Radiation Dose from Computed Tomography Scanning in Songklanagarind Hospital: Diagnostic Reference Levels

Dechen Pema

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Health Sciences
Prince of Songkla University
2019

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I hereby certify that this work has not been accepted in substance for any degree and is not being currently submitted in candidature for any degree.

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Abstract

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Background: Computed tomography (CT), an excellent tool to assist clinicians in medical diagnosis, has seen exponential growth. There has been growing concern about the possibility of CT radiation-induced cancer. Each CT unit has been encouraged to establish their dose reference levels (DRLs) in order to optimize CT radiation dose and imaging quality.

Objective: To determine CT radiation dose in terms of median and inter-quartile range of the CTDI and DLP to obtain the institute DRL for CT scans of the head, chest and abdomen for patients at Songklanagarind Hospital, Prince of Songkla University, Hat Yai.

Materials and methods: A retrospective analysis of total 464 CT studies from 416 patients who underwent head, chest and abdominal CT scans in Songklanakarind Hospital from July 1st to 31st 2017. The volume CT dose index ($CTDI_{vol}$), dose length product (DLP) and clinical indications were recorded. The range, mean, and third quartile values were analysed and compared to other standard international DRLs. Kruskal-Wallis rank sum test was used to evaluate significance for the above variables and clinical indications.

Results: The DRLs according to our study at the CT unit of Songklanagarind Hospital were: $CTDI_{vol}$ of 57.50 mGy; DLP of 1102.60 mGy.cm for head CT, $CTDI_{vol}$ of 11.63 mGy; DLP of 474.7 mGy.cm for chest CT and $CTDI_{vol}$ of 13.15 mGy; DLP of 624.40 mGy.cm for abdominal CT. The most common clinical indications for CT head, chest and abdomen were stroke (29.1%), malignancy (73.6%) and malignancy (49.6%) respectively.

Conclusion: These results show that the DRLs of each CT region have increased when compared to the DRLs of a limited study at Songklanagarind hospital in 2010. However, the values of our study are mostly below standard international DRLs.

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Dechen Pema

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CHAPTER 1

INTRODUCTION

1.1 Background and rationale

Technology in all fields, in particular the medical, have developed and evolved at an astonishing pace over the last few decades. Modern tools such as computed tomography (CT), magnetic resonance imaging (MRI) are now considered essential to medical diagnostics with ever increasing reliance on them. Their advantages are in assisting in forming a more concrete diagnosis which results in more efficient management and most importantly, prevents unnecessary invasive procedures and surgeries. The disadvantages are the side effects and increased cost. Clinicians are starting to rely more on investigative findings instead of their clinical findings, which can result in over or under treatment. Also, in this rapidly modernizing world with freely available internet, patients now expect and indeed demand for ultrasounds, CT scans and MRIs for even the smallest illnesses or trauma. The likelihood of an overuse of the facilities available due to unnecessary scans and duplication of scans as well as overtreatment of harmless conditions found incidentally during the scans is very real.

With this background, the importance of radiation dose of CT scans cannot be overstated. Computed tomography was first developed in 1972 with the multi-detector CT (MDCT) invented in 1998. The total number of CT examinations performed annually in the United States has risen from approximately 3 million in 1980 to nearly 70 million in 2007.(1) A study in the United States in 2009 found that CT alone is responsible for 75.4% of effective radiation dose from medical imaging while it accounts for only 11% of X-ray based examinations.(2) CT scans are extremely helpful in forming a diagnosis but is also a major source of ionizing radiation. Multiple studies and articles in medical literature have increasingly discussed the importance of radiation doses patients receive from medical imaging

recently, particularly with CT.(3) A study by Berrington de Gonzalez et al concluded that 29,000 future cancers from total 56.9 million CT examinations could be related to CT scans performed in the United States in 2007. The largest contributions were from scans of the abdomen, pelvis, head and chest CT angiography.(4)

It is still a matter of debate about the exact amount of radiation that causes cancer but increasing number of researches shows a definite relationship. New research by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has suggested the range of absorbed dose for low-LET radiation about 10 to 100 mGy are dose to an individual from multiple whole body computerized tomography scans.(5)

In 1996, International Commission on Radiological Protection (ICRP) proposed diagnostic reference levels (DRLs) to help optimize radiation dose to patients. DRL was defined as an investigational level that applies to an easily measured quantity using a standard phantom or representative patient. The ICRP emphasized DRLs are not dose limits or constraints but a test to identify unjustified high and low doses in clinical practice. DRLs in adults are expressed by the CT dose index (CTDI), dose length product (DLP) and effective dose.(6) A rising number of publications and reports on CT have concentrated on the important issue of optimized imaging practically and patient dose. This is in part due to recent technological advance resulting in the remarkable rise in the number of CT scans being requested and performed. Beneficial new CT imaging applications like cardiac CT, CT colonography, angiography and urology are increasingly being improved. Interventional radiology is a rapidly growing field with many benefits and more procedures being developed every day. Paediatric patients undergoing CT scans have also increased.

The published available medical literature was appraised for information concerning the effective dose levels during the most common CT examinations. Large dose variations (up to 32-fold) with some individual sites exceeding the recommended DRLs were detected. There is a large possibility to introduce practices and reduce excessive radiation dose. Current estimations on radiation-related cancer risks are alarming. CT doses contribute to about 70% of aggregate

dose in the UK with the highest being from diagnostic radiology. However, the majority of the prescribing clinicians underestimate the risk due to a reduced level of awareness. Exposure parameters are not always adjusted correctly according to the indication or to patient size, especially for children. There are techniques for lowering radiation dose, simple adjustments like tube-current modulation, low voltage protocols and even prospective instead of retrospective coronary angiography and iterative reconstruction algorithms. The justification principles are discussed along with optimization methods or alternative innovations to help clinicians in decision-making and management processes. The potential to avoid clinically non-indicated CT scans by replacing them with alternative investigations especially for children or patients receiving multiple CT scans is possible. (5). The IRCP emphasized that DRLs should be derived from regional, national or local data where possible. The "As Low as Reasonably Achievable" or ALARA principle should be adhered to regarding the exposure of patients to radiation in order to minimize the potential hazards of ionizing radiation.

Studies on CT radiation doses have been carried out in Thailand, but no national survey or diagnostic reference levels have been established. A study titled "Abstract: An analysis of Radiation dose from CT" by Ittivisawakul at Rajavithi Hospital in 2012 concluded that while the CT radiation dose of brain was below DRLs of the UK, EU and ICRP, the radiation doses of CT chest, upper abdomen and whole abdomen exceeded DRLs of UK and USA. The study concluded that all personnel involved should be more aware of CT radiation dose and to lower them.(7)

Trinavarat P, *et al* in 2010 undertook a study "Radiation dose from CT scanning: can it be reduced?" at five university hospitals in Thailand to find the CT radiation doses and DRLs of adult brain, chest, upper abdomen and whole abdomen regions. They concluded that although there was a wide variation in CT doses between the hospitals, when compared to DRLs of UK and EU the doses were within acceptable levels. However as the number of patients and CT radiation doses varied widely, they encouraged every CT unit to develop their own mechanism to optimize utilization of CT scans.(8)

1.2Objectives of the study

Main objective

To determine the CT radiation dose in terms of median and inter-quartile range of the CTDI and DLP to obtain the institute DRL for CT scans of the head, chest and whole abdomen for adult patients at Songklanagarind Hospital, Prince of Songkla University, Hat Yai, Thailand.

Specific objectives

To compare these baseline CT radiation DRLs to international DRLs

To determine the median and inter-quartile range of radiation dose from CT scans for various clinical indications.

1.3 Expected benefits

The objective of this study was to determine the radiation dose of patients during the most commonly carried out CT scans and to calculate what can be considered the CT diagnostic reference levels (DRLs) in Songklanagarind Hospital to optimize patient effective radiation exposure. Justification for any excessively high or low doses compared to these DRLs can be monitored and improvements made. Protocols for different anatomical regions or various clinical indications can be optimized.

1.4 Scope

A study such as this carried out to determine CT radiation diagnostic reference levels would be useful for other hospitals or diagnostic centers in Thailand for comparison and optimizing their own DRLs. This could help in the establishment on Thailand's national DRLs.

This study also benefits as a reference point for the establishment of national diagnostic reference levels of other countries in the surrounding region.

For example, in Bhutan, there has been no prior study about DRLs and CT radiation doses. There is a lack of documented long-term reliable data at the Jigme Dorji Wangchuck National Referral Hospital, currently the only center with CT facility. It is impossible to conduct such research in Bhutan at the present moment but the future holds possibilities and opportunities.

1.5 Definitions

Radiation protection glossary

ICRP Publication 103: The 2007 Recommendations of the International Commission on Radiological Protection

Absorbed dose (D)

The fundamental dose quantity given by D = dε / d*m* where dε is the mean energy imparted to matter of mass d*m* by ionising radiation.

The SI unit for absorbed dose is joule per kilogram (J kg^{-1}) and it is called "gray" (Gy).

Averted dose

The dose prevented or avoided by the application of a protective measure or set of protective measures, i.e., the difference between the projected dose if the protective measure(s) had not been applied and the expected residual dose.

Collective effective dose, S

The collective effective dose due to individual effective dose values between $E_1$and E_2 from a specified source within a specified time period DT is defined as:

$$S(E_1,E_2,\Delta T)= \int_{E1}^{E2} E\left(\frac{dN}{dE}\right)\Delta T \, dE$$

It can be calculated as $S = \Sigma_i E_i N_i$ where E_i is the average effective doses for a subgroup i, and Ni is the number of individuals in this subgroup. The time period and

number of individuals over which the effective doses are calculated should always be specified. The unit of the collective effective dose is joule per kilogram (Jkg^{-1}) and its special name is man Sievert (man Sv). The number of individuals experiencing an effective dose in the range E_1 to E_2, N (E_1, E_2,ΔT) is

$$N\,(E_1,E_2,\,\Delta T) = \int_{E1}^{E2} E\left(\frac{dN}{dE}\right)\Delta T\;dE$$

and the average value of effective dose $\bar{E}$ (E_1, E_2,ΔT) Þ in the interval of individual doses between E_1 and E_2 for the time period $\Delta T$is:

$$\bar{E}(E_1,\,E_2,\Delta T) = \frac{1}{N(E1,E2,\Delta T)}\int_{E1}^{E2} E\left(\frac{dN}{dE}\right)\Delta T\;dE$$

Committed effective dose, E (ſ)

The sum of the products of the committed organ or tissue equivalent doses and the appropriate tissue weighting factors (W_T), where ſ is the integration time in years following the intake. The commitment period is taken to be 50 years for adults and to age 70 years for children.

Committed equivalent dose, H_T(ſ)

The time integral of the equivalent dose rate in a particular tissue or organ that will be received by an individual following intake of radioactive material into the body by a *reference person*, where ſ is the integration time in years.

CT dose index, CTDI

The CTDI denotes the radiation dose of a single CT slice and is calculated using cylinder acrylic phantoms of a standard length with diameters of 16 cm and 32 cm. Unit: mGy.

Weighted CTDI, $CTDI_w$

The $CTDI_w$ is the weighted sum of two-thirds peripheral dose and one-third central dose in a 100-mm range in acrylic phantoms.

Volume CTDI, $CTDI_{vol}$

The $CTDI_{vol}$ is determined as $CTDI_w$ divided by the beam pitch factor. It is the most commonly cited index for modern MDCT equipment.

Dose length product, DLP

The DLP is the $CTDI_{vol}$ multiplied by the scan length in centimeters. Unit mGy.cm

Deterministic effect

It is also called as tissue reaction. This effect occurs when the cell injury has a specific threshold dose beyond which if the radiation dose is increased further, a corresponding escalation in the magnitude of the reaction occurs. In a few circumstances, deterministic effects can be modified by post-radiation procedures including biological response modifiers.

Detriment

The total harm to health experienced by an exposed group and its descendants as a result of the group's exposure to a radiation source. Detriment is a multidimensional concept. Its principal components are the stochastic quantities: probability of attributable fatal cancer, weighted probability of attributable non-fatal cancer, weighted probability of severe heritable effects, and length of life lost if the harm occurs.

Detriment-adjusted risk

The probability of the occurrence of a stochastic effect, modified to allow for the different components of the detriment in order to express the severity of the consequence(s).

Diagnostic reference level (DRL)

Used in medical imaging with ionizing radiation to indicate whether, in routine conditions, the patient radiation dose or administered activity (amount of radioactive material) from a specified procedure is unusually high or low for that procedure

Dose coefficient

Used as a synonym for dose per unit intake of a radioactive substance, but sometimes also used to describe other coefficients linking quantities or concentrations of activity to doses or dose rates, such as the external dose rate at a specified distance above a surface with a deposit of a specified activity per unit area of a specified radionuclide.

Dose constraint

It is a prospective and source-related restriction on the individual dose from a source, which imparts a limited level of protection for those people, most highly exposed from a source. It also works as an upper limit on the radiation dose required in optimisation of protection for that source. For occupational exposures, the dose constraint is the quantity of individual radiation dose used to restrict the range of options accounted for in the process of optimisation. For public exposure, the dose constraint is an upper limit on the annual doses that members of the public should receive from the planned operation of any controlled source.

Dose equivalent, H

The product of D and Q at a point in tissue, where D is the absorbed dose and Q is the quality factor for the specific radiation at this point, thus:

$$H = DQ$$

The unit of dose equivalent is joule per kilogram (J kg^{-1}) or Sievert (Sv).

Dose-threshold hypothesis

A given dose that, though above background radiation dose, is below the limit hypothesised that the risk of excess cancer and/or heritable disease is zero.

Dose limit

The value of the effective dose or the equivalent dose to individuals from planned exposure situations that shall not be exceeded.

Effective dose, E

The tissue-weighted sum of the equivalent doses in all specified tissues and organs of the body, given by the expression:

$$E = \sum_{T} w_T H_T$$

where H_T is the equivalent dose in a tissue or organ, T, and w_T is the tissue weighing factor. The SI unit for the effective dose is the same as for absorbed dose, J kg^{-1} or Sievert (Sv).

Equivalent dose, HT

The dose in a tissue or organ *T* given by:

$$H_T = \sum_{R} w_R D_{T,R}$$

where $D_{T,R}$ is the mean absorbed dose from radiation R in a tissue or organ T, and w_R is the radiation weighting factor. Since w_R is dimensionless, the SI unit for the equivalent dose is the same as for absorbed dose, J kg^{-1} or Sievert (Sv).

Exposed individuals

The Commission distinguishes between three categories of exposed individuals: workers (informed individuals), the public (general individuals), and patients, including their comforters and carers.

Justification

The process of determining whether either (1) a planned activity involving radiation is, overall, beneficial, i.e. whether the benefits to individuals and to society from introducing or continuing the activity outweigh the harm (including radiation detriment) resulting from the activity; or (2) a proposed remedial action in an emergency or existing exposure situation is likely, overall, to be beneficial, i.e., whether the benefits to individuals and to society (including the reduction in radiation detriment) from introducing or continuing the remedial action outweigh its cost and any harm or damage it causes.

Linear dose response

A statistical model that demonstrates the risk of an adverse effect as being proportional to the radiation dose received.

Linear-non-threshold (LNT) model

A dose-response model based on the assumption that in the low dose range, radiation doses greater than zero will increase the risk of excess cancer and/or heritable disease in a simple proportionate manner.

Linear-quadratic dose response

A statistical model that expresses the risk of an effect (e.g., disease, death, or abnormality) as the sum of two components, one proportional to dose (linear term) and the other one proportional to the square of dose (quadratic term).

Mean absorbed dose in a tissue or organ (T), DT

The absorbed dose DT, averaged over the tissue or organ T, which is given by

$$DT = \frac{\varepsilon T}{m_T}$$

Where εT is the mean total energy imparted in a tissue or organ T, and m_T is the mass of that tissue or organ.

Nominal risk coefficient

Sex-averaged and age-at-exposure-averaged lifetime risk estimates for a representative population.

Personal dose equivalent, $H_p(d)$

An operational quantity: the dose equivalent in soft tissue (commonly interpreted as the 'ICRU sphere') at an appropriate depth, *d*, below a specified point on the human body. The unit of personal dose equivalent is joule per kilogram (J kg^{-1}) or Sievert (Sv). The specified point is usually given by the position where the individual's dosimeter is worn.

Public exposure

Exposure experienced by the general population from radiation sources, eliminating any occupational or medical exposure and the normal natural background radiation.

Quality control (QC)

Part of *quality management* intended to verify that *structures, systems and components* correspond to predetermined *requirements*

Radiation detriment

A concept used to quantify the harmful health effects of radiation exposure indifferent parts of the body. It is defined by the Commission as a function of several factors, including incidence of radiation-related cancer or heritable effects, lethality of these conditions, quality of life, and years of life lost owing to these conditions.

Radiation weighting factor, w_R

A dimensionless factor by which the organ or tissue absorbed dose is multiplied to express the higher biological effectiveness of high-LET radiations compared with low-LET radiations. It is used to derive the equivalent dose from the absorbed dose averaged over a tissue or organ.

Reference Person

An idealised person for whom the organ or tissue equivalent doses are calculated by averaging the corresponding doses of the Reference Male and Reference Female. The equivalent doses of the Reference Person are used for the calculation of the effective dose by multiplying these doses by the corresponding tissue weighting factors.

Reference phantom

Voxel phantoms for the human body (male and female voxel phantoms based on medical imaging data) with the anatomical and physiological characteristics defined in the report of the ICRP Task Group on Reference Man (Publication 89, ICRP 2002).

Stochastic effects of radiation

Dose without threshold resulting in the probability of an effect such as malignancy and heritable defects is noted. However, its severity is not depicted.

Threshold dose for tissue reactions

The dose estimated to result in only 1% incidence of tissue reactions.

Tissue weighting factor, wT

The factor by which the equivalent dose in a tissue or organ T is weighted to represent the relative contribution of that tissue or organ to the total health detriment resulting from uniform irradiation of the body

Voxel phantom

Computational anthropomorphic phantom based on medical tomographic images where the anatomy is described by small three-dimensional volume elements (voxels) specifying the density and the atomic composition of the various organs and tissues of the human body.

CHAPTER 2

LITERATURE REVIEW

2.1 Radiation exposure from CT scanning: Current scenario

Computed tomography (CT) is a diagnostic tool that utilizes ionizing radiation to form three-dimension images. The MDCT invented in 1998 made new CT imaging applications like cardiac CT, CT colonography, angiography and interventional procedures possible. This led to a progressive exponential boom in the number of CT scans being carried out. In 2007, 72 million CT examinations were carried out in the USA compared to the 3 million per year in 1980.(4)

Medical imaging is now the second highest source of ionizing radiation exposure to human, second only to natural background radiation. Fazel R *et al* in a 2009 study in the United States concluded CT alone is accountable for 75.4% of effective radiation dose from medical imaging.(2) The cumulative per-capita effective dose sustained from medical imaging in the US has increased around 6-fold from 0.5 mSv to 3.0 mSv, from 1980 to 2006.(9)(10)

Ionizing radiation can cause biological adverse side effects. (10)(11) The rising risk of cancer and a smaller probability for hereditary diseases when gonads are in direct beam have been of significant concern. It is generally accepted that there is no threshold dose for this kind of stochastic radiation effect.(12) The other category of radiation effect, deterministic effect, has a threshold dose. It can cause skin redness, depilation or peeling when exposed to radiation above that particular threshold level. The concept of association of ionizing radiation with subsequent development of cancer has been based mainly on data obtained from studies of survivors of the atomic bombs dropped in Japan in 1945 and the assessments of the increased relative risk of development of cancer in those with occupational exposure to radiation within the nuclear industry.(13,14)

There is extensive difference of opinion on the level of cumulative radiation dose from medical imaging which elevates the probability of cancer.(11) A study in 2007 from the US estimated that about 29,000 future cancers from total 56.9 million numbers of CT scanning would develop primarily due to CT abdomen and pelvis and then CT chest, head and angiography. Females accounted for around 60% of CT scans and 2/3 of the approximate future malignancies.(4)

Table 1: Effective dose from radiology and the lifetime risk of cancer (15)

Procedure	Effective Dose(mSv)	Increased Risk of cancer
No Dose		
- MRI	Not defined/applicable	Not known
- Ultrasound		
Low Dose		
- Chest Xray	<0.1	1 in a million
- Extremities		
Intermediate Dose		
- IVP	1 to 5	1 in 10000
- Lumbar spine		

2.2 Dose parameters for CT and factors

CT dose index (CTDI) depicts the radiation dose of a single CT slice. It is calculated using cylinder acrylic phantoms of standard length 16 cm and 32 cm diameters. It is measured in milliGray (mGy). 1 Gray = 1 joule per kilogram.

$CTDI_{vol}$ is defined as $CTDI_{vol} = CTDI_w \times NT/I$ where $CTDI_w$ (units: mGy). It shows a dose index providing a weighted average of the center and peripheral dose distribution within the scan plane.

Dose length product (DLP) is a measure of the mean absorbed dose to the patient of each series in CT exam and defined as the product of $CTDI_{vol}$ X exposed scan length. (unit: mGy.cm)

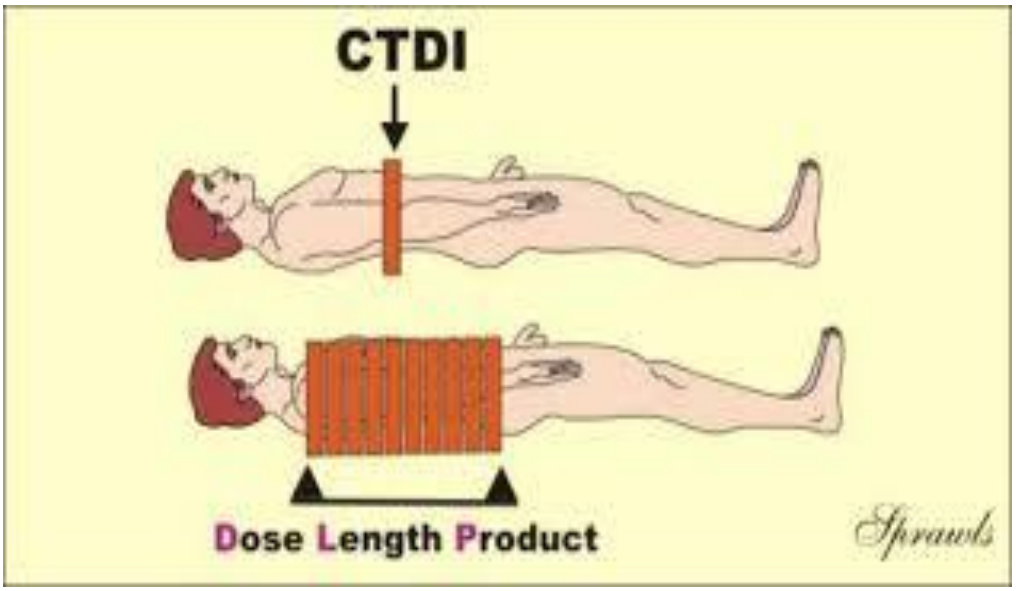


Figure 1: CTDI and DLP
(Source: Radiation Quantities and Units by Perry Sprawls, Ph.D. at sprawls.org)

CTDI is displayed on the monitors of new model MDCT machines to simulate patient radiation dose is within the diagnostic reference levels (DRLs). According to standard International Electrotechnical Commission, IEC 60601 2-44 (1999) proposed the displayed $CTDI_w$ corresponding to particular scanner parameter selected and IEC 60601 2-44 (2002) has defined the displayed $CTDI_{vol}$ referring to the 16-cm phantom in diameter for head examination and 32-cm phantom in diameter for body examinations. DRLs were taken as the 75^{th} percentile (third quartile) of patient dose distribution (DLP, CTDI) for each protocol.

Many countries have their own CT DRLs. Others use the DRLs of the European Commission and United Kingdom for comparison and adjusting CT doses accordingly.(16) However the ICRP encourages the establishment of DRLs at national or regional levels using the local data available. Other factors

that determine baseline CT dose levels are the CT scanner model, CT study type, section thickness, patient size and scanning parameters such as the tube current, tube voltage and pitch. CT scans for different anatomical regions also have different radiation dose levels according to the area they cover. Different clinical conditions require a variety of phases of CT scan according to protocol, which means a varying amount of radiation exposure.

Table 2: Conversion Factor/ Coefficient of area, specific for adults

Region	Conversion Factor (mSv/mGy.cm)
Head	0.0023
Neck	0.0054
Chest	0.017
Abdomen	0.015
Pelvis	0.017

Source: European Commission: European Guidelines on Quality Criteria for CT

Table 3: Adult Effective doses for various CT procedures (17).

Examination	Average Effective Dose (mSv)
Head	2
Neck	3
Chest	7
Chest for pulmonary embolism	15
Abdomen	8
Pelvis	6

Three-phase liver study	15
Spine	6
Coronary Angiography	16
Calcium scoring	3
Virtual colonoscopy	10

Most modern MDCT machines have an automated exposure control system (AEC) or automatic tube current modulation (ATCM). When AEC system is used, the CTDI varies between patients of different cross-sectional size. Almost all MDCT scanners have this modulation technique installed with different settings among the different vendors. The ATCM is an automatic tube current adjustment in the axial plane (XY axis or angular modulation) or the long axis of the patient (Z axis modulation) or combined XY-Z axes according to the user settings and patient's body geometry acquired from a scanogram which can achieve constant image noise level and a reduced radiation dose. Several previous studies have reported that ATCM modulation can significantly reduce the radiation dose without compromising image quality in neck, chest, abdominal, and pelvic adult CT scans compared with constant or fixed tube current.

Greess *et al.* found a 10–60% reduction in mAs depending on patients' geometry and anatomical regions while the mean reduction was about 22.3% (neck 20%, thorax 23%, abdomen 23%, thorax and abdomen 22%) without deterioration of image quality by using the CARE dose technique.(18)

2.3 Establishment of diagnostic reference levels (DRLs) for CT

The International Commission on Radiological Protection (ICRP) in 1996 proposed the establishment of diagnostic reference levels, using the third quartile (75th percentile) of the CT dose parameters namely CTDI and DLP values. This proposal was to help optimize CT radiation dose to patients and identify unjustified high and low dose practices, whilst keeping in mind the "As Low as Reasonably Achievable" (ALARA) principle. DRL helps avoid unnecessary radiation dose that does not contribute to diagnostic purpose for the patient. The best quality image derived from maximal radiation dose is not necessarily required for diagnostic purposes. The ICRP also emphasize that DRLs should be derived from relevant regional, national or local data. Some countries have their own CT DRLs whereas others apply the DRLS of the European Commission and of the United Kingdom as international standards to compare and adjust CT radiation doses. (8,16,19)

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) still continue to acquire data via web-based surveys to establish national DRLs for diagnostic imaging. The first set of DRLs to be established were for multi detector computed tomography (MDCT). The survey samples MDCT dosimetry metrics: dose length product (DLP, mGy.cm) and volume computed tomography dose index ($CTDI_{vol}$, mGy), for six common protocols: Head, Neck, Chest, Abdo-Pelvis, Chest-Abdo-Pelvis and Lumbar Spine from individual radiology clinics and platforms. A practice reference level (PRL) for a given platform and protocol is calculated from a compliant survey containing data collected from at least ten patients. The PRL is defined as the median of the DLP/CTDIvol values for a single compliant survey. Australian National DRLs are defined as the 75th percentile of the distribution of the PRLs for each protocol and age group. Australian National DRLs for adult MDCT have been determined in terms of DLP and CTDIvol. In terms of DLP the national DRLs are 1,000 mGy cm, 600 mGy cm, 450 mGy cm, 700 mGy cm, 1,200 mGy cm, and 900 mGy cm for the protocols Head, Neck, Chest, Abdo-Pelvis, Chest-Abdo-Pelvis and Lumbar Spine respectively. Average dose values obtained from the European survey Dose Datamed I reveal

Australian doses to be higher by comparison for four out of the six protocols. This survey is still ongoing, allowing for optimization of dose delivery as well as the periodic update of DRLs to reflect changes in technology and technique. (15)

Hatziioannou K *et al* carried out dose measurements in Northern Greece involving six routine CT examination regions in order to compare their levels with the currently proposed European reference dose values and to produce a preliminary set of data for the establishment of local diagnostic reference levels.(20) Six routine CT examinations, namely routine head, cervical spine, chest, abdomen, lumbar spine and pelvis, were selected for their study. For each CT examination, data concerning examination parameters such as kVp, mAs, number of slices, slice thickness and couch increment, for five consecutive average sized patients were recorded in every CT clinic. The results revealed significant discrepancies in dose values among the CT scanners, which can be mainly attributed to variations in the examination protocols and the different models of scanners. Significant overdosing compared with the European reference levels was not observed, except for the routine head examination, where 47% of the scanners exceeded the corresponding CTDI value. CT scans in the trunk region resulted in higher effective doses with estimated maximal values up to 15 mSv.

A study by Mohsen Najafi *et al* in 2014 selected 24 MDCT centers from the public and private sectors in Iran and installed a computer program to collect data.(21) Participation was voluntary and users were trained to record data including information about the patients, scanners and exposure conditions, pertaining to common CT examinations for adults in 6 months. Only those centers that provided full reports for at least 10 adult patients (> 19 years of age) were included in the final analysis of data. A pilot study was carried out in 5 hospitals, randomly selected from above hospitals, in order to investigate the most common CT procedures during a month from the Picture Archiving and Communication System (PACS) and Radiological Information System (RIS). The most common procedures were CT brain, sinus, chest, abdomen and pelvis. About 60% of total CT scanners were valid for CT reports. Dose values

exceeding twice the standard deviation, outliers, were excluded and finally 885 reports were analyzed. The results were compared to DRLs of Australia, Europe and Netherlands. In terms of DLP, the DRLs of adult age group are 700, 290, 330, and 550 mGy.cm for the Head, Sinus, Chest, and Abdomen and Pelvis protocols respectively, which most cases were less than the international reference values.

In 2015, a study aimed to establish the first diagnostic reference levels (DRLs) for CT examinations in adult and pediatric patients in Turkey and compare these with international DRLs was undertaken by Ataç G *et al*.(22) The study was conducted in two phases: a survey data collection period followed by data analysis. The survey form for the first phase comprised of two parts. The first part collected the following information: hospital name, address, production year of the CT equipment, number of patients who underwent examinations for each protocol in 2013, number of examined patients and scanned body regions. Protocol parameters including name and contact information of the person who provided the information, scanning mode (axial or helical), kV, mA, slice thickness and gap, rotation time, beam collimation, pitch value and CT dose index ($CTDI_{vol}$) were recorded in the second part of the survey. In each survey, radiology departments provided 25 protocol parameters for five different age groups (< 1year, 1 to<5 years, 5 to <10 years, 10 to<15 years, adults >15years). CT performance information and examination parameters from 1607 hospitals were collected via a survey over one-year period. They found that the radiation dose indicators for adult patients were similar to those reported in the literature, except for those associated with head protocols. CT protocol optimization for adult head and pediatric chest, HRCT-chest, abdominal and pelvic protocols were proposed.

After the introduction of MDCT, Foley, S *et al* in 2012 carried out a countrywide study to update the DRLs of Ireland. (19) They first carried out a pilot study from 4 hospitals (two large urban academic teaching hospitals (>500 beds), a private hospital and a rural public hospital (>130 beds). Nine examinations were selected for the main survey as these accounted for 89% of the total number performed. Consequently, 30 CT sites with 34 scanners

collected data to complete a survey booklet which recorded the CT parameters for each of 9 types of CT examinations during a 12-week period. Dose data on a minimum of 10 average-sized patients in each category were recorded to calculate the mean values. The mean $CTDI_{vol}$ and DLP per CT examination were calculated for each site and used to compare doses across CT centers. The CT head exam showed the smallest variation between the minimum and maximum mean doses, with a difference of 250% in $CTDI_{vol}$ and 96% in reported DLP. High-resolution CT (HRCT) scans had the largest variation, with an almost 24-fold difference in both $CTDI_{vol}$ and DLP values. The rounded 75th percentile was used to calculate a DRL for each site and the country by compiling all results. They found the values were lower than the current DRLS and comparable to other international studies.

In Thailand, a retrospective study "An analysis of Radiation dose from CT" by Ittivisawakul at Rajavithi Hospital was conducted using data from 2062 patients who had CT imaging done between January 1st to April 30th, 2012.(7) The mean values of CTDI, DLP and effective doses of the brain, chest, upper abdomen and whole abdomen were collected and compared to international reference DRLs. They concluded that while the CT radiation dose of brain was below international reference DRL, the radiation doses of CT chest, upper abdomen and whole abdomen exceeded international reference DRLs. It was recommended all personnel involved should be more aware of CT radiation dose and to lower them.

Trinavarata P, *et al* in 2011 conducted a brief survey of the use of CT scan in adult patients in five university hospitals in Thailand and estimated current CT doses at these hospitals.(8) The mean values of dose parameters were compared to the DRLs of the United Kingdom and European Commission. They found that the mean CTDI values in Thailand were not above those standard levels but mean DLP value of some types of CT scanning in many hospitals was above the levels. The survey also showed considerable variation in doses across the institutions. They concluded that a national survey was needed and also encouraged every CT unit to develop a mechanism for justification for the use of CT scans.

India does not have national DRLs due to the vast population, diversity and other factors. However, several states and individual institutes have carried out their own surveys into radiation doses of CT with the goal of establishing future regional diagnostic reference levels. One such comprehensive survey was carried out by Livingstone R. and Dinkaram P. in 25 districts of Tamil Nadu, South India. It covered a total of 127 CT scanners of various models for a period of 2 years, between 2006 and 2008, using a survey booklet.(23) The data collected was used to calculate the CTDI, DLP and mean effective dose. The CTDI, DLP and mean effective doses for thorax, abdomen and pelvic CT examinations were found to be generally within those set by the European Union. However, the significant variation of doses recorded during the survey was thought to be due to the differences in scanning protocols and scanner-related parameters as there was no standard protocol.

Saravanakumar A *et al.* conducted a study that involved six out of the ten CT scanners in Pudhuchery.(24) An initial questionnaire to collect data on the model of the machines and the most common CT protocols was filled. CT dose measurements were carried out using an ionization chamber, electrometer and two phantoms to simulate average sized patients, one for head and the second for the body. Each CT scanners carried out 50 head, 50 chest and 50 abdomen examinations of the phantoms with a total of 900 CT scans over one year. The doses received by the phantom was used to calculate the CTDI v and DLP and estimate the DRL (third quartile). Compared with the European Commission DRL, the DRLs of the CT scanners in this study were found to be lower. However, they also found some scanners had doses higher than the DRLs which they attributed to machine operator protocols.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study design

Retrospective descriptive study with analytic component.

3.2 Location of the study/Trial site

Department of Radiology, Songklanagarind Hospital, Faculty of Medicine, Prince of Songkhla University, HatYai, Songkhla, Thailand

3.3 Materials:

3.3.1 Equipment

- CT system: **CT scanner**
  Manufacturer: Toshiba
  Model type: Aquilon^{TM} PRIME
  Serial number: BKA 1522134
  Number of slices: 80 slices
  Year of installation: 2012
- Quality control: Verification of read out data on the PACS system.
  - Carried out by the CT technicians using the 16 cm and 32 cm diameter phantoms.
  - Calibration with air done daily.
  - Calibration with water done weekly.
  - The company technicians calibrate the CT scanner every 2 months

3.4 Target population

All adult patients who had CT scan examinations of the Head, Thorax, and Whole Abdomen performed at Songklanagarind Hospital except those in the exclusion criteria during from July 1st to 31st, 2017.

3.5 Research participants/Subjects

3.5.1 Inclusion criteria

- All patients who had CT scans of the head, chest, and whole abdomen regions performed at Songklanagarind Hospital during the study period.

3.5.2 Exclusion criteria

- Age less than 15 years
- Contiguous CT chest and abdomen
- HRCT of the chest

3.6 Sample size calculation

$$n = \frac{(Z_{\alpha/2} + Z_{\beta})^2 \times \chi^2}{SD^2}$$

$n = Sample\ size$

$Z_{\alpha/2} = 1.96\ (95\%\ confidence\ interval)$

$Z_{\beta} = 0.84\ (power)$

$\chi = Mean\ derived\ from\ previous\ study$

$SD = Standard\ deviation\ derived\ from\ previous\ study$

$$n = \frac{(1.96 + 0.84)^2 \times \chi^2}{SD^2}$$

Table 4: Mean and SD of DLP (mGy cm) of previous study carried out in Iran(21).

Study region	Mean	SD	Sample size
Head	589.23	225.72	53
Chest	269.59	115.50	43
Whole Abdomen	429.62	171.45	49
Total sample size	145		

Table 5: Mean and SD of $CTDI_{vol}$ (mGy) of previous study carried out in Iran(21).

Study region	Mean	SD	Sample size
Head	32.18	13.37	45
Chest	16.08	7.85	11
Whole Abdomen	8.85	4.56	30
Total sample size	86		

Minimum sample size = 145 participants or CT studies

Table 6: Sample size of each CT study region according to proportionate allocation of the total number patients who had CT scans performed in July 2017 in our institute.

Study region	Sample size
Head	254
Chest	72
Whole Abdomen	137
Total Sample size	**463**

The total sample size selected for the study was **463**; subdivided into the three most common anatomical CT regions of Head, Chest and Whole Abdomen.

3.7 Variables of the study

3.7.1. Dependent and independent variables

Demographic data:

Age, gender, clinical indication for CT scan

CT data:

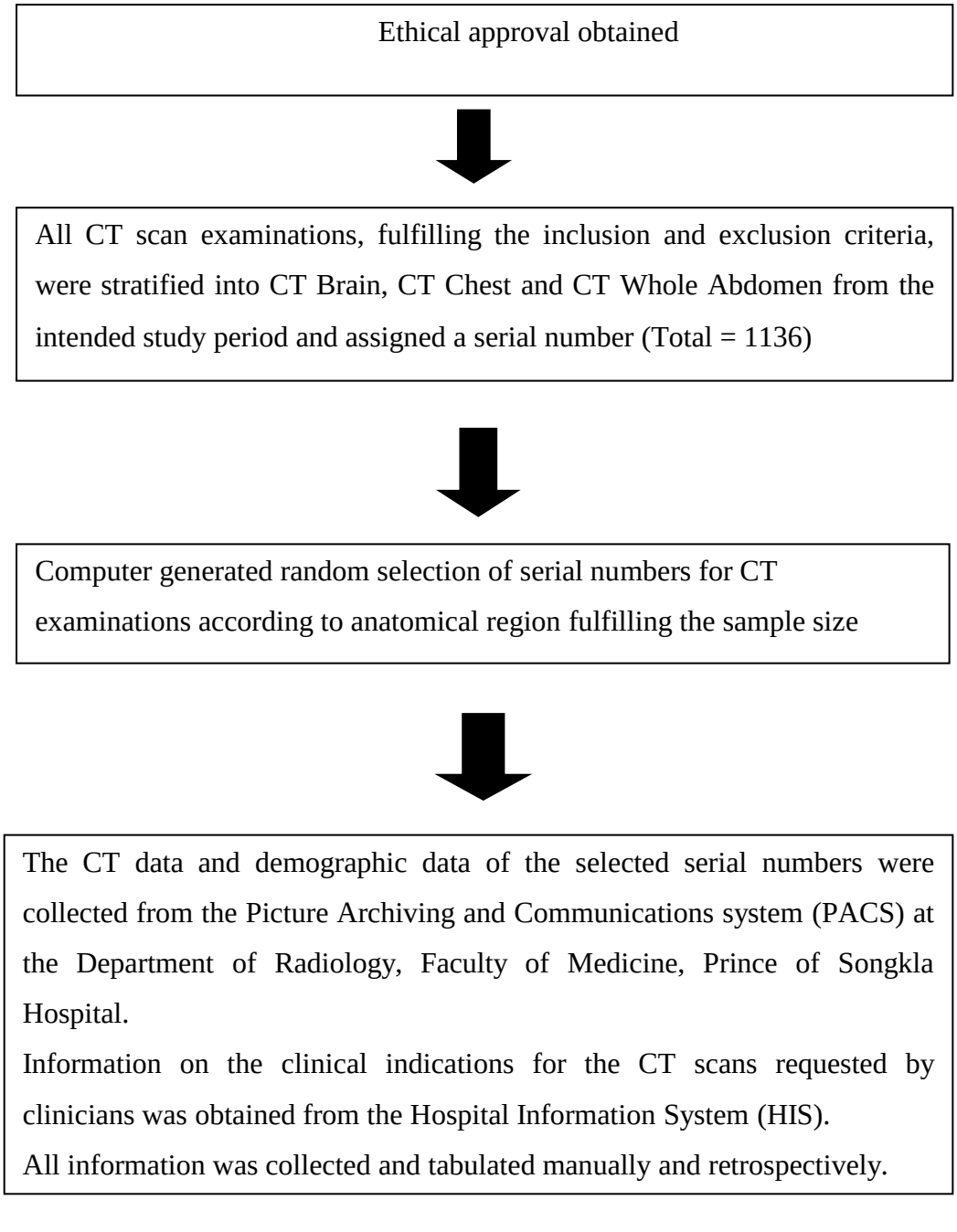
- $CTDI_{volume\ (}CTDI_{vol}$): The $CTDI_{vol}$ is defined as $CTDI_w$ divided by the beam pitch factor. It is the most commonly cited index for modern MDCT equipment.
- DLP (dose length product): The DLP is the $CTDI_{vol}$ multiplied by the scan length in centimeters. Unit: mGy.cm.

3.7.2. Methods to minimize bias(es) during study

Study population was selected via random sampling using a computer program.

The data of only these randomly selected patients were collected, for both CT radiation dose and demographic data.

3.7.3 Conceptual framework



3.8 Statistical analysis

The categorical variables were presented as counts and percentages. These included mainly the demographic data and the distribution of CT scans and clinical indications.

The mean $\pm$ standard deviation as well as the median and inter-quartile range of the $CTDI_{vol}$ and DLP values were calculated for each CT of the various anatomical regions.

The effective dose of each study was calculated using the formula:

Effective Dose = DLP x Conversion coefficients for the particular anatomical region accordingly.

DRLs were defined and calculated as the 75^{th} percentile of patient dose distribution (median) for each protocol.

Significant evaluations for these variables and the clinical indications for each of the three CT anatomical regions were carried out by the Kruskal-Wallis rank sum test.

The radiation doses of calculated DRLs obtained by this study were compared to the DRLS of the previous study at the same unit as well as international reference levels in tabular form.

Ethical Consideration

Ethical clearance was obtained from the Ethics Committee of the Prince of Songkla University.

The privacy and confidentiality of the patients have been strictly maintained. All CT examinations were assigned a code number. Only the randomly chosen code numbers had their data recorded. All raw data was recorded manually by just one person (researcher). The names, hospital numbers or any other identifying features were avoided.

CHAPTER 4

RESULTS

4.1 Demographic data

4.1.1 General information

Data from a total of 463 CT studies from 416 patients were collected. Of the total 416 patients, 224 (53.6 %) were female and 192 (46.4 %) were male. To break down the details, 210 patients had CT Brain of which 112 (53.3%) were female and 98 (46.7%) were male; the 71 patients with CT Chest had 33 (46.5%) female and 38 (53.5%) male and of the 135 patients who underwent CT Whole abdomen, 79 (58.5%) were female and 56 (41.5%) were male.

The ages of the patients ranged between 15 to 91 years of age. The mean age was 57.01 $\pm$ 17.98 years with a median age of 59 years of the total. The mean ages of patients with CT Brain, CT Chest and CT Whole Abdomen were 57.56 $\pm$ 19.7 years, 59.38$\pm$ 16.78 years and 54.91 $\pm$ 15.76 years respectively. (**Table 7**)

Table 7: Demographic data of the study population

	Brain	Chest	Whole Abdomen	Total
Number of CT studies	254	72	137	463
No. of patients	210	71	135	416
Sex				
Male	98 (46.7%)	38 (53.5%)	56 (41.5%)	192 (46.2%)
Female	112 (53.3%)	33 (46.5%)	79 (58.5%)	224 (53.8 %)

Age (years) Mean ± SD Median (IQR)	57.56 ± 19.7 60 (16-91)	59.38± 16.78 63 (15-89)	54.91 ± 15.76 56 (18-90)	57.01 ± 17.98 59 (45 - 70)

4.1.2 Clinical indications for CT scan of different anatomical regions in adults

The clinical indications for which the CT scans were requested by the clinicians varied widely but were organized and sorted into six broad categories: Trauma, Infection/Inflammation, Malignancy, Congenital, Stroke (only for CT brain) and Others (miscellaneous). (**Table 8**)

For CT head, the most common clinical indications were stroke = 74 (29.1%), followed by trauma = 73 (28.7%) and malignancy = 59 (23.2%). Infection/inflammation = 15 (5.9%), congenital = 16 (6.3 %) and others = 17 (6.8%) contributed to total indications for 254 CT studies.

For the 72 CT chest examinations, malignancy was the most common clinical indication. The CT chest for 41 (56.9 %) were to follow up, diagnose or stage lung cancer and thus included the entire chest and upper abdomen down to the lower pole of right kidney. CT chest for 12 (16.7 %) patients included only the entire thorax and mainly followed up thoracic metastases or pulmonary nodules. This was followed by infection/inflammation = 16 (22.2%), others = 2 (2.8%) and congenital = 1 (1.4%).

Malignancy was the major clinical indication for CT whole abdomen with 68 (49.6%) of the total 137 studies. The rest were infection/inflammation = 42 (30.6%), others = 14 (10.2%), trauma = 12 (8.8%) and finally congenital = 1 (0.7%).

Table 8: Clinical indication distribution according to CT anatomical regions in adults

Clinical Indications	No. of CT Brain	No. of CT Chest	No. of CT Whole abdomen
Trauma	73 (28.7%)	-	12 (8.8%)
Infection/Inflammation	15 (5.9%)	16 (22.2%)	42 (30.6%)
Malignancy	59 (23.2%)	12 (16.7 %) *	68 (49.6%)

		41 (56.9 %) **	
Congenital	16 (6.3 %)	1 (1.4%)	1 (0.7%)
Stroke	74 (29.1%)	N/A	N/A
Others	17 (6.8%)	2 (2.8%)	14 (10.2%)
Total	254 (100%)	72(100%)	137 (100%)

*Scan length covering only entire chest

** Scan length covering entire chest + Upper abdomen down to inferior pole of right kidney

4.1.3 CT dose parameters according to clinical indicatons (**Table 9**)

For CT head, malignancy has the highest DLP with mean 1926.16 $\pm$ 417.44 and median of 2067.20 with the 3rd quartile 2160.60 followed by infection and inflammation category which has mean of 1926.16 $\pm$ 417.44, median 1952.70 and 3rd quartile 1079.60. CT brain indicated by stroke has a mean of 1090.13 $\pm$ 295.56 and 3rd quartile value 1102.60.

CT chest has the highest DLP in the others category with mean 516.55 $\pm$484.44, median 516.50 and 3rd quartile 678.80. This may be due to the smaller number of studies carried out. The two types of CT scans done for malignancy (* only chest; **Chest and upper abdomen) have similar DLP values. CT chest only has mean 370.0 $\pm$176.89 and 3rd quartile 473.60. Meanwhile CT chest including upper abdomen has mean 370.0$\pm$177.68 and 3rd quartile 473.10. CT chest done for infection/inflammation had mean of 350.37 $\pm$ 182.99 and 3rd quartile of 348.50.

The DLP values of CT whole abdomen are depicted as others with mean 1621.61 + 898.38 mGy.cm and 3rd quartile 1415.60 mGy.cm; trauma with mean 1349.37 $\pm$ 898.38 mGy.cm and 3rd quartile 1415.60 mGy.cm; infection/ inflammation with mean 1300.70 $\pm$ 793.65 mGy.cm and 3rd quartile 1619.80 mGy.cm and malignancy with mean 1171.95 $\pm$ 825.73 mGy.cm and 3rd quartile 1467.00 mGy.cm. The congenital category had only one CT scan done with the value of 2247.40 mGy.cm. (**Table 9)**

The clinical indications of each adult CT region were compared with the DLPs of malignancy for any significant difference. (**Table 10**)

In CT head, there was significant difference between malignancy and trauma, congenital and stroke with the $p = 0.0000$. There is also significant difference between malignancy and others ($p = 0.0009$) and malignancy with infection/inflammation ($p = 0.01$).

CT chest data depicts no significant difference between the clinical indications with p varying from 0.84 to 0.99.

CT whole abdomen shows no significant difference in the p between the clinical indications.

Table 9: Median and inter-quartile range according to clinical indications: DLP (mGy.cm).

	Trauma	Infection/ Inflammation	Malignancy	Congenital	Stroke	Others
Head						
Median	1069.0	1952.70	2067.20	1025.80	1048.10	1322.10
25th percentile	1009	1032.7	1920.0	977.90	981.10	1048.10
75th percentile	1115	1079.60	2160.60	1079.60	1102.60	2113.20
Chest						
Median	N/A	275.75	325.50* 357.30**	478.60	N/A	516.50
25th percentile		258.20	266.90* 277.80**	*only 1 observation*		345.30
75th percentile		348.50	473.60* 473.10**			678.80

Whole abdomen						
Median	1173.75	1072.20	992.4	2247.40	N/A	1499.50
25th percentile	913.90	648.60	604.10	*only 1 observation*		1220.50
75th percentile	1415.60	1619.80	1467.00			1415.60

*Scan length covering only entire chest

** Scan length covering entire chest + Upper abdomen down to inferior pole of right kidney

Table 10: Comparison and significant difference between clinical indications in different CT regions

Clinical Indications	*p* of CT		
	Head	Chest	Whole abdomen
Malignancy VS Trauma	0.0000	N/A	0.9583
Malignancy VS Infection/Inflammation	0.0189	0.9987* 0.9276**	0.9304
Malignancy VS Congenital	0.0000	0.9999* 0.9919**	0.6913
Malignancy VS Stroke	0.0000	N/A	N/A
Malignancy VS Others	0.0009	0.8425* 0.8965**	0.3406

*Scan length covering only entire chest

** Scan length covering entire chest + Upper abdomen down to inferior pole of right kidney

4.2 CT scan imaging results

4.2.1 Distribution of CT phases according to anatomical region (**Table 11**)

The distributions of the phases of CT studies were according to the clinical indications as requested by the clinicians. A total of 254 CT head scans had been done, the majority were of the plain/ non-contrast phase 186 (73%) and remaining 68 (27%) were plain + venous phases. All 72 of the CT chest were with the additional venous phase. The 137 CT whole abdomen carried out were distributed as: plain only phase = 17(12.4%), plain + arterial phases = 20 (27%), plain + arterial + venous phases = 56 (40.9%) and plain + arterial + venous + delayed phases = 44 (32.1%).

Table11: Distribution of phases of the CT scans according to anatomical region

Phases	Plain	Arterial	Venous	Delayed	Total No
Brain	186 (73%)	N/A	68 (27%)	N/A	254
Chest	N/A	N/A	72(100%)	N/A	72
Whole abdomen	17 (12.4%)	20 (27%)	56 (40.9%)	44 (32.1%)	137

4.2.2 Median, inter-quartile range (P25-P75), effective dose and DRLs of CT Head. (**Table 12**)

Median, inter-quartile range **(P25-P75)**, effective dose and DRLs of CT dose are represented in terms of $CTDI_{vol}$ and DLP.

All 254 CT brain studies had non-contrast (NC) or plain phases. The $CTDI_{vol}$ dose had a median 55.80 (52.30 - 57.50) mGy. The DLP values have a median of 1048.7 (990.7 0 - 1102.60) mGy.cm. 64 NC + contrast enhanced CT brain studies with a median $CTDI_{vol}$ dose of 55.93 (52.30 - 57.50) mGy are noted. The median DLP was 57.50 (1990 – 2188) mGy.cm. The total CT brain studies had median of 57.50 (1009.20 -1924.60) mGy.cm. Effective doses were calculated by multiplying the DLP by the conversion co-efficient factor for the respective anatomical regions. The

effective doses of the NC CT brain and contrast enhanced CT brain were 4.82 and 2.49 mSv and for the total number of CT brain studies was 3.13mSv.

The third quartile also known as 75th percentile of the distribution of $CTDI_{vol}$ and DLP values are defined as the DRL for each protocol.

According to our findings, the **$CTDI_{vol}$ value of 57.50 mGy** and **DLP of 1102.60 mGy.cm** are considered the DRLs of CT brain in this study.

Table 12: Median, inter-quartile range (P25-75) and effective dose of brain CT

Phase (No. of studies)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	Effective Dose (mSV)
Non-contrast (NC) (254)			
Median	55.80	1048.7	2.49
25th percentile	52.30	990.7 0	2.27
75th percentile	57.50	1102.60	2.54
NC + Contrast (64)			
Median	57.50	2113	4.86
25th percentile	52.30	1990	4.63
75th percentile	57.50	2188	5.07
Total (254)			
Median	55.80	1089.9	2.51
25th percentile	52.30	1009.20	2.32
75th percentile	57.50	1924.60	4.43

4.2.3 Median, inter-quartile range (P25-P75) effective dose and DRLs of CT chest. (Table13)

All 72 CT chest studies were contrast studies in the venous phase. The $CTDI_{vol}$ doses had a mean of 9.34 mGy, SD of 4.40 and a range from 6.18 -11.63 mGy. The DLP had a mean of 385.37 mGy.cm with SD of 184.36 and range from 260.60 -474.70 mGy.cm. The effective dose of the CT chest was 5.39 mSv.

The **$CTDI_{vol}$ and DLP values of 11.63 mGy and 474.7 mGy.cm** are considered the DRLs of CT Chest in this study.

Table 13: Median, inter-quartile range (P25-75) and effective dose of chest CT

No. of studies	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	Effective Dose (mSv)
Contrast (72)			
Median	7.90	317.00	5.39
25^{th} percentile	6.18	260.60	4.43
75^{th} percentile	11.63	474.70	8.07

4.2.3 Median, inter-quartile range (P25-P75) effective dose and DRLs of CT whole abdomen (Table 14)

137 CT whole abdomen examinations were conducted in four phases. The number and type of phases included were according to the clinical indication.

The plain phase with 110 studies had $CTDI_{vol}$ dose with a mean of 11.21 mGy with SD of 4.71 and range from 7.83 - 26.80 mGy. The DLP values had a mean of 465 mGy.cm with SD of 268.16 and range from 299.1 - 488.7 mGy.cm. The calculated effective dose was 6.98 mSv.

78 CT studies conducted in arterial phase had $CTDI_{vol}$ dose with a mean of 10.70 mGy with SD of 4.24 and range from 7.60 – 13.00 mGy. The DLP values

showed a mean of 465 mGy.cm with SD of 268.16 and range from 299.1 - 488.7 mGy.cm. The calculated Effective dose was 5.64 mSv.

135 CT studies carried out the venous phase. The $CTDI_{vol}$ dose had a mean of 10.70 mGy with SD of 4.38 and range from 7.65 – 13.15 mGy. The DLP values had a mean of 516.00 mGy.cm with SD of 248.85 and median (IQR) of 351.70 – 624.40 mGy.cm. The calculated effective dose was 7.74 mSv.

57 delayed phase CT studies had been done. The $CTDI_{vol}$ dose had a mean of 13.84 mGy with SD of 5.86 and range of 9.10 – 16.50mGy. The DLP values had a mean of 437.44 mGy.cm with SD of 259.29 and inter-quartile range of 257.20 – 547.30 mGy.cm. The calculated Effective dose was 6.54 mSv.

Of the total 157 CT studies carried out, $CTDI_{vol}$ had a mean of 10.75 $\pm$ 4.41 mGy and median 1091.7 mGy (7.70 – 13.2). The DLP values showed a mean of 1280.79 $\pm$ 824.19 mGy.cm with median 1091.7 mGy (677.8 – 1521.7). The calculated effective dose was 19.21 mSV.

The DRLs of the CT whole abdomen were considered as the third quartile values **$CTDI_{vol}$ of 13.15 mGy** and **DLP of 624.40 mGy.cm** of the venous phase.

Table14: Median, inter-quartile range (P25-75) and effective dose of abdominal CT

Phases (No. of studies)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	Effective Dose (mSv)
Plain (110)			
Median	9.65	397.8	5.97
25^{th} percentile	7.83	299.1	4.49
75^{th} percentile	26.80	488.7	7.33
Arterial (78)			
Median	9.25	324.90	4.82
25^{th} percentile	7.60	223.90	3.34
75^{th} percentile	13.00	469.20	6.99
Venous (135)			
Median	9.40	449.20	6.74

25th percentile	7.65	351.70	5.28
75th percentile	13.15	624.40	9.37
Delayed (57)			
Median	13.10	340.00	5.10
25th percentile	9.10	257.20	3.86
75th percentile	16.50	547.30	8.20
Total (137)			
Median	9.40	1091.70	16.38
25th percentile	7.70	677.80	10.17
75th percentile	13.20	1521.70	22.83

4.2.4 The number of CT studies with $CTDI_{vol}$ (mGy) and DLP (mGy.cm) above the 75th percentile in our study (Table 15)

In addition to our diagnostic referral levels, it was essential to discover the number of patients that had radiation dose above the 75th percentile of both $CTDI_{vol}$ and DLP of each CT region. As detailed in table 15; for CT head, the radiation dose above the 75th percentile of $CTDI_{vol}$ was 11.8% and DLP was 21.3% while for CT chest, $CTDI_{vol}$ and DLP were both 25% of the total number of scans. The radiation dose above the 75th percentile of CT whole abdomen had 24.8 % of total scan above the DRL values.

Table 15: Number of CT studies with $CTDI_{vol}$ (mGy) and DLP (mGy.cm) above the 75th percentile (DRLs)

	Head	Chest	Whole abdomen
$CTDI_{vol}$ (mGy)			
➢ 75th percentile	(>57.5)	(>11.6)	(>13.2)

Number of *p* studies (%)	34 (24.8%)	18 (25%)	34 (24.8%)
DLP (mGy.cm) ➢ 75th percentile Number of studies (%)	(>1102.6) 54 (21.3 %)	(>474.7) 18 (25%)	(>1102.6) 34 (24.8%)

4.2.5 The DRLs of this study compared with the previous study in Prince of Songkla University and international DRLs (**Table16**)

The DRLs, namely $CTDI_{vol}$ and DLP, of all three CT brain, chest and whole abdomen studies are all below international reference DRLs. The only exception is that of the CT brain where the $CTDI_{vol}$ is slightly higher than that of the US and the DLP which was above those of the UK, EU, US and Australia. However, these values were lower than that of the DLP of Japan.

In addition, the DRLs of all three CT regions have increased from the DRLs of the previous study undertaken at Songklanagarind Hospital, Prince of Songkla University *i.e.* the same CT unit in 2010.

Table 16: The $CTDI_{vol}$ and DLP of this study compared with the previous study in Prince of Songkla University and international DRLs

	DRLs of Songklanagarind Hospital		International DRLs				
CT Anatomical Region	**This study**	**Previous study in 2010 (8)**	UK (2014) (25)	EU (2014) (26)	US (2014) (27)	Australia (2013) (16)	Japan (2015) (28)

Brain							
$CTDI_{vol}$ (mGy)	**57.50**	**45**	60	60	56	60	85
DLP (mGy.cm)	**1102.60**	**1089**	970	970	962	1000	1350
Chest							
$CTDI_{vol}$ (mGy)	**11.63**	**8.6**	12	10	13	15	15
DLP (mGy.cm)	**474.70**	**355**	610	400	469	450	550
Whole abdomen							
$CTDI_{vol}$ (mGy)	**13.15**	**11.3**	15	25	15	15	20
DLP (mGy.cm)	**624.40**	**552**	745	800	755	700	1000

CHAPTER 5
DISCUSSION

5.1 Discussion

Rapidly increasing use of imaging in medical practice, especially CT examinations, are a reality in clinical use. However, patient radiation doses must be monitored closely in order to avoid the unnecessary extra radiation. This matter is a concern world-wide as newer procedures and technology that make use of CT imaging develop rapidly. The International Commission on Radiological Protection (ICRP) proposed diagnostic reference levels (DRLs) as a means for optimization and justification of CT radiation dose. It was emphasized that DRLs should be obtained from existing regional, national or even local data. A previous study in Thailand encouraged CT units to maintain their own DRLs due to the wide variability of CT scanner models and protocols in different facilities.

This study can be considered an update of the previous study carried out at the Department of Radiology, Songklanagarind Hospital, Prince of Songkla University in 2010.(8) This time, a larger sample population and correlation with the clinical indications have been included.

The data showed that CT head was the most commonly performed CT scan examination followed by the whole abdomen and chest CTs. CT head was mainly done for stroke, trauma and malignancy. Although its DLP was high, the conversion factor of the brain is low as it is not a radio-sensitive organ. Therefore, the total effective dose of CT head was not high. The total effective dose was highest with CT whole abdomen due to multiple reasons. The longer scanning area compared to the other two regions, high conversion coefficient due to many intra-abdominal organs

with high tissue weighting factors and multiple phases of scanning (according to protocols for clinical indications) all contributed to this high total effective dose.

The added contrast enhanced phase for CT head study is usually the venous phase as per the clinical indications of malignancy or infection/ inflammation. Therefore, since the CT parameter and scan length in venous phase of CT head are equal to the non-contrast study, the studies performed with non-contrast and contrast phases provide twice the dose than the non-contrast study alone.

In the analysis of the CT head and its relationship with clinical indications, CT head depicted significant statistical difference between malignancy and trauma, congenital and stroke with the $p = 0.0000$. There was also significant difference between malignancy and others ($p = 0.0009$) and malignancy with infection/inflammation ($p = 0.01$). The reason for such significant difference could be due to the fact that most trauma and stroke cases only do non-contrast phase. CT brain for malignancy uses contrast phase in addition to non-contrast phase. Others category mainly include investigation of chronic headaches for which non-contrast CT brain is performed. Malignancy versus infection/inflammation show statistically significant difference but the p-value is more than those of trauma and stroke. This is likely due to the fact that the patient numbers were less even though contrast phase is usually done for infection/inflammation indication.

Only the venous phase was done for all CT chest studies. The CT chest for malignancy such as lung cancer that included the upper abdomen had almost the same with only slightly higher DLP values than the CT chest for other malignancy which include only the chest. The value might be higher as the area covered by the scan was longer.

CT chest data depicts no significant difference between the malignancy and other clinical indications with *p* varying from 0.84 to 0.99. The mean reason could be that almost the same identical protocol is used for all the clinical indications and all images had only contrast venous phase. The *p* of the two different protocols for malignancy, one whose scan length covers only the chest and the second whose scan length covers the entire chest and includes the upper abdomen down to inferior pole

of right kidney, do not show much difference. For example, in the analysis of malignancy versus others the *p* was 0.8425 and 0.8965 for the first and second types of CT chest.

For CT whole abdomen, the total DLP which included all the phases, was the highest leading to the highest effective dose. The venous phase had the highest DLP compared to plain, arterial or delayed phase which can be explained by the fact that the plain, arterial or delayed phases does not cover whole abdomen whereas venous phase covers the whole abdomen. CT whole abdomen shows no statistically significant difference between the different clinical indications.

The $CTDI_{vol}$ and DLP of this study were higher than the previous study in 2010 in all three CT regions. This could be due to different CT machines, different CT parameter settings to obtain diagnostic quality image and rapidly changing protocols over time.

Comparing the dose parameters of our study to DRLs from UK, European Commission and Australia, we found that the mean $CTDI_{vol}$ and DLP values in our unit are not above their level. However, CT head had the $CTDI_{vol}$ value slightly above that of the US and the DLP was above those of the UK, EU, US and Australia. This could be due to our protocol for CT brain in trauma is similar to CT head and neck, which scans downward to the C2 spine resulting in longer scan length than other indications. The $CTDI_{vol}$ and DLP of all three CT regions of our study were lower than that of the DRLs of Japan. This finding may be significant as the physiognomy of the people of Thailand and Japan are more similar than those of the Caucasian people. More studies from Asian countries need to be conducted as the international reference levels utilized at the moment may be inaccurate regionally due to physical and physiognomy differences.

Our study also showed that the number of CT scans with radiation dose more than the 75^{th} percentile (DRL) of both $CTDI_{vol}$ and DLP were quite high; 11.8% and 21.3% for CT head, 25% for CT chest and 24.8 % for CT whole abdomen respectively. Radiation dose above DRL levels need to be justified for clinical reasons where the benefits outweigh the risks. A retrospective analysis of the CT scans, CT

parameters setting, and their corresponding clinical indication would be helpful to clarify the reason for the number of CT scans above 75th percentile.

Clear communication between radiologists and the physicians, about the patient's details and indication for the CT scan, need to be established in order to optimize the scanning procedure as well as recommendations for alternate options for the patient. Unnecessary scanning phases can be avoided as otherwise there is a tendency to over-scan in order not to miss any important findings.

The limitations of this study were that we did not include HRCTs and Chest-Abdomen-Pelvis (CAP) contiguous CT scans and that the DRLs were categorized for p-values between clinical indications.

CHAPTER 6

CONCLUSION

6.1 Conclusion

CT scanning is a very beneficial mode of imaging for diagnosis in the medical field but also is the greatest source of X-ray radiation exposure. There is concern about the cancer risk from radiation. Diagnostic reference levels (DRLs) are a simple way to identify over or under patient absorbed dose for optimization and justification. The ICRP recommends each unit to maintain their DRL parameters. Our study showed that the radiation doses for almost CT scans in adults at our unit were below the international standards. There was significant difference in the DLP values of malignancy versus other clinical indications mainly in CT brain and CT chest. It should be part of the CT unit's practice to record the number of studies above the DRLs and review them to see the cause of higher radiation dose and justification in each case.

6.2 Recommendations

We recommend a review of the CT protocols among radiologists, medical physicists and radiographers periodically, especially when new hardware or software is obtained and installed.

Monthly or quarterly review of CT studies above DRLs should be performed in order to justify its use, setting of the CT parameters and clinical indication. Thus, CT radiation dose can be optimized, or other alternative investigations advised. A similar study or survey to my study carried out every 4-5 years could be helpful in the optimization of radiation doses. Studies that include CT scans of a wider range of anatomical regions, different techniques and for different indications should be considered in the future as imaging is a rapidly evolving field.

The maintenance of a CT dose index registry will help in the analysis of data and development of diagnostic reference levels in the future. The verification of CT dose in digital display should be performed by qualified medical physicists during the quality control procedure of the CT scanner annually. Establishment of national diagnostic reference levels should be done in the future for uniformity throughout all the facilities.

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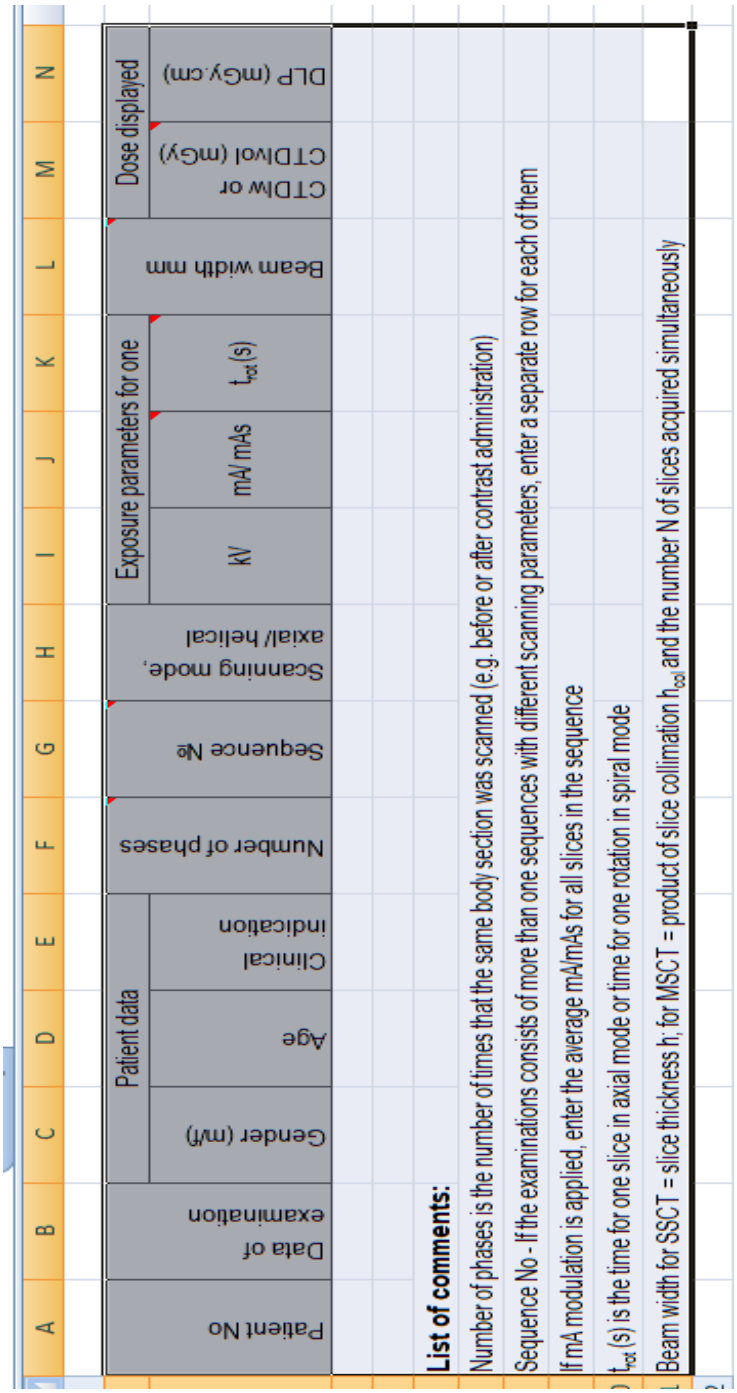
APPENDIX

CT scan data from PACS database and data entry page



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