RADIATION DOSE MEASUREMENT OF ABDOMINAL CT AND CATEGORISATION ACCORDING TO REFERRAL ORIGIN AND DESIGN OF CT STUDY IN ADULT PATIENTS

Dr Jacinta Adrigwe

Department of Diagnostic Radiology
University of the Witwatersrand

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Declaration

I, Jacinta Adrigwe, declare that this research report is my own work. It is being submitted for the degree of MMed (RadD) at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

DR JACINTA ADRIGWE

On this 4th day of June 2018.

To my Father, my guide and inspiration.

Publications and presentations

This work has never been published or presented at any local or international congresses.

Abstract

INTRODUCTION: Abdominal CT scan remains the biggest culprit of man-made radiation affecting humans. With the increase in medical litigation and evolvement of CT technology, there has also been an increased utilisation of CT scanning. It is the radiologist's responsibility to keep radiation to patients As Low As Reasonably Achievable (ALARA) while still obtaining an image adequate enough for correct interpretation. To do this effectively, radiologists and referring clinicians need to know the doses received by patients during CT procedures, and if dosages are above recommended acceptable reference levels, measures need to be taken to reduce the potentially detrimental dosages at the health facility.

AIM: The aim of this study was to determine adult radiation dose measurements from abdominal CT scans in diagnostic radiology at Helen Joseph and Rahima Moosa Mother and Child Hospital Complex and to compare our results to internationally recommended Diagnostic Reference Levels (DRLs) for abdominal CT scans. The radiation dosages between the number of abdominal CT scan phases performed, the referral origin and the hospitalisation status of the patient was also compared.

METHOD: Records of adult patients who underwent abdominal CT scans were obtained from the radiology department patient registration books. The department of origin of the patient and whether the patient was an inpatient or outpatient, as well as the phases of the scans performed, the dosimetry (DLP and $CTDI_{vol}$) values were all retrieved from the patient's archived scan which is stored in the department of radiology.

RESULTS: Using the European Commission guidelines for DLP and $CTDI_{vol}$ as our reference levels, which applies to single phase scans, we found that adult patients who had had CT abdominal scans at Helen Joseph and Rahima Moosa Mother and Child Hospital Complex received radiation doses which were below the recommended diagnostic reference levels. When assessing the overall radiation doses, regardless of the number of phases done per patient, we found the the radiation doses received by patients is dependent on the number of abdominal CT scan phases performed, with a linear increase in the DLP and $CTDI_{vol}$ values as the number of phases increases. This was further confirmed by the coefficient of linear

regression. Radiation doses received by patients differed significantly depending on the referral origin with hepatobiliary patients receiving the overall highest total radiation dose. Analysis of single phase scans demonstrated the urology patients receiving the least radiation dose. Inpatients were found to receive higher radiation doses than outpatients. This difference, however, lacked statistical significance.

CONCLUSIONS: Our study emphasises the continuous need for periodic radiation dose audits within our institution and rigid implementation of CT dose optimisation techniques in an attempt to further curb the detrimental stochastic and deterministic biological effects of ionising radiation.

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List of Abbreviations and Terminology

ACR	American College of Radiologists
ALARA	As Low As Reasonably Achievable
ANOVA	Analysis of Variance
ATCM	Automatic Tube Current Modulation
C.I	Confidence Interval
Coef.	Coefficient
CT	Computed Tomography
$CTDI_{air}$	Computed Tomography Dose Index in air
$CTDI_{vol}$	Computed Tomography Dose Index (volumetric)
$CTDI_{w}$	Computed Tomography Dose Index (weighted)
DECT	Dual Energy Computed Tomography
DLP	Dose Length Product
DRLs	Diagnostic Reference Levels
EC	European Commission
i	Individual scans in a series
I	Table distance per rotation
ICRP	International Commission on Radiological Protection
IEC	International Electrotechnical Commission
IIR	Iterative Image Reconstruction
KUB	Kidney Ureters and Bladder
Kv	Kilovolt
L_i	Length in centimetres, of the patient covered during the scan
mGy	Milligray
mGy-cm	Milligray per centimetre
NT	Total nominal collimation width
PACS	Picture Archiving and Communication System
SANAS	South African National Accreditation System
SD	Standard Deviation
SECT	Single Energy Computed Tomography
UK	United Kingdom

1. Introduction

1.1. Motivation and rationale for this study

There has been a significantly increasing use of CT over the past decades (1). Advances in CT technology with better representation of anatomical detail has led to the surge in the utilisation of CT scans (2). CT remains one of the highest contributors of ionising radiation exposure in medicine (3). Regulatory bodies are in place in an attempted to curb the over usage of CT scanning and unnecessary unindicated exposure to this potentially detrimental source of radiation (4).

There have been numerous studies done with respect to abdominal CT scanning, the radiation doses acquired by the patients, and numerous ways in possible dose reduction (5). Modern multi-detector CT scanners have a built in metric of the dose imparted which takes into account the distance covered and number of phases performed, and is known as the Dose Length Product (DLP) (6). In some states of the United States of America it is a legal requirement (e.g the California Senate bill 1237) to provide the DLP in each and every CT scan report (7). In line with this, the DLP may become a medico-legal indicator of radiologist performance.

In addition to the numerous patient factors attributing to increased exposure to radiation e. g patient body habitus, there are machine factors, which if possible should be avoided as they could result in an additional dose (8). A comparison made between Dual versus Single Multidetector CT scanning found that radiation dose in Dual Energy CT (DECT) was higher than Single Energy CT (SECT) with set protocols. This was attributed to the increased scan time in DECT (9).

A retrospective study by Guite et al (2) looked at multiphase scanning and the American College of Radiologists appropriateness criteria for each phase. The appropriateness of phases in multiphase scanning on the basis of the patient clinical presentation requires re-enforcement with elimination of additional unindicated phases of no clinical benefit.

In 1997, the European Union introduced the concept of radiation dose surveillance in diagnostic imaging as one of the dose reduction attempts in radiology. Upper limits of the acceptable ranges were also defined as falling on the 75th percentile of dose distribution range (4). There are various known dose reduction methods that can be implemented by the machine users. These methods include implementing weight based lowering of tube current and peak kilovoltage per patient and shortening scan time if feasible (7). However, these have the potential to degrade diagnostic quality by increasing image noise, so a balance needs to be achieved between all parameters without compromising image quality and scan interpretation.

Establishment of Diagnostic reference levels (DRLs) at an institutional, regional or national level is another dose lowering technique whereby the staff in a radiology department should aim to keep the radiation dose below these recommended values. As there are no published South African national diagnostic reference levels for CT abdomen in adult patients, our results were compared with the recommended European Commission guidelines for $CTDI_{vol}$ and DLP. Currently diagnostic reference levels have been established only for single phase scans (either non-contrast or post intravenous contrast administration) (10). The additional analysis of the multiphase scan dosimetry in this study was to illustrate the number of multiphase scans at our institution, and the radiation dose impact on our patients.

AlSuwaidi (11) advocates the continuous monitoring of CT dose using the Picture Archiving and Communications System (PACS) as one time dose measurement does not provide a cumulative radiation dose on a patient with repeated scans over a period of time. This method of continuous CT abdomen radiation measurement can further be used in the implementation and modification of a radiology departments dose lowering techniques taking into account the cumulative doses a patient receives. The biggest challenge thus far in CT dose reduction remains the patient body habitus (8).

With the increasing utilisation of CT scanning, there has been an increase in the number of studies by radiologists and medical physicists measuring the radiation doses received by patients, their long term and short term effects, as well as methods of reducing overall radiation dose. There is however a paucity of studies comparing the medical subspecialty specific cumulative patient doses based on the referral origins. Furthermore, there remains a

lack of knowledge and underestimation of radiation doses and risks among referring clinicians (12). Part of the outcome of this study will be feedback to and education of the various sub-specialties in terms of appropriateness of requests and cautious referral of patients for abdominal CT scans.

1.2. Aims and Objectives

1.2.1 Aims

The aim of this study was to determine adult radiation dose measurements from abdominal CT scans in diagnostic radiology at Helen Joseph Hospital and Rahima Moosa Mother and Child Hospital Complex, categorise them according to referral origin (department and in/outpatient) and examination design and finally compare our results to internationally accepted dosages for abdominal CT scans.

1.2.2. Objectives

1. To determine adult radiation dose measurements from abdominal CT Scans in diagnostic radiology at Helen Joseph and Rahima Moosa Hospital Mother and Child Hospital Complex, and to categorise the dose based on relevant literature values.
2. To compare abdominal CT doses:

- Between referral origin groups (at a sub-specialty level).
- Between inpatient and outpatient referrals.
- Between types of examination design / protocol.

3. To compare our results to internationally accepted dosages for abdominal CT scan.

2. Materials and Methods

2.1 Study design

This was a retrospective cross-sectional study.

2.2 Study setting

The study population was patients who had abdominal CT scans done at Helen Joseph and Rahima Moosa Mother and Child Hospital Complex in Johannesburg, South Africa.

2.3 Study sample

A total of 200 adult patients who had undergone abdominal CT scanning

2.4 Study period

The study period was from January 2014, and consisted of the first 200 patients that fulfilled the inclusion and exclusion criteria.

2.5. Inclusion criteria

Only adult patients (over 18yrs) with all the relevant clinical information available, were considered for inclusion into the study.

Only patients who had undergone an abdominal CT scan were included, regardless of referral origin and CT scan indication.

2.6. Exclusion criteria

- Any incomplete CT abdomen studies
- Cases where the dose is not available or the scan has not been archived
- Cases where the referral information was unavailable
- Any patients presenting for interventional CT guided abdominal procedures
- Patients with combined chest and abdomen scans or pan scans

- Patients with sub-optimal abdominal CT scans due to image degradation by artefact who had repeated scanning done
- Patients who had undergone CT Angiography and other specialised CT scans of the abdomen

2.7. Data collection

Data was collected on a data collection sheet [see appendix B] and entered into an Excel spreadsheet for statistical analysis.

The Dose Length Product and volumetric CT Dose Index, as calculated and recorded by the CT scanner software was documented. These values are recorded in mGy-cm (milligray per centimetre) and mGy (milligray) respectively. The American College of Radiology CT accreditation program dose reference levels for an adult abdomen are 25mGY with a maximum allowable dose of 30mGy as measured in $CTDI_{vol}$ (13).European Commission guidelines (1999) recommend an allowable weighted CT Dose Index 35mGy and Dose Length Product 900mGy-cm (13) value. This was later updated in 2004, with a volumetric CTDI value of 25mGy, however the DLP was kept at 900mGy-cm. Of note is that diagnostic reference levels apply only to single phase CT abdomen scans (10). The 2004 values are used as baseline values for the study. There are as yet no published dose reference levels for CT abdomen in South Africa.

Departments of origin were grouped into surgical and medical with the following subsections: General surgery, Urology, Gynaecology, Hepatobiliary, Colorectal and Medicine.

The data comprised of the patient demographics (age, gender), referral origin, study protocol used during the study, the number of sequences done, the use of contrast agents and the total dose recorded during the study.

Pre-planned servicing of the machines by the vendor were done quarterly and a quality assurance test done annually. The quality assurance test was performed by an inspector accredited by the South African National Accreditation System (SANAS) and approved by the South African Department of Health. Calibrated results for $CTDI_{vol}$ and $CTDI_{air}$.were then

provided amongst other tests done. Pencil ionisation chambers are used for the accurate determination of $CTDI_{vol.}$. In accordance with the International Electrotechnical Commission (IEC) standard 61674 (1997), a chamber length of 50% should be irradiated to obtain an accurate calibration factor in order to produce reliable CTDI results. Ionisation chambers are calibrated in air kerma using a reference x-ray field(14). In addition, daily calibration tests were done on the CT scanners at the hospitals used in the study using test phantoms to assess machine performance in order to produce images of acceptable diagnostic quality and display reliable accurate reproducible radiation dosages post the procedure.

2.8. Statistical analysis

1. Radiation dose was expressed as frequencies and descriptive measurements (mean values and standard deviation values) were computed.
2. Comparison between subspecialties was achieved by testing the mean dosages using the Analysis Of Variance (ANOVA) test, if the data is normally distributed or the Kruskal-Wallis test, if data was not normally distributed. The Bonferroni test was used to allow a pairwise comparison between groups.
3. Comparison between the inpatient and outpatient groups was achieved using the independent t-test given that our sample size was large enough. We applied the Theorem of Central Limit which stipulates that 'the distribution of the sum (or average) of a large number of independent, identically distributed variables will be approximately normal, regardless of the underlying distribution' (15).
4. Comparison between scan protocols was achieved by testing the mean dosages using the Analysis Of Variance (ANOVA) test, if the data was normally distributed or the Kruskal-Wallis test, if data was not normally distributed.

2.9. Ethics

Ethics approval for this study was granted by the University of Witwatersrand Human Research Ethics Committee (Clearance Certificate #: M150449) (Appendix A) on the 6th May 2015.

3. Results

3.1 Demographics distribution and referral pattern of study population.

A total number of 200 randomly selected patients met the inclusion criteria for the study. With reference to Table 3.1, of the 200 patients, there were 120 (60%) female patients and 80 (40%) male patients resulting in a female to male ratio of 3:2. The female predominance in our study can be explained by the fact that Rahima Moosa is specifically a mother and child hospital, where half of our study sample was obtained. A similar study done in Belgium by Pyferroen et al, also found that their study sample for CT abdomen and pelvis had a female predominance(16). This can also be explained by the increased multitude of female pelvic gynaecological pathology requiring CT scan investigation.

The patients had age range of 18-82 years with the mean age being 48 years (SD 16 years) and median age of 47 years. The average ages of the female patients was 49 years, and 47 years for the male patients. The difference in average ages between male and female patents was statistically significant (p-value) and suggested that in a larger population, one would expect to see the same pattern, with females undergoing CT scans being older than males.

Inpatients comprised 61.5% of the sample and outpatients 38.5%. Of these, the referral patterns per department were, colorectal 2.5%, hepatobiliary 7.5%, urology 14%, medicine 17%, gynaecology 19% and the highest being general surgery comprising 40% of the patients.

Table 3.1. The percentages and frequencies of study population according to Gender, Hospitalisation status and Referral pattern

Variable	Category	Frequency	Percent %
Gender	Female	120	60%
	Male	60	40%
Hospitalisation status	Inpatient	123	61.5%
	Outpatient	77	38.5%
Referral origin	Colorectal	5	2.5%
	Hepatobiliary	15	7.5%
	Urology	28	14%
	Medicine	34	17%
	Gynaecology	38	19%
	General Surgery	80	40%

3.2 CT Abdomen scan phases

The CT abdomen scan phases are the pre-contrast, arterial, portal venous and delay phases. As illustrated in Table 3.2, 60 patients had a pre-contrast phase, 69 an arterial phase, 185 a portal venous phase and 145 a delay phase as part of their imaging. Depending on their clinical history provided of the CT request form and the protocol decided upon by the radiologist, the portal venous phase appears to be standard practice at our institution

Table 3.2. Types of CT abdomen scan phases in relation to the number of patients

Type of Phase	Frequency	Percentage
Pre-Contrast	60	30%
Arterial	69	34.5%
Portal Venous	185	92.5%
Delay	145	72.5%

In total 43 patients received 1 phase, 76 patients received 2 phases, 30 patients received 3 phases and 21 patients received 4 phases as illustrated in Table 3.3. From this, we can

appreciate that there was a predominance of multiphase imaging (63.5% of patients) as compared to the single phase.

Table 3.3. Frequency of number of CT abdomen scan phases

Number of Phases	Frequency	Percentage
1	43	21.5%
2	76	38%
3	30	15%
4	21	10.5%

In Table 3.4 we reviewed the number of CT abdomen phases in relation to the referral origin and found that there was a statistically significant (p-value: 0.001) association between these two variables. The hepatobiliary patients who had the overall highest total radiation were also seen to have the highest percentage of patients receiving 4 scan phases. The gynaecology, colorectal and urology patients were found to only have had 3 or less phases done with the colorectal patients having the least documented total radiation dose. This further illustrates the increase in radiation dose with the increase the number of CT phases done, variables which were assessed and discussed further as part of the study.

Table 3.4. Frequencies and percentages of CT abdomen phases in relation to the referral origin

# phase	Medicine n (%)	Gynaecology n (%)	HPB n (%)	Colorectal n (%)	Urology n (%)	Gen Surgery n (%)	Total n (%)	p-value
1	5 (14.7%)	3 (7.9%)	2 (13.3%)	3 (60.0%)	11 (39.3%)	19 (23.8%)	43 (21.5%)	0.001
2	8 (23.5%)	20 (52.6%)	1 (6.7%)	2 (40.0%)	0 (0.0%)	45 (56.2%)	76 (38%)	
3	11 (32.4%)	15 (39.5%)	5 (33.3%)	0 (0.0%)	17 (60.7%)	12 (15.0%)	60 (30%)	
4	10 (29.4%)	0 (0.0%)	7 (46.7%)	0 (0.0%)	0 (0.0%)	4 (5.0%)	21 (10.5%)	
Total	34	38	15	5	28	80	200	

Note: p-value from Pearson Chi-square test

3 .3 CT dose and number of phases

As shown in Table 3.5, the radiation dose incurred by patients is dependent on the number of CT scan phases performed, with an increase in the DLP and $CTDI_{vol}$ as the number of phases increases.

Table 3.5. DLP(mGy-cm) and $CTDI_{vol}$(mGy) values and number of phases

Number of phases	DLP Mean (SD)	p-value	CTDI Mean (SD)	p-value
1	709.4 (384.7)	0.001	24.55 (15.2)	0.001
2	1286.2 (506.3)		42.66 (13.6)	
3	1531.6 (705.6)		53.62 (17.7)	
4	1886.7 (648)		69.57 (19.3)	

Furthermore, as per the coefficient of linear regression (Table 3.6), we found an increasing trend between our average measured DLP and $CTDI_{vol}$ values and number of phases. For example, the $CTDI_{vol}$ levels for patients who had 2 scan phases was increased by about 18 mGy (coef.: 17.7; 95% C.I.: 11.5 – 23.9) compared to those who had only 1 phase. This difference was statistically significant across different numbers of phases for both DLP and $CTDI_{vol}$ values.

Table 3.6. Coefficients of linear regression for DLP(mGy-cm) and $CTDI_{vol}$(mGy) for number of phases

Number of phases	Coefficient DLP (Coef., 95% C.I.)	Coefficient $CTDI_{vol}$ (Coef., 95% C.I.)
1	Ref	Ref
2	682.3 (458.3 – 906.4)	17.7 (11.5 – 23.9)
3	898.3 (664.3 – 1132.3)	30.5 (24.0 – 37.0)
4	1149.2 (820.3 – 1478.2)	39.6 (30.4 – 48.7)

3.4 CT dose in relation to European commission guidelines

Using the European Commission guidelines for DLP and $CTDI_{vol}$ as our reference level, with values of 900mGy-cm (EC 1999) and 25mGy (EC 2004) respectively(17). Based on this, we

found that, on average adult patients who had had CT abdominal scans at Helen Joseph and Rahima Moosa Mother and Child Hospital Complex received radiation doses which were below the recommended ranges. Average dose values for DLP were 709.3 mGy-cm and $CTDI_{vol}$ values of 24.5 mGy. These are graphically represented in Figure 3.1. On further interrogation of our data, in Figure 3.2, we assessed patient dosages as a whole, regardless of the number of CT phases done per patient and found that the overall average dose for patients were a DLP value of 1299 mGy-cm and a $CTDI_{vol}$ value of 45 mGy.

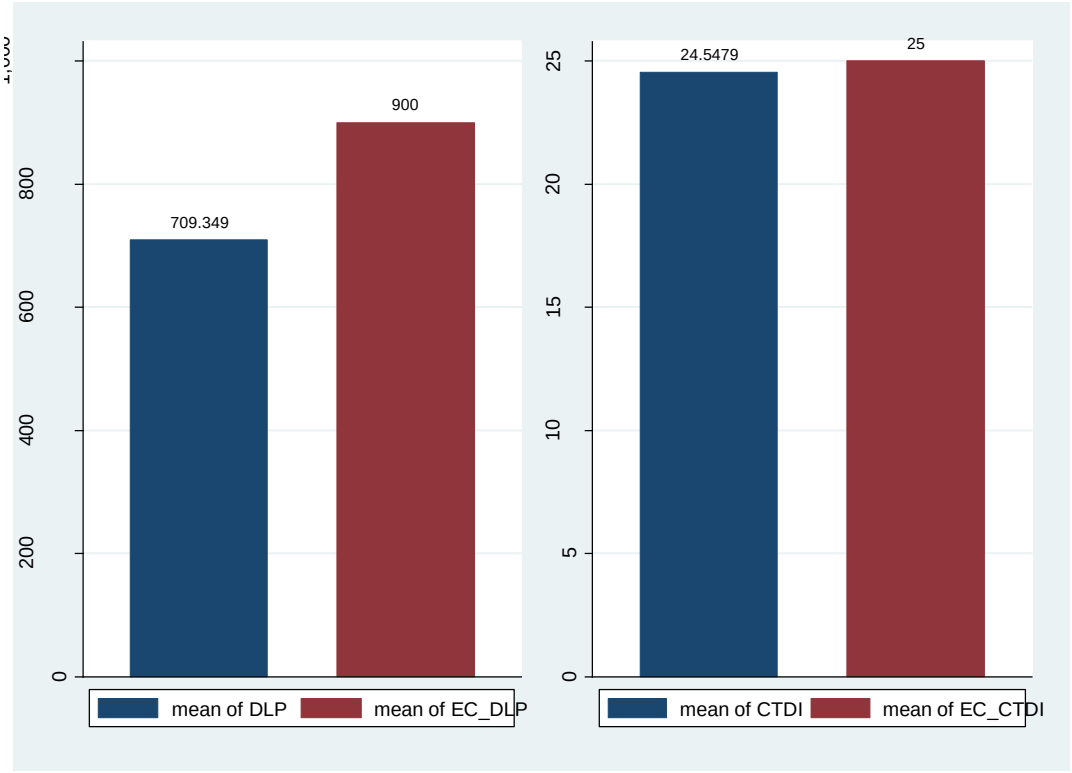

Figure 3.1. Radiation dosages single phase studies: Helen Joseph and Rahima Moosa Mother and Child Hospital Complex as compared to European Commission guidelines

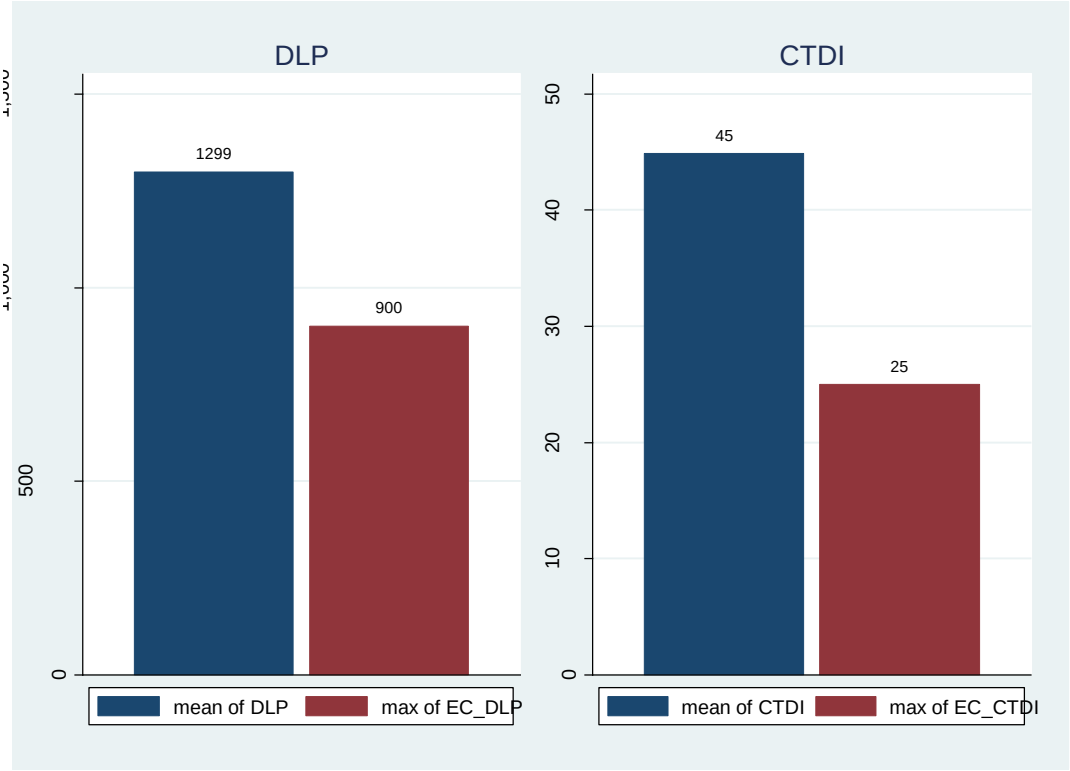

Figure 3.2. Radiation doses all phases: Helen Joseph and Rahima Moosa Mother and Child Hospital Complex as compared to European Commission guidelines

3.5 CT dose by referral origin

We found the radiation doses received by patients differed significantly depending on the referral origin (p-value: 0.07 and 0.001, respectively for DLP and $CTDI_{vol}$). Figures 3.3 and 3.4 demonstrate that on average hepatobiliary patients received the highest total radiation doses with respect to DLP (mean: 1585 mGY.cm ± 661 mGy-cm) and $CTDI_{vol}$ (mean: 57 mGy ± 17 mGy). Colorectal patients recorded the least radiation doses with $CTDI_{vol}$ (31 mGy) and DLP (892 mGy-cm).

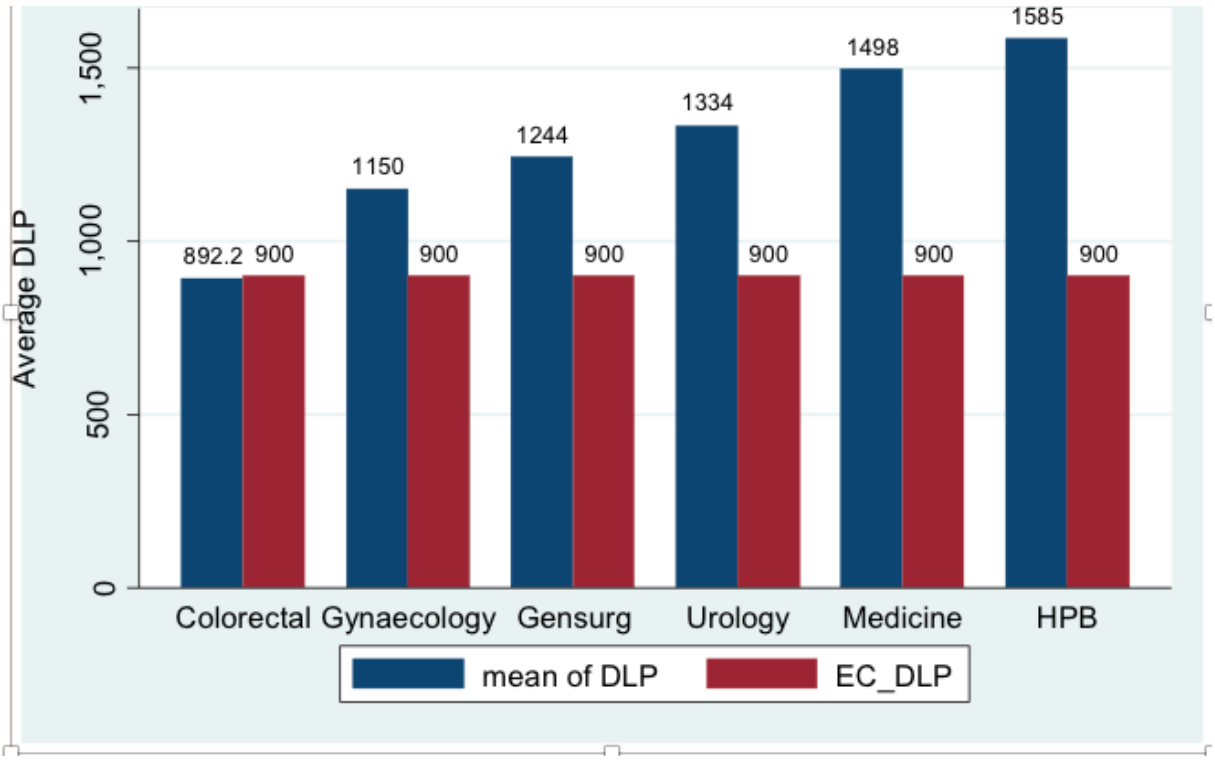

Figure 3.3. Demonstrates overall average DLP value by referral origin as compared to European Commission guidelines

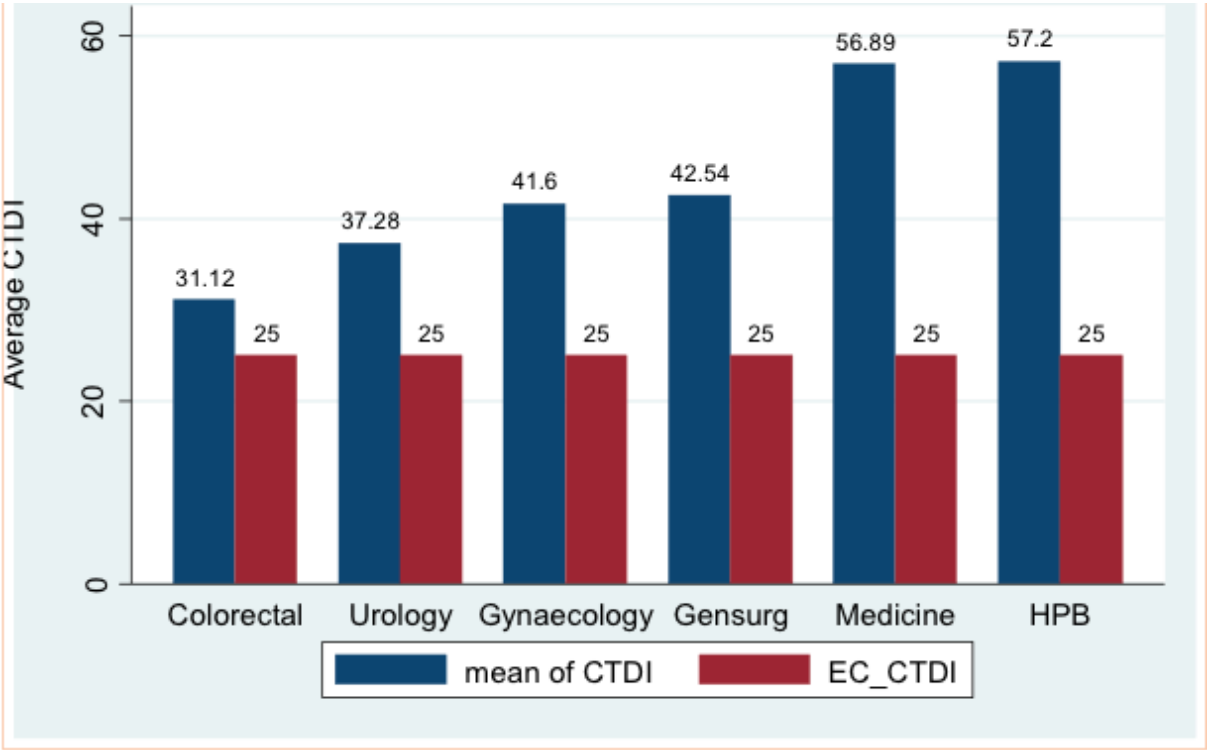

Figure 3.4. Overall average $CTDI_{vol}$ value by referral origin as compared to European Commission guidelines

Interestingly though, as depicted in Table 3.7, we observed that for the patients who only had one CT phase, 90.9% of the urology patients had radiation dosages below the recommended EC guidelines. This was followed, in descending order by hepatobiliary (50%), medicine (40%), general surgery (36.8%) and finally both gynaecology and colorectal with (33.3%).

Table 3.7. Acceptable single phase radiation dose in percentages per department

Urology	Hepatobiliary	Medicine	General surgery	Colorectal	Gynaecology
90.9%	50%	40%	36.8%	33.3%	33.3%

3.6 CT dose by hospitalisation status

As illustrated in Table 3.8 there was no significant relationship between the hospitalisation status of the patients and the CT radiation dosages received. Although inpatients received overall higher doses compared to outpatients, this difference was not statistically significant

Table 3.8. Relationship between CT abdomen doses and hospitalisation status of the patient

Hospitalisation Status	DLP Mean (SD)mGy-cm	p-value	$CTDI_{vol}$ Mean (SD)mGy	p-value
Outpatients	1221.9 (676.4)	0.20	41.8 (19.0)	0.09
Inpatients	1347.0 (660.2)		46.84 (21.5)	

Note: p-value from independent t test

Results from the regression models (Table 3.9) further depict that overall DLP values were higher among inpatients (coef. 329.3 mGy-cm) compared to outpatients, although not statistically significant.

Table 3.9. Coefficients of linear regression for DLP(mGy-cm) and $CTDI_{vol}$(mGy) according to hospitalisation status

Hospitalisation Status	Coefficient DLP (Coef., 95% C.I.)	Coefficient $CTDI_{vol}$ (Coef., 95% C.I.)
Inpatients	329.3 (139.8 – 518.9)	0.3 (0.04 – 2.5)

Outpatients	Ref	Ref

When applying the acceptable doses as DLP < 900 mGy-cm and $CTDI_{vol}$ < 25 mGy to all our patients regardless of the number of CT phases done, we found no ground to infer that the 24 patients who received radiation in the acceptable doses, differed based on their hospitalisation status. Of the 123 Inpatients, only 12 patients (representing 9.7%) received acceptable dose; whereas of the 77 outpatients, only 12 patients (representing 15.6% of the outpatients) received acceptable levels of radiation.

With regards to single phase scans, in Table 3.10 we see 66.7% of the inpatients and all the outpatients having EC acceptable DLP values. Again, in Table 3.11, the outpatients are observed to have a higher percentage of acceptable $CTDI_{vol}$ values when compared to the inpatients (60% vs 20%).

Table 3.10. Single phase average DLP values by hospitalisation status as compared to EC guidelines

	Department					
	Medicine	**Gynaecology**	**Hepatobiliary**	**Colorectal**	**Urology**	**General surgery**
Inpatient	1001.8	524.3	1189.3	765	679.1	782.7
Outpatient	345.6	-	424.9	-	513.3	773.6

EC guidelines DLP = 900mGy-cm

Table 3.11. Single phase average $CTDI_{vol}$ values by hospitalisation status as compared to EC guidelines

	Department					
	Medicine	**Gynaecology**	**Hepatobiliary**	**Colorectal**	**Urology**	**General surgery**
Inpatient	38.7	30.6	37.3	28.8	14.2	27.2
Outpatient	26	-	25	-	10.0	28.6

EC guidelines $CTDI_{vol}$ = 25mGy

4. Discussion

4.1 Overview of CT dose measurements

Currently CT scanners provide the dose information following any CT examination. The parameters recorded are the volume CT dose Index($CTDI_{vol}$) and the Dose Length Product (DLP). These two parameters are calculated estimates the radiation dose output by the CT Scanner and do not represent the actual radiation dose received by the patient (7).

The $CTDI_{vol}$, expressed in milligrays (mGy), is a standardised measure of the radiation output of a CT scanner. It is measured using a 16cm and 32cm acrylic phantom for head CT and body CT respectively , and is dependent purely on, and therefore varies with the type of scanner and the scan acquisition parameters used (18). The scan parameters influence the radiation dose output in their various ways and these include, the tube peak voltage, tube current, pitch, tube rotation time, current-time product, reconstructed slice thickness and noise index.

The $CTDI_{vol}$ is calculated by the following equation (19),:

$$CTDI_{vol} = CTDI_{w} \cdot \frac{NT}{I} = \frac{CTDI_{w}}{\text{Pitch factor}}$$

or simply put , $CTDI_{vol}$ =1/pitch x $CTDI_{w}$.

$CTDI_{w}$ (Weighted CTDI) approximates the average absorbed radiation dose over a single slice. NT represents the total nominal collimation width. I is the table distance per rotation during a helical scan (pitch factor I/NT) (19). Pitch is defined as the ratio of table increment per gantry rotation to the total nominal collimation width(13).

The Dose Length product (DLP), a derivative of the $CTDI_{vol}$, is represented in SI Units milligrays-cm (mGy-cm) and is calculated by the following equation (19):

$$DLP = \sum_{i=1}^{N} (CTDI_{vol})_i \cdot L_i$$

or simply put, DLP = $CTDI_{vol}$ x Scan length and is therefore directly proportional to changes in the $CTDI_{vol}$ and scan length. In the equation above, i represents the individual scans in the series and L_i is the length in cm, of the patient covered during the scan (19).

4.2 European Commission Guidelines Diagnostic reference levels (DRLs) for CT abdomen

Diagnostic reference levels are an estimation of the radiation exposure from the CT machine to a standard sized adult patient and the aim of any radiology department is to optimise radiation exposure to patients by having values below these DRLs(5). The DRLs are not the maximum dose per say for an investigation, but rather a dose level at which the radiation exposure to the patient is deemed above warranted for the investigation necessitating the implementation of dose lowering techniques at the facility. They are essentially a radiation reduction measure aimed at protecting the patient from exposure to unnecessarily high radiation doses and are applicable to a variety of investigations in diagnostic and interventional radiology. DRLs have progressively been implemented worldwide since the inception of the concept by the International Commission on Radiation Protection (ICRP) in 1990(17). These diagnostic reference levels vary between institutions, regions and countries and need to be updated regularly considering the rapid evolution on CT Technology. The national DRLs are typically set at the 75^{th} percentile of the dose distribution from a survey conducted across various institutions nationwide using a specified dose measurement protocol and phantom(17) . Of note is that, these values also vary for CT imaging of the head and trunk.

In 1999, the European Commission published the European Guidelines of Quality Criteria and noted the $CTDI_w$ and DLP as the two parameters used to establish the DRLs. For abdominal CT, the $CTDI_w$ and DLP were set at 35mGy and 900mGy-cm respectively. This was updated in 2004, with the implementation of a new parameter, the $CTDI_{vol}$ of 25mGy (17). These values, compared to recommended values from other countries are illustrated in Tables 4.1 and 4.2.

Table 4.1 The European Commission adult $CTDI_w$(mGy) and DLP(mGy-cm) recommended values and comparison with other countries

	Head		Abdomen		Abdomen and Pelvis			
	Whole Exam		Whole Exam		Pelvis		Whole Exam	
	$CTDI_w$	DLP	$CTDI_w$	DLP	$CTDI_w$	DLP	$CTDI_w$	DLP
EC 1999	60	1050	35	900	-	-	35	780
ACR 2002	60	-	35	-	-	-	-	-
UK 2003	-	930	20	470	-	-	20	560
Germany 2003	60	1050	25	770	-	-	24	1500
Switzerland 2004	60	800	20	710	30	540	-	-
Taiwan 2007	72	850	31	680	28	520	-	-

EC= European Commission; ACR= American College of Radiology; UK= United Kingdom.

Table 4.2 The European Commission adult $CTDI_{vol}$ (mGy) and DLP(mGy-cm) recommended values and comparison with other countries

	Head		Abdomen		Abdomen and Pelvis			
	Whole Exam		Whole Exam		Pelvis		Whole Exam	
	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP
EC 2004	60	-	25	-	-	-	15	700
ACR 2008	75	-	25	-	-	-	-	-
UK 2003	65-100	930	14	470	-	-	14	560
Netherlands 2008	-	-	-	-	-	-	15	700
Sweden 2002	75	1200	25	-	-	-	-	-

EC= European Commission; ACR= American College of Radiology; UK= United Kingdom.

4.3 CT Abdomen Scan phases

The four CT abdomen scan phases are, the non-contrast phase, and 3 other phases which are done following intravenous contrast administration, and these are the arterial phase, portal venous phase and the delay phase. The contrast enhanced phases are done at certain pre-set times on the machine.

AlSuwaidi et al, documented that 71% of their patients who had had abdominal CT scans had undergone multiphase scanning (11). Our results are comparable to this, with 78.5% of our patients having had between 2 to 4 of scan phases. Multiphase CT scanning is becoming a common occurrence in this era with the increasing disease spectrum, ongoing frequent advancement of CT technology and the increase in medical litigation. This trend however is resulting in a detrimental rise in CT radiation exposure to the patients (20).

4.4 CT Abdomen dose and number of scan phases

The decision as to which scan phases the patient requires is determined by the pathology suspected by the referring clinician. The radiation dose increases markedly with multiphase CT scanning (2). This is further confirmed in another study done by Liang et al published in 2017, which found the radiation dose to have doubled or in some instances to have more than doubled from single to multiphasic scans (21). Tables 3.5 and 3.6 of our results illustrate this trend. Of particular note was an increase in the $CTDI_{vol}$ and DLP values from one to 2 phase scanning in our study. The extra scan phases done are often not required and result in unnecessary excess radiation exposure to the patient. This can be overcome by the implementation of patient specific scan protocols depending on their clinical presentation. To address this in the United States of America, The American College of Radiology (ACR) implemented the ACR Appropriateness Criteria for CT scanning, in which there were scan protocols set for specific patient clinical presentations. A scan phase was deemed 'appropriate' or indicated if the ACR Criteria score was >4. One third of all abdominal scan phases were deemed unwarranted according to the ACR Appropriateness Criteria. These unindicated scan phases were then reviewed by the institution that was used in the study (2).

The implementation of fixed disease specific scan protocols, could however face a number of diagnostic challenges if suboptimal or incorrect clinical information is provided by the requesting clinician. In addition to that, the patient's clinical presentation is not always as per typical signs and symptoms documented in medical textbooks, and in some cases scan protocols may require modification to encompass the various multisystemic ailments a single patient may present with at a given hospital visit.

4.5 CT Abdomen dose and department of origin

We found no literature assessing the CT abdomen dose received in relation to the patient's department of origin. With the knowledge that scan protocol is determined by the clinical scenario documented by the referring clinician on the CT request form, Figures 3.3 and 3.4 of our study showed that the highest overall total radiation dose was attained by the hepatobiliary patients with an average DLP of 1585mGy-cm and an average CTDI value of 57.2mGy. This trend can be explained by the fact that these patients initially require 3 or 4 scan phases depending on the suspected disease pathology, be it in the hepatic parenchyma, the biliary tract or the pancreas, as the different disease processes are better appreciated with particular phases.

When purely assessing single phase scans, we observed that the urology patients by far had radiation dosages below the recommended EC guidelines. The majority of the urology patients were being investigated for possible urolithiasis, for which a CT KUB (Kidney Ureters and Bladder) was done. This is a non-contrast CT scan. A non-contrast CT scan has been proven to have a lower radiation dose than a contrast enhanced CT scan (22). The gynaecology and colorectal patients who mainly had multiphase scans, had the least number of patients below the recommended values (<35%). When defining single phase, this could be any of the four phases mentioned earlier.

4.6 CT abdomen dose and hospitalisation status

There is also no found literature evaluating the CT abdomen dose received by patients in relation to the hospitalisation status. The decision to assess and discuss this possible correlation was based on the reasoning that the inpatients are usually more debilitated than the outpatients and hence possibly needing more scan phases which in turn amounts to a higher radiation dose attained. Following the results of our study, it was found that the inpatients did receive a higher radiation dose than the outpatients. The difference, however was not statistically significant. With reference to Table 3.1, we found that there were more inpatients (61.5 %) undergoing CT abdomen scans than the outpatients (38.5%). This can be explained by the fact that the study was hospital based with more inpatients presenting for radiology investigations. The inpatients are also more debilitated than the outpatients requiring more investigations. The outpatients are more prone to defaulting their booked CT date thus further reducing the outpatient number scanned.

4.7 Discussion of statistical results

4.7.1 Overall dosages in comparison to other similar studies

Table 4.3. Comparison of reviewed previous literature with the current study

Author (Year)	Tsapaki et al (2001)	Pyfferoen et al (2017)	This Study (2018)
Study design and method.	Prospective	Retrospective cross-sectional study.	Retrospective cross-sectional study.
Country	Greece	Belgium	South Africa
Study population number	160	CT abdomen comprised 5948 (18.8%) of a total of 31,709 patients	200
Age range in years	Not stated	18 – 101	18 – 82
Number of CT series assessed.	Single phase	Single phase	Single phase and multiphase
Reference	EC guidelines	Established regional and national DRLs	EC guidelines
RESULTS			
Male to female ratio	Not stated	1:1	3:2
Average DLP	278-583 mGy-cm	Below 75TH percentile of national DRLs	709.3 mGy-cm
Average $CTDI_{vol}$	Not measured	Below 75TH percentile of national DRLs	24.5 mGy
Conclusion	$CTDI_w$ and DLP below European Commission reference guidelines.	$CTDI_{vol}$ and DLP values were below the national DRLs for all CT studies.	$CTDI_{vol}$ and DLP values were below the European Commission reference guidelines.
Other information	$CTDI_w$ measured (Instead of $CTDI_{vol}$). Dosages for other body regions also assessed in the study.	Dosages for other body regions also assessed in the study and comprise 81.2% of the study population.	EC DRL guidelines used as no South African national DRL guidelines available. The patient's referral origin, hospitalisation status and CT phases done also comprised parts of the study.

Table 4.3 demonstrates the comparison between this study and two similar studies. The comparison studies were both European based and assessed almost similar dosimetry related data with the Pyferroen et al (16) and our study comparing the dosimetry values to the updated European commission guidelines. Our study, as well as the study done by Tsapaki et al (23) met the recommended EC reference guidelines. There are recommended

scanning protocols specific to body regions that are pre-set in the CT machine. These protocols are not always strictly implemented by the attending radiologist. There is the constant use of disease based scanning protocols, at times with the modification of the pre-set scan protocols among radiologists at our institution with the aim of eliminating phases of no added diagnostic value. This practice may explain the results of our study. The availability of more advanced CT scanning technology in Greece, a first world country, and the implementation of Greek national DRLs explains the Greek results.

The study done by Pyferroen et al (16), was solely country based and assessed multicentre adult CT dosages and compared them to the established regional and national DRLs. Their study found that their measured DLP and $CTDI_{vol}$ values were below the 75^{th} percentile of the national DRLs for all CT studies. Interestingly this study and our study demonstrated that the female patients undergo more CT examinations than male patients. This may be attributed to the internal location of the majority of the female reproductive organs, requiring imaging due to the increase in gynaecological malignancies with increasing age and evolving times.

This study, along with the comparison studies highlight the importance and dose lowering value of establishing continuous evaluation and establishment of diagnostic reference levels.

4.8. Current applications

Currently at our institution, for quality control purposes, the DLP and $CTDI_{vol}$ are being documented for every CT scan done. This is in accordance with international radiation protection recommendations and in some countries, law enforced regulations. There are however, no audits being done on these values, facilitating further optimisation of radiation doses at our institution.

Some of the new CT dose optimisation techniques mentioned in literature include the adaptation of Automatic Tube Current Modulation (2004-2005) and the reintroduction of Iterative Image Reconstruction (2010) (16). Automatic Tube Current Modulation (ATCM) involves the use of algorithms to adjust the tube current and machine gantry rotation time dependent on the patient's body habitus. This tube current-time product, measured in milliampere second (mAs), results in linear decrease in patient radiation dose (8). Iterative

Image Reconstruction(IIR) is a technique that post processes low dose noisy images, improving spatial resolution and producing images of good diagnostic quality (24). Both these techniques are already being used at our hospital and their adequate functioning is reviewed on a regular basis by the technicians from the machine vendor.

4.9. Limitations of the current study

Since the dosages and the scan phases done per patient were obtained from the archived patient discs and some discs were corrupted, these patients were not considered for inclusion in the study at the data collection stage. The information regarding patients' referral origin and hospitalisation status (inpatient or outpatient) is hand written on the CT scan request form by the requesting clinician. Illegibility of the handwriting resulted in these patients being disregarded from the study. These two factors made the data collection a time consuming and tedious process, but did not pose any limitations to the study as our data collection continued until complete and relevant information was obtained on 200 patients.

The poor filing system for the archived discs at the hospitals prolonged the data collection process. The presence of a Picture Archiving and Communications System (PACS) at Helen Joseph Hospital and Rahima Moosa Mother and Child Hospital at the time of data collection would have shortened the data collection time.

Due to the long waiting list for outpatient CT scans, referring clinicians incorrectly and deliberately book outpatients in the inpatient slots to get quicker scan dates, these patients eventually come from home for their scans and ended up being in the inpatient group during data collection. Due to bed shortages in the hospital, some patients are booked for CT Abdomens while admitted as inpatients, are then discharged from the hospital and come as outpatients for the scans. These patients are also recorded in the inpatient group in the data collection sheet. Patients with either of these scenarios should actually be in the outpatient group. This situation could have possibly impacted on the inpatient:outpatient ratio in the data evaluation.

4.10. Future applications

The findings of our study will serve as a basis for the awareness of the exposure of our population to man-made radiation at our institution, which in the long term, may lead to unnecessary stochastic and deterministic biological radiation effects, if not monitored at a patient (the annual cumulative radiation dose from radiology investigations is not assessed per patient) and institution level.

The appropriateness of phases in multiphase scanning requires re-evaluation with elimination of additional unindicated phases of no clinical benefit.

The periodic use of medical physicists regarding evaluating the machine exposure factors and post processing image reconstruction algorithms will further aid in radiation dose reduction.

With the constant evolution of CT technology, investment in the current, faster and more efficient CT scanners and new dose tracking systems will further assist in the radiation dose reduction. In our setting, this will however pose a financial challenge.

As mentioned earlier, part of the outcome of this study will be feedback to and education of the various specialties with emphasis on the cautious referral of patients for CT scans and other medical radiation exposing procedures. Studies can be done evaluating the appropriateness of the request forms and CT scan phases done based on the documented clinical presentation, and necessary action taken if the results are deemed inappropriate. Furthermore, a study can be done at our hospital similar to the UK study by Uri et al to assess the level of clinician knowledge on the effects of radiation and the necessary education given based on the results of the findings(12).

To date, there is no study published in South Africa similar to our study. There have been many South African studies measuring radiation doses but none comparing the CT Abdomen dosimetry values with international reference values. A study done by Meyer et al (25) further proves the deficiency of published DRLs in low and middle income countries. Our study paves the way, in conjunction with identical studies from other institutions in various

regions for the establishment of national diagnostic reference levels for abdominal CT scanning.

5. Conclusion

Although the hospital complex used in the study meets the recommended EC guidelines for DLP and $CTDI_{vol}$ for single phase scans, the findings of our study still highlight the importance of radiation dose audits and rigid continuous implementation of various literature based CT dose optimisation techniques.

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Appendix A: Ethics Clearance Certificate

R14/49 Dr Jacinta Adrigwe and Prof Savvas Andronikou

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M150449

NAME: (Principal Investigator)	Dr Jacinta Adrigwe and Prof Savvas Andronikou
DEPARTMENT:	Diagnostic Radiology Charlotte Maxeke Johannesburg Academic Hospital Helen Joseph Hospital Rahima Moosa Mother and Child Hospital Complex
PROJECT TITLE:	Radiation Dose Measurement of Abdominal CT and Categorisation According to Referral Origin and Design of CT Study in Adult Patients
DATE CONSIDERED:	24/04/2015
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr Susan Lucas
APPROVED BY:	Professor P Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	06/05/2015

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Secretary in Room 10004, 10th floor, Senate House, University.

I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**.

ADRIGWE — 15/07/2015

Principal Investigator Signature — Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix B: Data collection sheet

Study number _____ Date of scan _____ Age_____ Gender_____

Referred from	Inpatients	Outpatient	Medicine	Gynaecology	Hepato-biliary	Colorectal	Urology	General Surgery

Scan protocol used	Pre-Contrast	Arterial	Portal Venous	Delay

Dose	DLP measured	$CTDI_{vol}$ measured

Appendix C: Note on referencing style

Please note that the referencing in this thesis is a modification of the Vancouver Referencing style, done according to the Faculty of Health Sciences Style Guide as set out by the Wits Health Sciences Library.

The information on this WHSL Vancouver Citation Style Guide for Theses, Dissertations and Research Reports is available from http://libguides.wits.ac.za/whsl-vancouver updated on 30 January 2017.