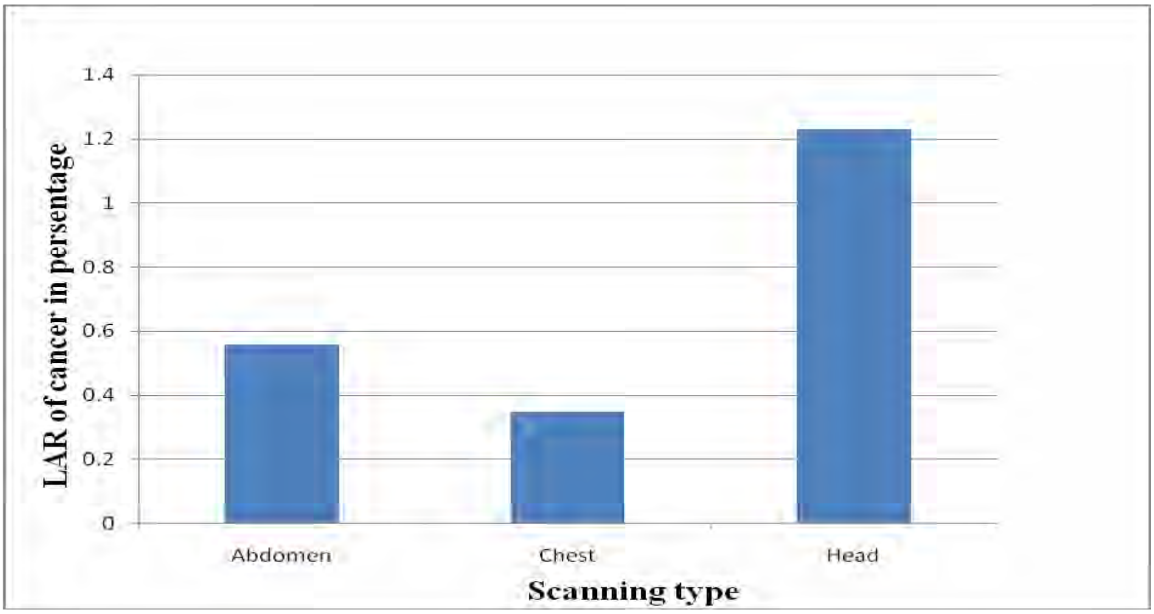


Figure 5.5: Estimated lifetime attributable risk (LAR) of cancer for different types of CT imaging procedure

The variation of LAR with patient-age, normalized to effective dose, is shown in Figure 5.6, for all categories of CT examinations. From Figure 5.6 it could be say that, the LAR of cancer increase with the decrease of patient‟s age and increase of effective dose regardless the type of scanning both for male and female patient. The older a patient, the shorter time (s) he has got to acquire cancer as a result of the radiation dose from a radiological examination. So, it has been seen that the pediatric patients are in higher risk than the adult patients due to ionizing radiation of CT imaging procedure.

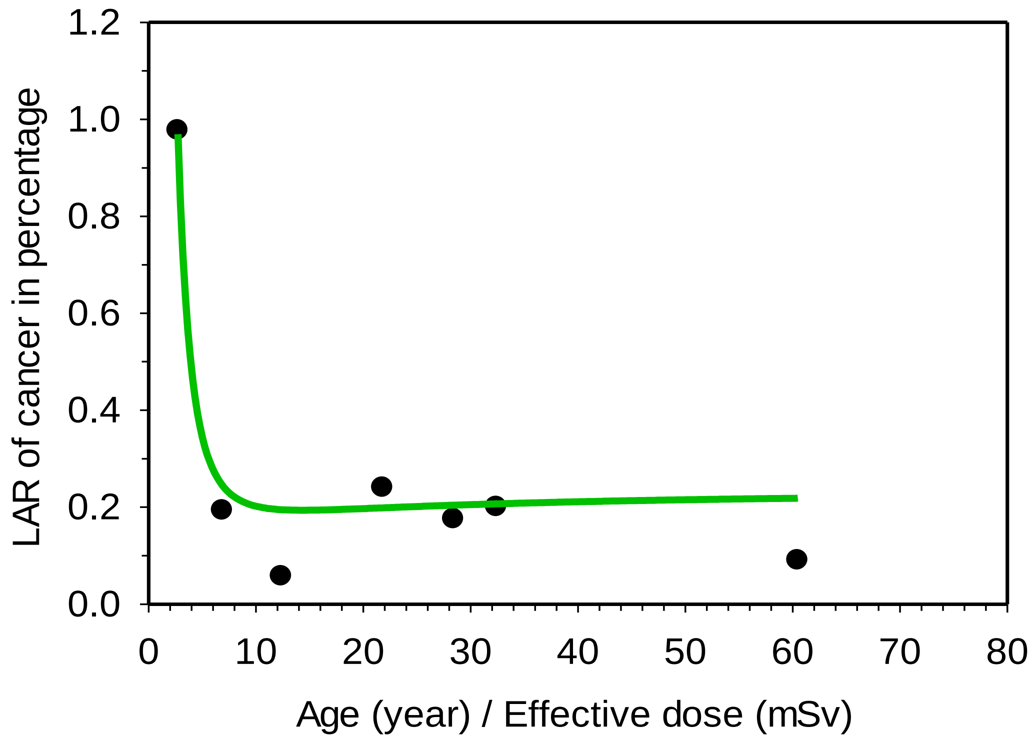


Figure 5.6: Dependence of LAR of cancer on age by effective dose for both male and female patients regardless the type of CT scan

Rashid M. H. et al.[23] and Islam M.R.[24] investigated that the LAR of cancer dependents on the age and effective dose. The result of the present study is same as their results.

6.1 Conclusion

Radiation is a part of our natural environment. The absorbed dose from these natural sources is very low. It is not possible to control these sources of natural radiation, but the man-made sources of radiation are possible to control. Radiation exposed on the patient during medical diagnostic test is one of the largest contributors to the radiation in human body [54]. Though there is no way to disagree the benefits of medical diagnostic procedures by using radiation, associated health risks are also available here. So the best way is to take the steps to minimize the patient dose.

Although the dose limits are not typical for medically-necessary exams or procedures and there is no compromise in the quality of image in CT scanning, the long term effects of ionizing radiation can be serious. So, the necessary steps should be taken to avoid any unnecessary exposure of ionizing radiation. The operators of the CT scanners need to be trained in the subject of radiation, dose, and their health effects, in order to stop unnecessary as less exposure of patients during radiological diagnostic procedures now it is expected that the radiation exposure dose is strictly monitored and the apparatus settings as well as the shielding materials are examined from time to time to avoid unnecessary exposure. Study on the hazard, safety and prevention of ionizing radiation is important.

It is known to all that prevention is better than cure. Since there is no way to avoid the ionizing radiation in medical diagnostic tests, so, it is the high time to estimate the relative value of risks and benefits of radiation exposures during medical diagnostic tests. Minimization of risks and amplification of benefits should intend of all diagnostic procedures as well as CT imaging procedure.

6.2 Suggestions and Recommendations

Study of patient‟s dose during CT imaging procedure is different than other studies of dose measurement because radiation comes from rotating X-ray tube which exposes radiation from different angles to the patients. CT dosimetry also contains some unique parameters. This study was started with traditional dose measurement procedure using TL chips. During the examination period, only the radiation doses at the scanning region was considered and the radiation dose surrounding the scanning region was neglected which was not negligible at all. Some suggestions for further study on CT dose measurement are as follows:

- A large number of TL chips should be used in a sheet to measure the patient dose during CT imaging procedure. In case of chest and abdomen scan scanning length is around 60 cm but in present study the length of each sheet was 45 cm. So that, to measure radiation dose at the scanning region, length of each sheet should be at least 60 cm and to measure radiation dose including the surrounding region of scanning region, length of each sheet should be 100 cm.
- Use of body phantom is the best way to study radiation dose during CT imaging procedure. This method gives the most accurate value of effective dose as well as the risk estimation.
- Different method of calculation should be used to compare the patient dose distinctly.

Suggestions to reduce patient dose for operators and hospital authorities for CT imaging procedure are as follows:

- As the patient dose depends on the different parameters such as tube current, tube voltage, exposure time etc. so appropriate use of CT protocol is important.
- Filter used in between X-ray tube and patient should be changed within three months. All hospital authorities are not aware about this.
- Different shielding materials should be used properly and in a regular way. During this study period lacking of awareness of using shielding materials was observed.
- CT operators and associated staffs should use TLD badge regularly. It was noticed that the radiation workers are not wearing the TLD badge regularly because they think that the absorbed dose for them is negligible.
- In case of head scan double scans were observed due to the movement of patient. Necessary steps should be used to prevent this unnecessary exposure.

- In case of scanning pediatric patients and female patients an extra care is demanded because they are in higher risk of CT dose.
- The number of average scan for whole imaging procedure was high. This observation recommended necessity of more training programs for operators to increase their skill.
- In some cases operators exposed radiation on patient no sooner supporting staffs got out from the room. This tendency should be avoided. In operating room entry of any extra person should not be allowed.

6.3 Further works on CT

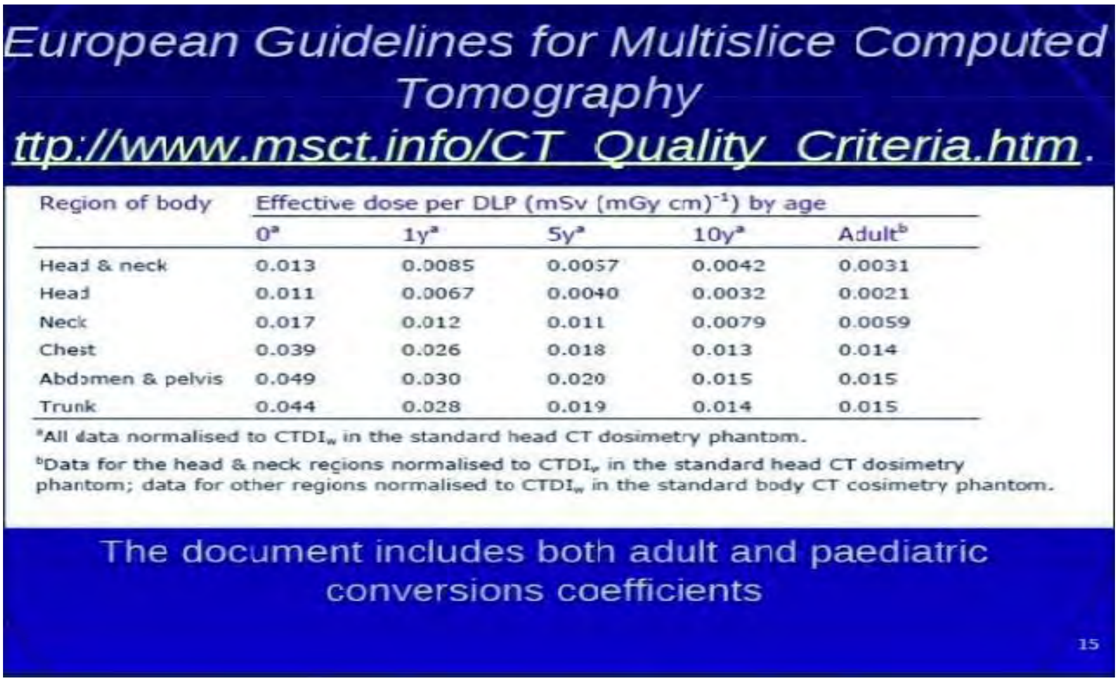
This thesis work is the first study on this CT machine. The aim of the study was to measure the patient dose during CT imaging procedures and hence determine the health risk specially cancer risk of the patients who undergo the CT technology. Patient dose of CT imaging procedures in different countries and different hospitals are not same at all because it depends on the tube current, tube voltage, scanning time and also specific design of the scanner etc. So, it is the demand of time to measure patient dose of CT imaging procedure in respect of Bangladesh in different ways. Further works on CT dose measurement should be as follows:

- Minimum 10 different types of CT imaging with 50 patients of each type should be collected.
- Comparison of patient‟s dose for CT imaging for different CT scanning.
- Patient dose of „CT head‟ was very high. So, this type of CT should be carefully monitored.
- Individual study for different types of CT is required so that the estimation of cancer risk be easier.
- There is no any study on the database of patient‟s dose report of CT in respect of Bangladesh. This study should be done gradually.
- Dose measurement using whole body phantom gives more accurate result than the method we used. So, this should be used to study CT dose like developed countries.

- There is no dose limit in diagnostic purpose. So, risk of ionizing radiation that comes from the CT should be estimated to compare between risks with benefits.
- At last, another database should be built mentioning the all information about the patient even with patient‟s address, so that it is possible to follow up the patient who underwent CT imaging procedure and who will undergo CT imaging procedures.

Finally, a database of CT dose measurement should be established by continuing this type of studies which will help the Government of Bangladesh to take pragmatic steps to reduce patient dose as well as associated health risk.

Table: A.1: Conversion coefficient of effective dose measurement



European Guidelines for Multislice Computed Tomography

ttp://www.msct.info/CT_Quality_Criteria.htm.

Region of body	Effective dose per DLP (mSv (mGy cm)$^{-1}$) by age				
	0[a]	1y[a]	5y[a]	10y[a]	Adult[b]
Head & neck	0.013	0.0085	0.0057	0.0042	0.0031
Head	0.011	0.0067	0.0040	0.0032	0.0021
Neck	0.017	0.012	0.011	0.0079	0.0059
Chest	0.039	0.026	0.018	0.013	0.014
Abdomen & pelvis	0.049	0.030	0.020	0.015	0.015
Trunk	0.044	0.028	0.019	0.014	0.015

[a]All data normalised to $CTDI_w$ in the standard head CT dosimetry phantom.

[b]Data for the head & neck regions normalised to $CTDI_w$ in the standard head CT dosimetry phantom; data for other regions normalised to $CTDI_w$ in the standard body CT cosimetry phantom.

The document includes both adult and paediatric conversions coefficients

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Table A.2: A Comparison of obtained DLP values with the diagnostic reference levels for MDCT.

CT Type	Diagnostic reference DLP (mGy.cm)	Obtained DLP (mGy.cm)
Abdomen	700	953.5
Chest	450	655.8
Head	1000	1473.36

Table A.3: Dose information of fifty six male patients of three different type CT scan

CT Type	No of Patients	Average measured dose (mSv)	Average dose per scan (mSv)	Average DLP (mGy.cm)	Average effective dose (mSv)
Abdomen	30	27.18	17.79	876.96	13.26
Chest	10	21.66	15.47	424.39	5.94
Head	16	88.30	57.57	1530.09	3.28

Table A.4: Dose information of forty four female patients of three different type CT scan

CT Type	No of Patients	Average measured dose (mSv)	Average dose per scan (mSv)	Average DLP (mGy.cm)	Average effective dose (mSv)
Abdomen	22	30.67	17.34	982.94	14.28
Chest	14	33.05	23.83	821.11	11.49
Head	8	72.39	56.51	1296.89	2.72

Table A.5: Dose information of all patients of three different type CT scan

CT Type	No of patients	Average measured dose (mSv)	Average dose per scan (mSv)	Average DLP (mGy.cm)	Average effective dose (mSv)
Abdomen	52	28.66	17.60	923.6	13.68
Chest	24	28.30	20.56	655.80	9.18
Head	24	83.00	57.22	1452.36	3.09

Table A.6: Patient's dose and risk of cancer due to 'CT Abdomen' (Male).

SL No	Age (year)	Scanning length (cm)	Measured dose (mSv)	Dose per scan (mSv)	Measured CTDIvol (mGy)	Measured DLP (mGy.cm)	Effective dose (mSv)	LAR of cancer (%)
01	1.5	23.5	4.09	4.09	2.53	75.88	2.27	0.08
02	3	23.5	21.81	21.81	13.79	335.19	10.06	0.4
03	24	27.0	21.19	21.19	14.37	481.11	7.22	0.22
04	26	42.6	14.64	14.64	6.59	411,40	6.17	0.14
05	27	50.95	23.45	23.45	13.68	804.05	12.06	0.22
06	31	40.1	23.1	23.1	16.54	757.11	11.36	0.2
07	33	40	29.8	29.8	17.18	798.56	11.98	0.24
08	33	38.5	70.5	10.07	36.74	1454.42	21.82	3.98
09	34	46.5	6.67	6.67	2.88	158.22	2.37	0.05
10	35	28.05	10.76	10.76	8.01	324.07	4.86	0.08
11	37	77.75	18.18	18.18	12.18	1078.2	16.17	0.13
12	39	49.0	55.26	18.42	12.66	2107.03	31.6	1.13
13	40	45	9.68	9.68	3.97	204.17	3.06	0.06
14	42	44.7	28.46	28.46	21.39	1353.69	20.31	0.18
15	43	44.1	41.3	41.3	9.13	2337.38	35.06	0.25
16	43	23.9	76.87	15.37	53.3	3061.95	45.93	2.36
17	44	43.0	23.86	23.86	15.49	701.23	10.52	0.14
18	46	48.65	13.58	13.58	6.87	401.75	6.03	0.08
19	48	26.1	20.00	20.00	13.79	617.21	9.26	0.11
20	50	47.5	9.15	9.15	4.63	249.82	3.75	0.05
21	52	50.2	31.64	6.33	36.18	991.67	14.87	0.76
22	53	40.0	21.5	21.5	15.63	660.75	9.91	0.1

SL No	Age (year)	Scanning length (cm)	Measured dose (mSv)	Dose per scan (mSv)	Measured CTDIvol (mGy)	Measured DLP (mGy.cm)	Effective dose (mSv)	LAR of cancer (%)
23	55	34.0	6.34	1.27	23.81	1004.06	15.06	0.14
24	56	37.7	29.07	29.07	20.72	114.50	16.718	0.12
25	57	23.6	22.84	22.84	16.09	478,8	7.18	0.09
26	64	27.7	20.41	20.41	16.17	723.64	10.85	0.07
27	71	26	37.76	9.44	24.63	787.58	11.814	0.43
28	72	46.75	25.66	25.66	16.55	967.63	14.51	0.07
29	72	15.1	77.12	12.85	43.79	1459.59	21.89	1.06
30	79	40.0	20.75	20.75	11.72	544.65	8.17	0.05

Table A.7: Patient's dose and risk of cancer due to 'CT Chest' (Male)

SL No	Age (year)	Scanning length (cm)	Measured dose (mSv)	Dose per scan (mSv)	Measured CTDIvol (mGy)	Measured DLP (mGy.cm)	Effectiv e dose (mSv)	LAR of cancer (%)
01	35	10.8	15.02	15.02	9.68	246.23	3.45	0.11
02	50	29	14.65	14.65	8.41	336.28	4.71	0.07
03	54	26.9	13.49	13.49	9.19	339.77	4.76	0.06
04	61	27.7	16.17	16.17	10.38	425.24	5.95	0.06
05	62	23.3	24.56	24.56	8.14	353.72	4.95	0.09
06	63	13.3	69.8	23.26	68.49	815.7	11.42	0.74
07	65	29.6	14.7	14.7	11.03	466.38	6.53	0.05
08	65	24.3	13.24	13.24	8.16	362.88	5.08	0.04
09	67	32.8	10.72	10.72	5.84	233.31	3.27	0.03
10	70	32.2	24.24	8.08	17.28	664.37	9.3	0.21

Table A.8: Patient's dose and risk of cancer due to 'CT Head' (Male)

SL No	Age (year)	Scanning length (cm)	Measured dose (mSv)	Dose per scan (mSv)	Measured CTDIvol (mGy)	Measured DLP (mGy.cm)	Effective dose (mSv)	LAR of cancer (%)
1	6	13.2	58.92	58.92	57.01	969.24	3.87	3.99
2	21	8.55	55.16	55.16	68.64	1166.96	2.45	0.62
3	27	10.3	58.59	58.59	64.06	1153.51	2.42	0.56
4	34	9.15	226.18	56.54	216.45	3861.44	8.11	7.10
5	35	5.45	63.05	63.05	66.14	1190.45	2.5	0.48
6	35	12.2	42.66	42.66	42.91	772.44	1.6	0.33
7	39	7.35	79.05	79.05	76.4	1375.18	2.89	0.54
8	46	7.7	70.19	17.54	49.32	1447.93	3.04	1.58
9	48	6.1	115.47	38.49	125.4	1505.31	3.16	0.62
10	52	5.83	60.5	60.5	58.11	1116.56	2.34	0.29
11	55	6.16	69.37	69.37	68.26	1291.02	2.71	0.31
12	60	5	59.84	59.84	73.39	1207.78	2.54	0.23
13	65	50.56	75.2	75.2	69.18	1391.6	2.92	0.25
14	66	6.8	220.6	64.15	251.88	3575.92	7.51	3.34
15	68	9.5	56.05	56.05	73.21	1171.29	2.46	0.17
16	77	3.61	66.04	66.04	66.4	1284.87	2.7	0.18

Table A.9: Patient's dose and risk of cancer due to 'CT Abdomen' (Female).

SL No	Age (year)	Scanning length (cm)	Measured dose (mSv)	Dose per scan (mSv)	Measured CTDIvol (mGy)	Measured DLP (mGy.cm)	Effective dose (mSv)	LAR of cancer (%)
1	23	43.2	46.38	15.46	34.35	1751.09	26.27	2.35
2	24	27.1	23.35	23.35	15.99	683.73	10.26	0.38
3	27	46.0	17.56	17.56	10.71	626.04	9.39	0.26
4	28	12.7	20.7	20.7	14.13	434.54	6.52	0.29
5	29	40.5	70.61	14.12	65.38	3030.28	45.45	4.87
6	30	40.0	20.51	20.51	13.79	582.67	8.74	0.27
7	36	28.8	18.8	18.8	13.45	548.15	8.22	0.2
8	39	25.2	28.42	28.42	14.9	848.91	12.73	0.28
9	40	30.8	24.79	24.79	21.73	1092.53	16.39	0.24
10	40	41	6.15	6.15	2.88	136.63	2.05	0.06
11	42	26.5	18.99	18.99	13.10	508.02	7.62	0.17
12	47	30.2	17.49	17.49	6.91	379.57	5.69	0.13
13	48	53.9	18.6	18.6	7.98	434.91	6.52	0.13
14	50	28.1	23.84	23.84	14.4	608.48	9.13	0.16
15	53	43.5	22.63	22.63	11.41	570.28	8.55	0.14
16	54	39.4	27.9	27.9	15.49	719.87	10.8	0.16
17	56	74.4	20.33	10.16	5.29	872.7	13.09	0.11
18	60	39.9	7.87	7.87	3.75	245.35	3.68	0.04
19	61	42.3	74.97	14.99	84.22	2751.59	41.27	1.74
20	65	40	106.07	13.26	75.27	2920	43.8	3.44
21	75	34.8	7.36	7.36	4.71	252.09	3.78	0.02
22	84	35.2	51.58	8.6	48.11	1627.23	24.41	0.66

Table A.10: Patient's dose and risk of cancer due to 'CT Chest' (Female)

SL No	Age (year)	Scanning length (cm)	Measured dose (mSv)	Dose per scan (mSv)	Measured CTDIvol (mGy)	Measured DLP (mGy.cm)	Effective dose (mSv)	LAR of cancer In %
1	20	58.1	32.03	5.33	22.39	1164.31	16.3	3.6
2	42	58.5	18.6	18.6	10.7	823.91	11.53	0.17
3	42	12.3	60.36	60.36	42.89	817.44	11.44	0.54
4	44	38.5	78.89	19.72	53.92	2519.88	35.28	2.62
5	44	23.8	23.64	23.64	5.76	247.36	3.46	0.19
6	50	41	68.7	68.7	11.13	528.52	7.4	0.46
7	55	33.5	28.9	9.6	20.64	829.14	11.6	0.49
8	55	29.6	35.01	35.01	24.3	959.92	13.43	0.6
9	56	68.4	16.7	16.7	9.12	683.7	9.6	0.09
10	59	32.5	18.35	18.35	18.71	729.09	10.21	0.09
11	60	27.4	9.38	9.38	5.76	221.46	3.1	0.05
12	67	47	19.31	19.31	12.94	691.95	9.69	0.07
13	68	22.9	17.02	17.02	11.67	443.06	6.2	0.06
14	70	27.2	35.77	11.92	22.3	835.73	11.7	0.12

Table A.11: Patient's dose and risk of cancer due to 'CT Head' (Female)

SL No	Age (year)	Scanning length (cm)	Measured dose (mSv)	Dose per scan (mSv)	Measured CTDIvol (mGy)	Measured DLP (mGy.cm)	Effective dose (mSv)	LAR of cancer (%)
1	29	8	58.30	58.30	60.66	1031.27	2.17	0.80
2	30	9.3	61.85	61.85	60.03	963.31	2.02	0.83
3	30	11.3	50.02	50.02	59.07	886	1.86	0.67
4	32	12.5	64.24	64.24	65.22	1174.03	2.47	0.8
5	40	7.71	190.57	63.52	194.4	3404.4	7.14	5.43
6	70	10.88	59.24	59.24	64.7	1026.25	2.16	0.20
7	75	9.18	33.8	33.8	37.04	592.69	1.24	0.09
8	77	5.21	61.12	61.12	69.26	1297.18	2.72	0.17

Definitions:

* Radiation Dose

The energy is deposited when an ionizing radiation penetrates the human body. The energy absorbed from exposure to radiation is called a dose. There are three types of radiation dose: absorbed dose, equivalent dose, and effective dose.

*Absorbed Dose:

The quantity of energy deposited in a substance (e.g., human tissue) is called the absorbed dose. The unit of absorbed dose is gray (Gy). One gray is equivalent to a unit of energy (joule) deposited in a kilogram of a substance.

*** Equivalent Dose:**

When radiation is absorbed by living matter, there may be a biological effect observed. This effect will not be equal for equal amount of absorbed doses. It depends on the type of radiation (e.g., alpha, beta, gamma, etc) and the tissue or organ receiving the radiation. A radiation weighting factor is used to equate different types of radiation with different biological effectiveness. The amount of weighted absorbed dose is called equivalent dose. The unit of equivalent dose is sievert (Sv), millisivert (mSv) and microsivert (μSv). The equivalent dose provides a single unit which accounts for the degree of harm of different types of radiation.

*** Effective Dose:**

Different tissues and organs have different radiation sensitivities. The bone is much more radiosensitive than muscle tissue. To obtain overall health affect, the equivalent dose can be multiplied by a factor related to the risk for a particular tissue or organ. This result provides the effective dose absorbed by the body. The unit of effective dose is also the sievert (Sv).

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