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Cumulative Radiation Effective Dose

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1. Introduction

The CT scanners on the market offer a multitude of procedure protocols that enable many clinical questions to be answered quickly. CT scanners can be used to image all parts of the body, some common uses in our hospital include; acute inflammatory bowel diseases; acute appendicitis, trauma including head, spine and skeletal trauma, renal diseases including congenital, inflammatory and neoplastic, temporal bone diseases, neck swelling, diagnosing and staging cancer (using PETCT when appropriate) and planning radiotherapy treatment (using PETCT when appropriate).

Whatever the reason for a procedure a radiation dose is associated with the exam and this can range from a relatively small to a relatively large amount depending on the clinical requirements of the diagnostic test.

Since x-rays have the potential to damage cells in the body and there is no "safe" dose of radiation, the body's exposure to radiation should be kept to a minimum, a challenging task for CT imaging.

The radiation effective dose is a calculated quantity that is intended to give an estimate of the relative biological detriment resulting from a radiation exposure and is measured in units called Sieverts (Sv).

As the x-ray tube rotates around the patient it takes hundreds of x-ray pictures of a thin section of the body. In one rotation the "thin section" is determined by the number of detector rows and their collimation. Many rotations around the patient result in large body volumes being imaged. The images obtained from each section can be reconstructed to any slice width down to the width of the collimation of a single detector.

Technological advances in CT scanners have seen increases in the number of slices and detector rows leading to wider coverage of the patient anatomy per rotation of the x-ray tube around the patient. Helical scanners have led to even greater coverage of the patient anatomy in faster examinations.

However, CT procedures are inherently high radiation effective dose procedures, although the actual scanning takes from a few seconds to a few minutes, depending on the examination and type of scanner, it's easy to lose track of the actual radiation exposure to the patient.

The images obtained from CT provide much more diagnostic information than conventional radiographs or fluoroscopy but the radiation effective doses are much higher than for other x-ray exams.

Contrast agents enable multiple phases to be evaluated during procedures, the difference between pre and post contrast images can give the radiologist valuable information; a single procedure may therefore result in a multiple of scans over the same body region.
In itself, the radiation effective dose from a CT procedure may not differ greatly from one machine to another, nor will it be too large but used again and again on the same individual and multiple scans within those procedures will increase the cumulative effective dose to the patient and therefore increase the risk of chance effects, which have no threshold dose, called stochastic effects such as cancer induction. If left unmonitored, these risks will remain unknown.
The physician who requests a CT procedure for a patient must ensure that the benefits provided by the information obtained outweigh the risks associated with the radiation effective dose and that if the information required can be obtained by an alternative modality that does not involve ionising radiation such as MRI or ultrasound it should be used. In order to do this the physician needs to know the estimated effective dose of the procedure and must also be aware of other modalities that perform the required tests.
Moreover, since radiation dose is cumulative it is not enough for the physician to consider a radiation dose for a procedure in isolation for a patient as it may not be the only dose that the patient has received and it may not be the only dose that the patient is likely to receive in the future. A clear indication of radiation exposure history of the patient is needed at the point of request for a CT procedure, and the possibility of further CT procedures based on current practice for the diagnosis or follow up should be considered. Used responsibly, CT procedures should not cause unnecessary additional radiation risks to the individual.
The benefits in CT imaging are not in question here, however, rapid growth in the use of CT and PETCT in organizations where radiation safety programs focused on dose reduction are not in place, setup or maintained should be a cause for concern for unaware patients and physicians.
The cumulative dose received by the patient can be alarmingly high and it is likely that it will increase in the future as the utilization of CT further increases. A consequence of this may be a significant increased incidence of radiation related cancer in the future.
The International Commission on Radiation Protection, (ICRP, 1991) specifies that the nominal risk coefficient for induction of fatal cancer is 5% per Sv and total detriment, induction of all cancers and genetic effects is 7.3% per Sv when risk factors are averaged over the whole population. For doses over 100mSv there is little doubt over the potential for increased cancer risks (Wall et al, 2006).
This cumulative study of radiation effective dose reveals the current practice patterns and areas of improvement in a tertiary private hospital in Saudi Arabia. It has required good electronic records to piece together exposure history of its patients. Only CT and the CT part of PETCT have been included in the data so the results of the cumulative doses are conservative and do not include contributions from nuclear medicine studies, general radiographic, dental, fluoroscopic or interventional fluoroscopic procedures.

2. Materials and methods

The Siemens Definition 64 slice CT scanner is the main CT scanner used in the Radiology Department. The scanner provides a large number of preset protocols, the most commonly used of the Head, Chest/Thorax and Abdomen/Pelvis protocols along with the European Reference Levels for CT (Bongartz et al. 2004) are shown in Table 1. The European reference levels are not intended to be applied to individual exposures of individual patients but are aimed as guidance for standard procedures for groups of standard sized patients and are intended to assist in the optimization of protection by helping to avoid unnecessarily high doses to the patient.

Name	kV	mAs	mA	Rotation Time s	(Acquisition) Detectors x collimation n x mm	Pitch	CTDIvol mGy	Scanned Length cm	Dose Length Product (DLP) mGycm	Effect-ive Dose (E) mSv
Head 1	120	450	248	1	(19.2mm) 64 x 0.6	0.55	60.65	13	790	2.2
Head 2	120	450	248	1	(28.8mm) 24 x 1.2	0.55	55.69	12	670	1.9
European Reference Levels for Adult CT - Head							60	17.5	1050	-
Chest /Thorax 1	120	110	264	0.5	(19.2mm) 64 x 0.6	1.2	7.93	30	240	5.3
Chest /Thorax 2	120	170	408	0.5	(28.8mm) 24 x 1.2	1.2	11.24	27	305	6.7
European Reference Levels for Adult CT - Chest							30	21.7	650	-
Abdomen/ Pelvis1	120	210	378	0.5	(19.2mm) 64 x 0.6	0.9	15.14	27	410	8.9
Abdomen/ Pelvis 2	120	190	342	0.5	(28.8mm) 24 x 1.2	0.9	12.56	48	605	11
European Reference Levels for Adult CT - Abdomen							35	22.3	780	-

Table 1. Scanning protocols and effective dose (E) of typical Adult protocols for the Siemens Definition 64 slice CT Scanner and European guidance reference levels for Adult CT.

The scan parameters kV, mAs, mA, rotation time, acquisition, detectors and collimation and pitch used for an individual scan result in the associated volume computed tomography dose index (CTDIvol) and an associated dose length product (DLP) of the scan as shown in table 1.

The CTDIvol is a quantity that tells the operator how much radiation dose will be absorbed in a single rotation according to the specific setup. It is a measure of the average dose delivered to the scan volume and its numeric value depends only on the spatial distribution of individual rotations and is unrelated to the total scan length determined by the total number of successive rotations.

For helical scanners, the spatial distribution of individual rotations is dependent on the pitch; this is the ratio of the table movement per tube rotation to the beam width (number of detectors x collimated slice). Pitch conveys the degree of overlap of the radiation beam, a value of 1 indicates contiguous slices, less than 1 indicates overlap (hence a larger CTDIvol) and greater than 1 indicates a gap between slices (hence a lower CTDIvol). The pitch can be determined from the mAs, mA and rotation time of the scan and is equal to the product of the mA and rotation time divided by the effective mAs.

The dose length product, DLP, is a product of the CTDIvol dose and the scanned length, it is independent of what is actually being scanned; the reported DLP is the same whether a newborn or adult is being exposed if the scan length and other scan parameters are the same.

The scanned length shown in table 1. for the European reference level has been calculated from the DLP and CTDIvol; the scanned length in cm is equal to the DLP (mGy.cm) divided by the CTDIvol (mGy).

The adult protocols shown in table 1 represent a single scan of the indicated body region, the effective dose derived from the scanning parameters has been calculated using the ImPACT CT patient dosimetry calculator (version 1.0.2 12/11/2009) and associated NRPB-SR250 Normalised Organ Doses for X-ray Computed Tomography Calculated using Monte Carlo Techniques software (Jones & Shrimpton, 1993).
Variations in the protocols shown in table 1 are also used which can result in different doses, the benefit of the CTDIvol on the display is in allowing the operator to compare the radiation doses from different imaging protocols.
Children are particularly sensitive to radiation and have an increased susceptibility due to their developing bodies and smaller size; the risk of cancer induction is greater in children due to their longer potential life span. (Mettler et al., 2000 & Brody et al., 2007 & Stecker et al., 2009).
To estimate pediatric effective doses, results from the ImPACT CT patient dosimetry software can be multiplied by the age appropriate factors shown in table 2. The values shown in table 2 give a range of normalized effective doses at each age, relative to the adult dose (Khursheed et al. 2002). The minimum values were used in this study as representative for the Siemens Definition scanner.

	Newborn 0y	1 y	5 y	10 y	15 y	Adult
Head and Neck	2.3 – 2.6	2.2	1.6 – 1.7	1.2 – 1.3	1.1	1.0
Chest	1.4 – 2.2	1.3 – 1.9	1.2 – 1.6	1.1 – 1.4	1.0 – 1.1	1.0
Abdomen and Pelvis	1.4 – 2.4	1.3 – 2.0	1.2 – 1.6	1.2 – 1.5	1.0 – 1.1	1.0

Table 2. Typical normalized effective doses to pediatric patients relative to adults (ImPACT CT Patient Dosimetry software)

Techniques used in pediatric CT imaging may not necessarily be tailored to children's smaller bodies and adult protocols are used, resulting in radiation effective doses much greater than necessary. To illustrate the consequence of not adjusting parameters to pediatric sizes table 3 shows the effective doses estimated for the head protocols shown in table 1 if used unadjusted.

Name	kV	mAs	mA	Rotation Time s	(Acquisition) Detectors x collimation n x mm	Pitch	CTDIvol mGy	Scanned Length cm	Dose Length Product (DLP) mGycm	Effect-ive Dose (E) mSv
Head 1 Adult	120	450	248	1	(19.2mm) 64 x 0.6	0.55	60.65	13	790	2.2
Head 1 10 yr-old	120	450	248	1	(19.2mm) 64 x 0.6	0.55	60.65	13	790	3.5
Head 1 5 yr-old	120	450	248	1	(19.2mm) 64 x 0.6	0.55	60.65	13	790	4.8
Head 1 Newborn	120	450	248	1	(19.2mm) 64 x 0.6	0.55	60.65	13	790	5.1

Table 3. Estimate of effective dose for adult head protocols unadjusted for pediatric patients

Using techniques appropriate for pediatric CT imaging will result in much lower effective doses (Fujii et al., 2007) without detriment to the image quality required for the diagnostic image. Simply adjusting the protocol for kV, mAs and mA can significantly reduce the effective dose to the pediatric patient. A useful reference for assessing local optimization techniques in pediatric CT are found in the proposed diagnostic reference levels for pediatric patients for the head and chest (ICRP, 2007 and Shrimpton et al, 2005), as shown in table 4.

Examination	CTDIw (mGy)	CTDIvol (mGy)	Scanned Length (cm)	Dose Length Product, DLP (mGy.cm)
Head 0-1 yr old	23	12	17	204
Head 5 yr old	20	13	17.5	228
Head 10 yr old	26	17	21.6	368
Chest 0-1 yr old	28	28	9.6	270
Chest 5 yr old	43	43	10.8	465
Chest 10 yr old	52	51	12.1	619

Table 4. Proposed Diagnostic Reference levels for pediatrics

The weighted computed tomography dose index, CTDIw is a measure of the average dose delivered to the scan volume in polymethylmethacrylate, PMMA cylinders of 16cm diameter, representing adult head, pediatric head and pediatric body and 32cm diameter, representing adult body. CTDIw is used to account for the variation in the CTDI across the field of view which is higher at the surface of a body relative to the centre, CTDIw is equal to 1/3 CTDIcentre + 2/3 CTDIperiphery.

In pediatric patients, due to their smaller size, the difference between the dose at the surface and at the centre is not as large as it is in adults.

The CTDIvol is equal to the CTDIw divided by the pitch. Both quantities are equivalent if the pitch has a value of 1 and CTDIvol is less than CTDIw if the pitch has a value greater than 1. Both quantities indicate the average dose within the scan volume for a particular protocol but the displayed CTDIw does not account for the pitch.

Multiple scans involving contrast and phases such as arterial, venous and delayed are also used in many protocols, typically doubling, tripling and quadrupling the effective dose of the procedure. So although the effective dose for a single scan is low, care must be taken to ensure that the numbers of scans in a procedure are known and the consequence on the effective dose is understood.

This study was designed to provide a snapshot of the CT imaging procedures being undertaken on pediatric patients in the Radiology Department. Stage 1 involved data collection from the Hospital Radiology Information System (RIS). Cohort selection was an all inclusive group of pediatric patients (newborn to 18 years old) undergoing CT procedures in October 2010. Figure 1 shows a breakdown of the frequency of daily procedures performed on 53 patients, male pediatrics n=31, female pediatrics n=22.

A total of 55 procedures on the 53 patients were performed in the one month period of October 2010. Details about the procedures were recorded in an excel spreadsheet. To assess the number of cumulative CT procedures performed on the patients and the interval period between procedures, data collection expanded to include all previous CT procedures and all post October 2010 procedures performed up to March 2011 in the identified patients. Figure 2 shows the number of procedures and scans involved in those procedures on the patients.

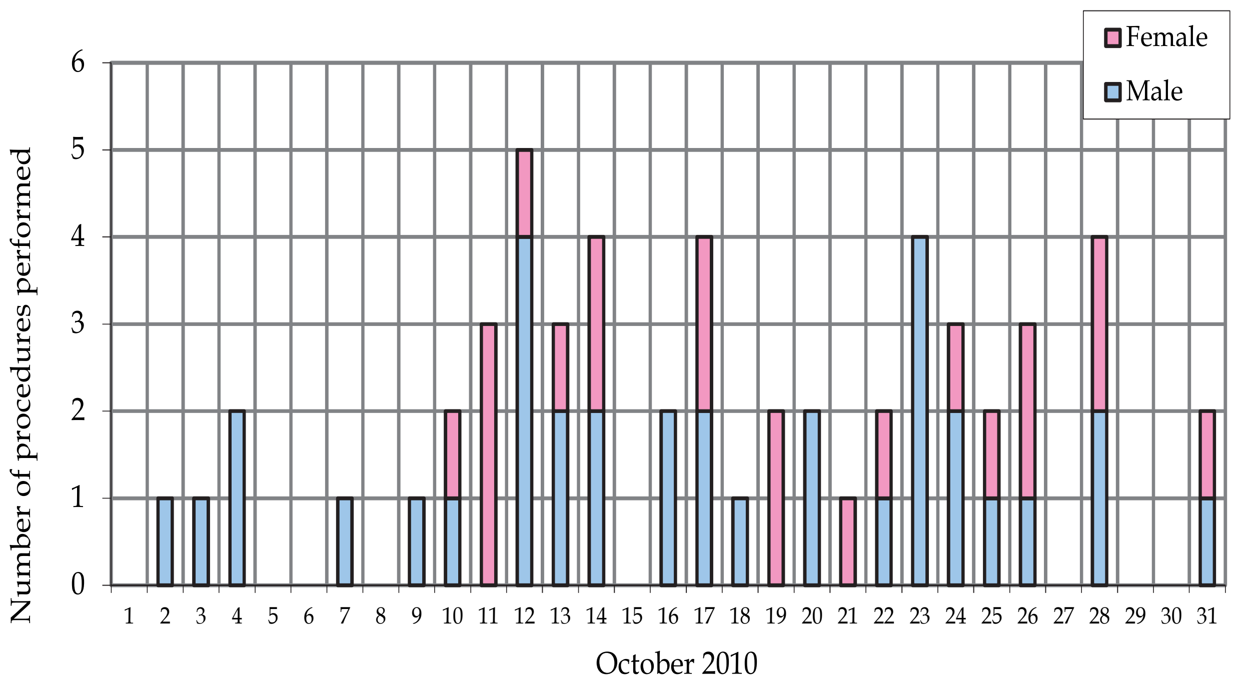


Fig. 1. Number of Procedures performed in October 2010.

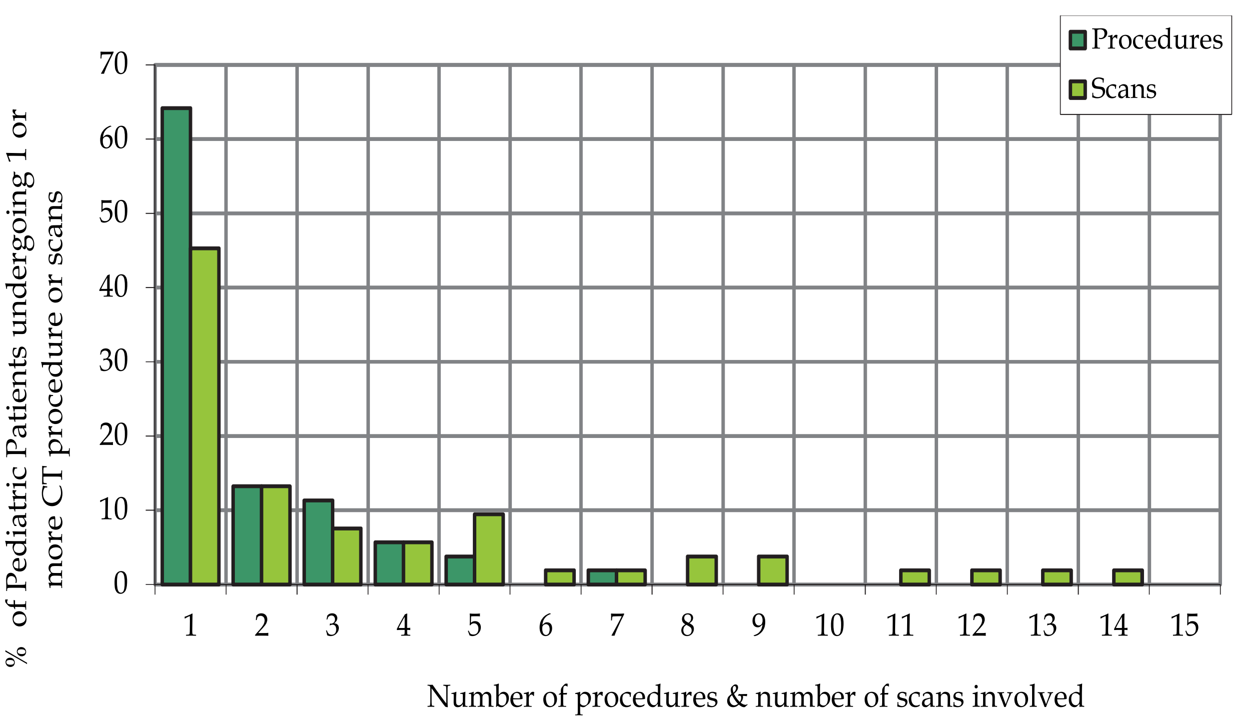


Fig. 2. Number of procedures & scans performed on pediatric patients.

A total of 95 procedures involving 184 scans were performed on the 53 pediatric patients ranging a 7 year period from October 2004 to March 2011.
For pediatric patients undergoing CT procedures consisting of one or more scans, 64% (n=34) underwent a single procedure, 24.5% (n=13) underwent 2-3 procedures and the remaining 11.5% (n=6) underwent between 4-7 procedures. Multiple procedures were performed on 36% (n=19) of the pediatric patients, for these patients the mean number of procedures was 3.2 ± 1.9 procedures/ patient.
Whilst only 45% (n=24) underwent a single scan, 21% (n=11) underwent 2-3 scans and the remaining 34% (n=18) underwent between 4-14 scans. Multiple scans were performed on 55% (n=29) of the pediatric patients, for these patients the mean number of scans per patient was 5.5 ± 4.2 scans/ patient.
Only 32.6% (n=24) procedures involved 1 scan per procedure, for the remaining 67.4% (n=64) procedures the mean number of scans per procedure was 3.5 ± 2.8 scans/ procedure
For patients undergoing multiple procedures, 69% (n=29) of the multiple procedures were performed within 6 months of a previous procedure. The interval period between multiple procedures is shown in figure 3.

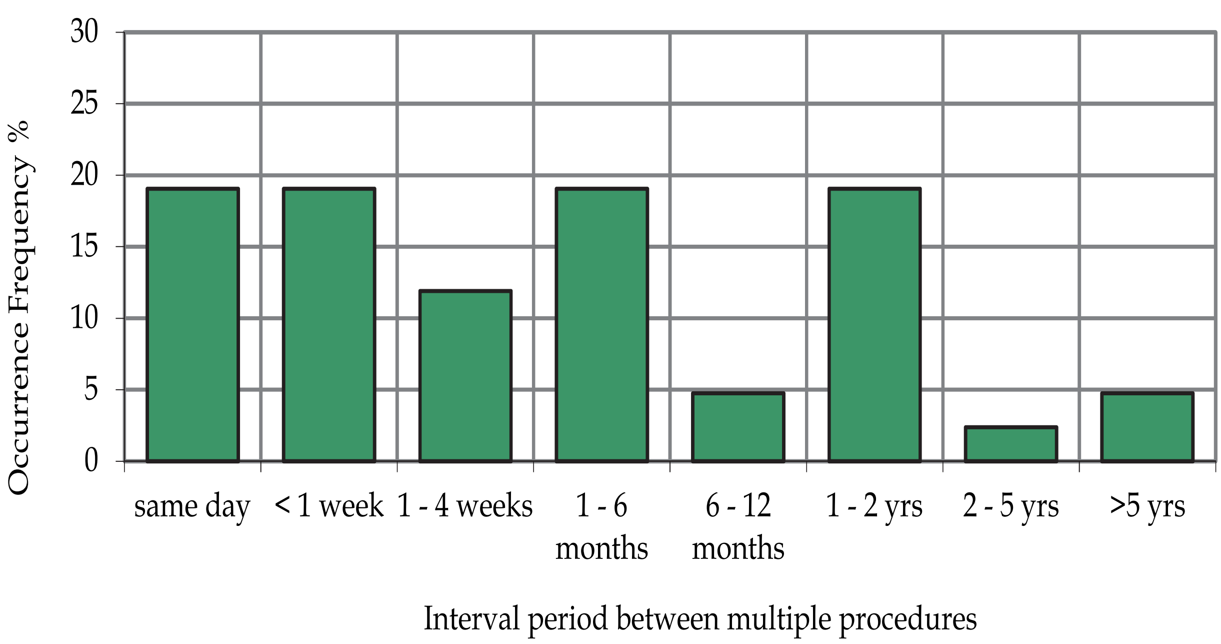
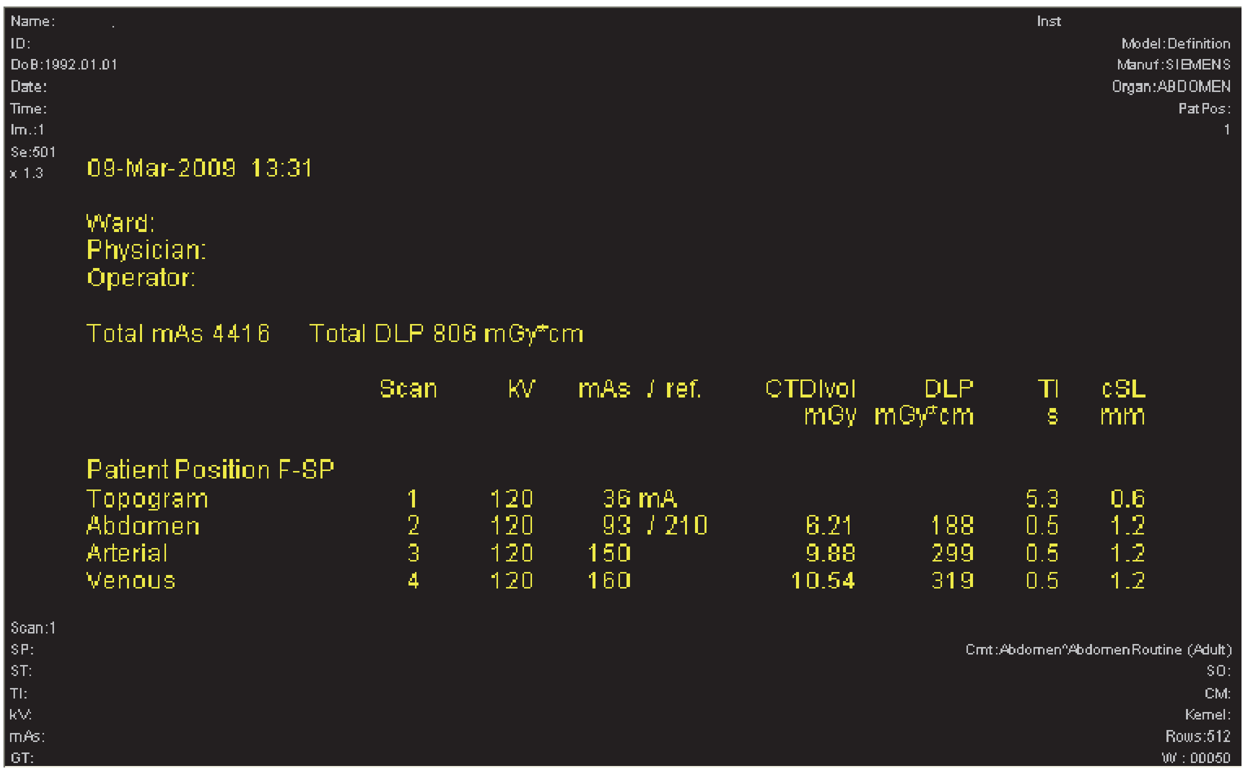


Fig. 3. Interval period between multiple procedures for pediatric patients.

In order to assess the effective dose of the scan, specific technical information of the parameters and techniques used in the actual scans was collected from the patient protocol and DICOM information from images obtained by the procedure.
The patient protocol is generated at the end of the exam for a patient and summarizes each exposure, giving the number of scans and phases along with technical parameters of the procedure. It is department policy to archive the patient protocol with the CT images as it provides much of the information required for assessing the effective dose of the procedure.
Data contained in the patient protocol is shown in figure 4 which was generated by the Definition 64-slice CT scanner during the performance of a routine abdomen scan with contrast on a 17 year old male patient. All the data required to calculate effective doses of the procedures was collected.

The volume computed tomography dose index (CTDIvol) for the individual scan at the parameters used and the associated dose length product (DLP) of the scan are shown in the patient protocol as well as the total DLP and total mAs of the procedure.
The total DLP for the whole procedure is the sum of the individual DLP's for each scan. The DLP as a dose metric has limited value but is a useful indicator of relative technique.


Name: . Inst
ID: Model:Definition
DoB:1992.01.01 Manuf:SIEMENS
Date: Organ:ABDOMEN
Time: PatPos:
Im.:1 1
Se:501
x 1.3

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Ward:
Physician:
Operator:

Total mAs 4416 Total DLP 806 mGy*cm

	Scan	KV	mAs / ref.	CTDIvol mGy	DLP mGy*cm	TI s	cSL mm
Patient Position F-SP							
Topogram	1	120	36 mA			5.3	0.6
Abdomen	2	120	93 / 210	6.21	188	0.5	1.2
Arterial	3	120	150	9.88	299	0.5	1.2
Venous	4	120	160	10.54	319	0.5	1.2

Scan:1
SP: Cmt:Abdomen^AbdomenRoutine (Adult)
ST: SO:
TI: CM:
kV: Kernel:
mAs: Rows:512
GT: W : 00050

Fig. 4. Patient protocol generated by the Siemens Definition 64 slice CT scanner

Some relevant information not provided in the patient protocol is the body region actually covered, often an abdomen scan covers both abdomen and pelvis, the scanned volume was therefore determined from the first and last image of each scan.
The pitch is also not provided in the patient protocol but can be determined from the mAs, mA and rotation time of the scan and is equal to the product of the mA and rotation time divided by the effective mAs.
Depending on the level of information available two methods for assessment of effective dose were applied in this study.
Method 1 was used where all the information was available in the data and the patient protocol had been archived, for the earlier procedures before archiving of the patient protocol was adopted the patient protocol had not been stored, for these procedures the reference effective dose for the typical procedure was used.
Method 1 uses values of kV, mAs, mA, rotation time, collimation, pitch and scanned body region from the patient protocol and CT images on the MiPACS MedView/CS (version MiPACS MedView 1.6.0_SP1 and the 1.7.0 update on 11/12/2010) along with measurements of CT dose index in air, CTDIair and weighted, CTDIw, made using a 10cm ionisation chamber during quality assurance tests on the CT scanner.
CTDIair is the average dose in air in the central region of a scan volume specific for the type of scanner and scanning parameters used.

All required fields were input into the ImPACT patient dosimetry software (version 1.0.2 12/11/2009) to calculate the effective dose of the scan. The effective dose of each scan in a procedure was summed to provide the effective dose of the procedure.
Method 2 was used if the CT scanner used for the procedure was not the Definition. This method for estimating effective dose involved calculating the product of the DLP and a conversion factor. Table 5 shows the conversion factors used in this study (k, mSv.mGy-1.cm-1) (ICRP, 2007 & Bongartz, et al. 2004, Shrimpton et al. 2006). The table gives the normalized effective dose per dose length product for adults (standard physique) and pediatric patients of various ages for various body regions. Although full range of pediatric sizes is not represented by the data, the method offers an approximation of the effective dose and has value due to its ease of use, providing a useful indicator of dose levels.

k mSv.mGy-1.cm-1	0-year-old	1-year-old	5-year-old	10-year-old	Adult
Head and Neck	0.013	0.0085	0.0057	0.0042	0.0031
Head	0.011	0.0067	0.004	0.0032	0.0021
Neck	0.017	0.012	0.011	0.0079	0.0059
Chest	0.039	0.026	0.018	0.013	0.014
Abdomen and Pelvis	0.049	0.030	0.020	0.015	0.015
Trunk	0.044	0.028	0.019	0.014	0.015

Table 5. Normalized effective dose per dose length product for adults (standard physique) and pediatric patients of various ages for various body regions.

For the routine abdomen protocol shown in figure 4 the two methods gave the following effective doses;

Method 1:

Information from routine quality assurance of the CT scanner and data collected yielded the information and result of the effective dose for the procedure shown in table 6. The dosimetry phantom range was estimated from the coverage of the organs as seen in the images. In this case the same coverage for all three phases was observed. However because the tube current (mA) used for each phase was varied, a different effective dose resulted, the non contrast abdomen scan resulted in the lowest effective dose due to the use of CAREdose. CAREdose is a feature of the Siemens scanners that provides current (mA) modulation over the scanned region according to body size. The effect on the effective dose is significant and can be achieved without loss of image quality for small and average sized patients. CAREdose is recommended for use with all pediatric scans.

Scan	Start Loca-tion	End Loca-tion	Phantom Range	mA	Effective mAs	pitch	kV	Rotation times	Slice collima-tion mm	Effective dose (mSv)	
Abdomen	390.5	650.5	27 - 47	168	93	0.9	120	0.5	1.2	2.8	12.1
Arterial	390.5	650.5	27 - 47	270	150	0.9	120	0.5	1.2	4.5	
Venous	390.5	650.5	27 - 47	288	160	0.9	120	0.5	1.2	4.8	

Table 6. Method 1 Data obtained from images (MiPACS MedView) and DICOM information input into the ImPACT CT dosimetry calculator yielding results for effective dose

Method 2:

Using the formula DLP mGy.cm x k mSv.mGy^{-1}.cm^{-1} and values of DLP from the patient protocol and values of k from table 5 the results shown in table 7 were obtained;

Scan	DLP mGy.cm	k mSv.mGy^{-1}.cm^{-1}	Effective dose (mSv)	
Abdomen	188	0.015	2.8	12.1
Arterial	299	0.015	4.5	
Venous	319	0.015	4.8	

Table 7. Method 2 calculation of effective dose

Although in this case the two methods gave the same result, in general it was found that using conversion factors resulted in effective dose estimates that ranged 40% lower to 60% higher than those calculated using method 1.

3. Pediatric results

53 pediatric patients were identified as undergoing a CT procedure in October 2010; the age range of the patients in October 2010 and at their first procedure is shown in figure 5. The mean age in October 2010 was 8.6 ± 6.2 years. 58.5% (n=31) of the pediatric patients were male with a mean age of 8.2 ± 5.8 years and 41.5% (n=22) were female with a mean age of 9.3 ± 6.7 years.

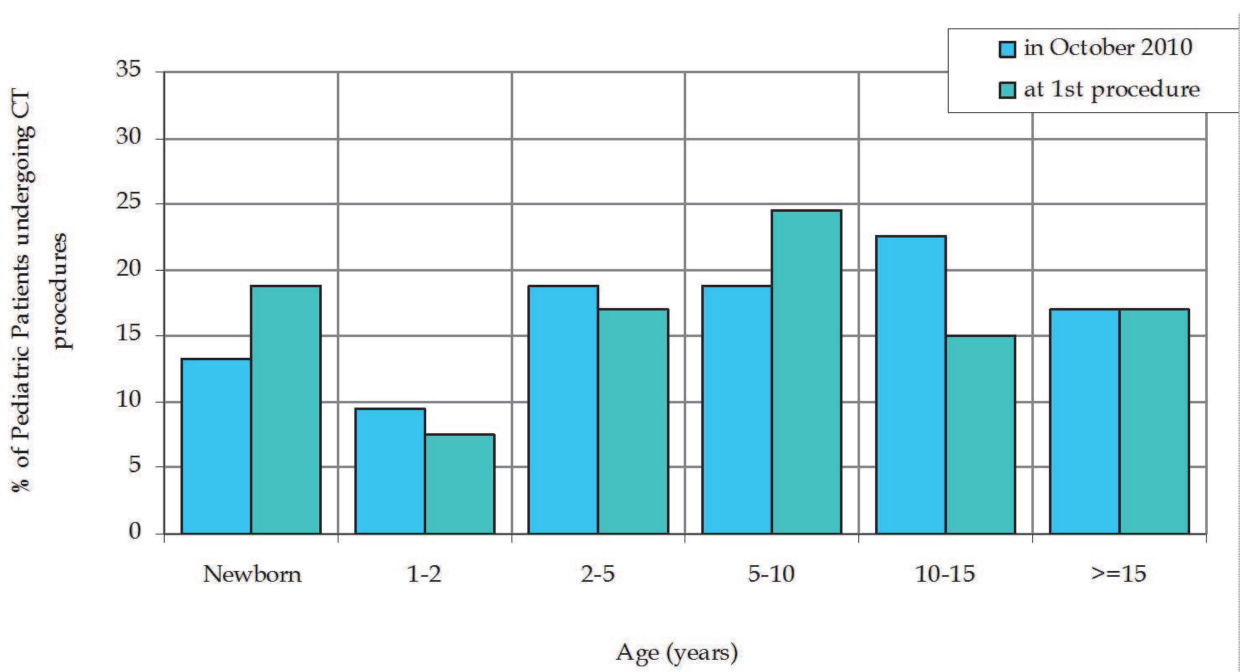


Fig. 5. Age Distribution of Pediatric Patients in October 2010 and at 1st procedure.

A total of 95 procedures were performed on these pediatric patients, 61% (58 procedures) on the male patients and 39% (37 procedures) on the female patients.
A total of 184 scans resulted from these procedures, 60% (110 scans) were performed on the male patients and 40% (74 scans) were performed on the female patients.

A breakdown of the scans performed according to gender and body region exposed is shown in figure 6.

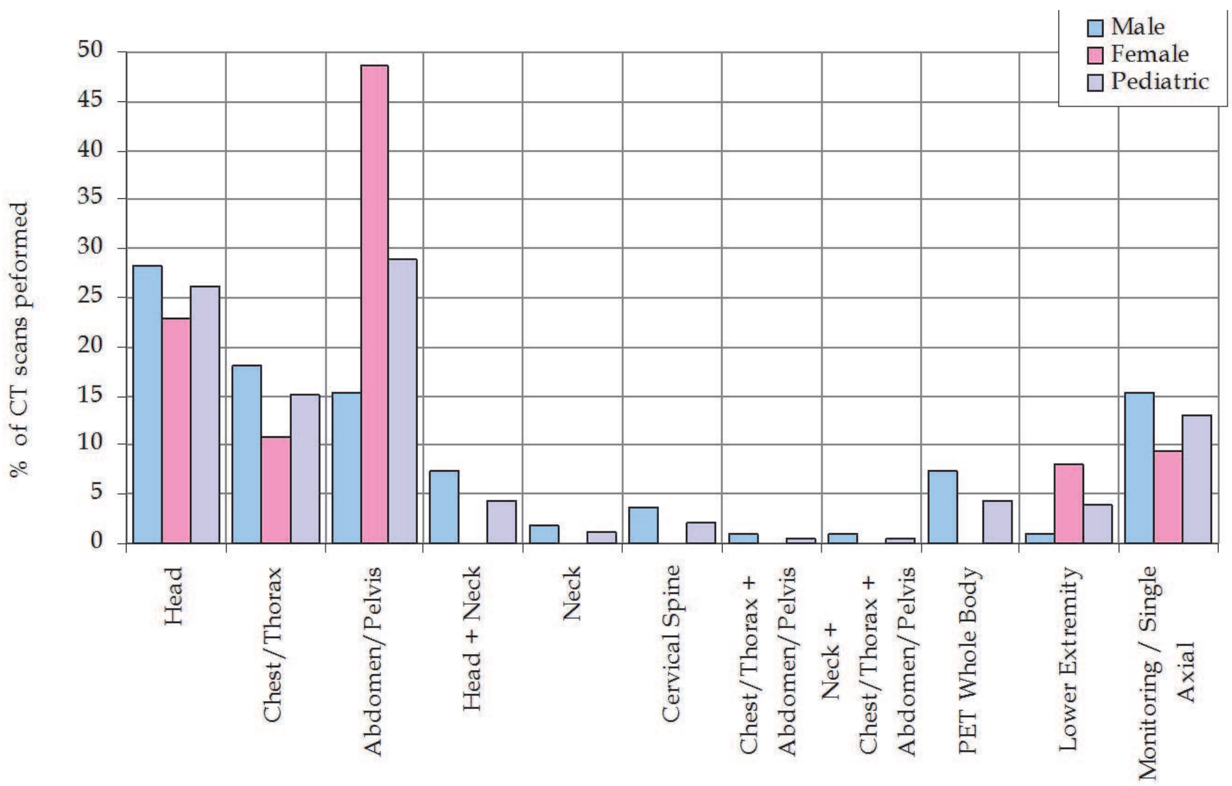


Fig. 6. Pediatric patients undergoing scans according to body region and gender

The most commonly exposed body regions and scans undertaken by the patients are shown in table 8.

Body Region	Parameter	Male	Female	All pediatrics
Head	Scans	28% (n=31 scans)	23% (n=17 scans)	26% (n=48 scans)
	Patients involved	64.5% (n=20)	54.5% (n=12)	60% (n=32)
Chest/Thorax	Scans	18% (n=20 scans)	11% (n=8 scans)	15% (n=28 scans)
	Patients involved	19% (n=6)	14% (n=3)	29% (n=9)
Abdomen/Pelvis	Scans	16% (n=17 scans)	49% (n=36 scans)	29% (n=53 scans)
	Patients involved	25% (n=8)	41% (n=9)	32% (n=17)

Table 8. Exposed body regions and scans undertaken by pediatric patients

For female pediatrics, abdomen/pelvis scans were the most performed, involving 41% (n=9) of the female patients. For male pediatrics, head scans were the most performed, involving 28% (n=31) of the male patients.

The patients could be grouped according to their number of procedures, scans and body regions exposed. Table 9 shows the group specification and the number of patients involved.

Group	Specification	Patients Involved
Group 1	Single Procedure involving a Single Scan on a Single Body Region	45.3% (n=24)
Group 2	Multiple Procedures involving a Single Scan/procedure on a Single Body Region	3.8% (n=2)
Group 3	Multiple Procedures involving a Single Scan/procedure on Multiple Body Regions	9.4% (n=5)
Group 4	Single Procedure involving Multiple Scans on a Single Body Region	18.9% (n=10)
Group 5	Multiple Procedures involving Multiple Scans on a Single Body Region	9.4% (n=5)
Group 6	Multiple Procedures involving Multiple Scans on Multiple Body Regions	13.2% (n=7)

Table 9. Patient exposure groups

To use the number of procedures or the number of scans as a cumulative radiation dose indicator would imply that Group 1 patients have the lowest cumulative effective doses and group 6 patients have the highest. However, the body region affects this.
For the purpose of this study cumulative effective dose levels for individuals have been specified according to the values shown in table 10.

Cumulative effective dose Level	Very Low	Low	Moderate	High	Very High
Effective dose range mSv	< 5	> 5 - 10	> 10 - 20	> 20 - 50	> 50 - 100

Table 10. Cumulative effective dose level categories

Figure 7 shows the cumulative effective dose to pediatric patients according to age and gender.
The distribution of cumulative effective dose varies considerably across all age groups, with a tendency of increasing for the over 10 year olds. Since the cumulative effective dose is dependent on the type of procedures carried out, the older age groups are more likely to have multiple phases and are likely being imaged as small adults, with protocols not being adjusted for size and weight unless the scanner specifies the appropriate child protocol. Childhood diseases and their detection and diagnosis using CT in pediatrics needs careful consideration to ensure that cumulative effective doses are minimized.
Figure 8 shows the cumulative effective doses received by pediatric patients according to the dose levels assigned.
The majority of pediatric patients, 64% (n=34) receive very low to moderate levels of cumulative dose. However, 28% (n=15) received high levels and 7.5% (n=4) received very high levels.

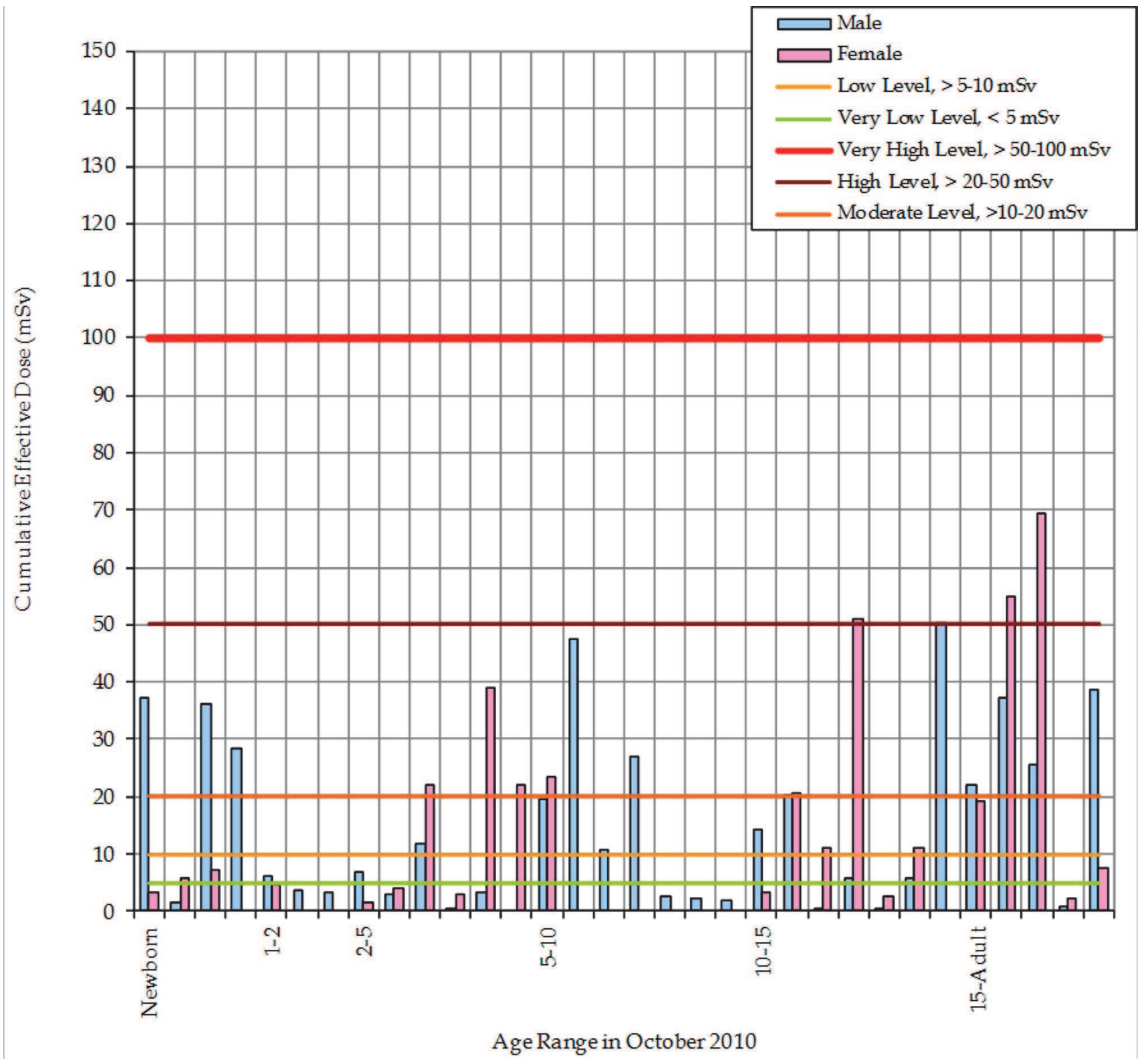


Fig. 7. Cumulative effective dose of pediatric patients according to age and gender

4. Discussion

Increased use of CT from new protocols and advances in technology means higher radiation dose in the patient population. Knowing the doses for CT protocols delivered through actual clinical studies in any radiology department is an important step towards developing reasonable strategies to optimize CT protocols and minimize unnecessary exposure. Understanding the physician's referral process and quantitative data about the numbers and types of procedures a patient has undergone is a useful aid to assessing the cumulative dose received by the patient.

Recent studies (Fazel et al., 2009 & Berrington et al., 2009) revealed higher-than-expected radiation dose in clinical CT studies and increased lifetime potential cancer risks as a result. The Northern California Childhood Leukemia Study in October 2010 has shown an increased risk of leukemia in pediatric patients that have had 3 or more radiology exams.

This study was intended to reveal the level of exposure and establish the scale of cumulative dose received by the pediatric patient population in a Private Tertiary Hospital in Saudi

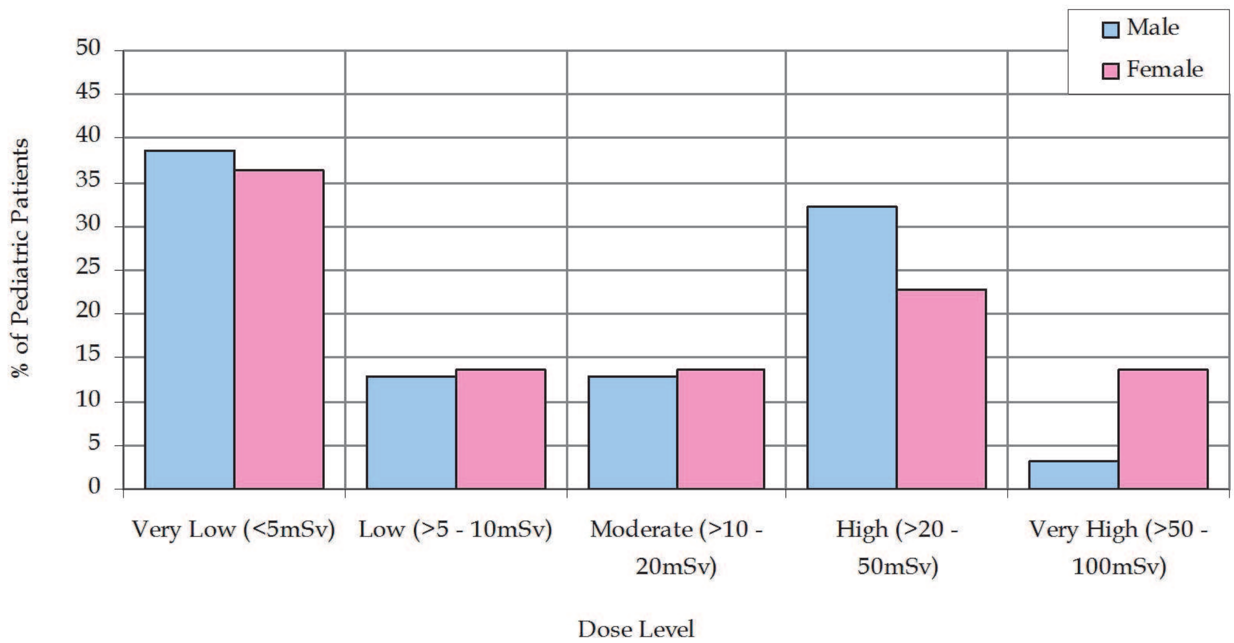


Fig. 8. Frequency of cumulative Effective Dose of pediatric patients according to dose level

Arabia. Calculating the radiation dose in clinical CT studies helped to establish reference dose levels for standard routine exams. In order to ensure justification of the exposure, benefit to the patient and to minimize risk to the individual, findings of the study have helped to develop protocols to address any inappropriate CT use and also started a process for monitoring cumulative dose to patients.

Considering the significant proportion of patients (55%, n=29, of our patient) undergoing multiple CT scans, often of the same body region, the cumulative effective dose easily reaches moderate to high levels and a small proportion, (7.5%, n=4, of our patients) reach very high levels of cumulative effective dose from CT alone.

As an indicator of the level of exposure and associated risk patients have accumulated from CT imaging procedures, simply knowing the number of procedures is not adequate, the type of procedure, body region exposed and number of scans in each procedure should also be known. From the number of scans a patient has undertaken, the body region and technique should also be known.

Using the dose length product as a dose metric is limited unless body region is also known. The effective dose calculated for a scan technique is the only indicator at present that provides the information necessary to estimate the associated biological damage and risk from cumulative procedures.

In order to provide accurate estimates, complete details of the procedure are necessary. However effective dose was not intended to provide individual doses but to provide a reference for the level of radiation dose to a standard sized adult phantom exposed under specific conditions. To measure the true dose to a patient would require direct measurement at the time of scanning.

Children are particularly sensitive to radiation from imaging scans and cumulative radiation dose to their developing bodies could well have adverse effects over time

In this study we have looked at the main clinical applications of CT in symptomatic pediatric patients and focused on the increasing number of CT scans being obtained and the associated radiation effective doses. To find that over one third of the pediatric patients have reached high to very high levels of effective dose from just CT imaging is of great concern.

The 7.5% (n=4) of pediatric patients who have reached very high levels of cumulative effective dose were reviewed for justification and benefit and to assess if any recommendations regarding future CT imaging can be determined.

Investigation of and justification of the 4 patients receiving very high levels of cumulative effective dose are now presented.

The first case was a 14.9 year old female who underwent a single procedure, dual source Coronary CTA child protocol, involving 3 helical scans, 1 pre monitoring axial scan and 4 IV bolus monitoring axial scans. Her resulting cumulative effective dose was estimated to be 51 mSv.

This patient had previous cardiac surgery and congenital anomaly of the aorta (right sided aortic arch and descending aorta), she had CT thorax (3 phases), an un-enhanced phase needed to trigger the contrast during maximum arterial opacification in the next arterial phase. The Venous phase was also done (resulting in approximately 18mSv, but could have been avoided).

The second case was a 17year old female who underwent a single urogram procedure involving 5 helical scans, (un-enhanced, arterial, venous and two delayed). Her resulting cumulative effective dose was estimated to be 55 mSv.

This patient's radiation exposure history also revealed 3 dynamic functional scintigraphy renograms using Tc-99m. The CT was performed to know the cause of bilateral pelviureteric junction partial obstruction, and the renogram preoperative to assess split renal function, intraoperative fluoroscopic guidance and postoperative renogram to asses split renal function. Proper and complete preoperative assessment necessitated the 5 phases in this patient.

The third case was a 12.8 year old male who underwent 2 procedures, the first procedure Carotid DSACT in May 2009 involved 3 helical scans plus 1 pre-monitoring axial scan and 3 IV bolus monitoring axial scans. The second procedure in October 2010 involved 4 helical scans (un-enhanced, arterial, venous and delayed). His resulting cumulative effective dose was estimated to be 51mSv.

This patient with neurofibromatosis diagnosed first by MRI of the neck and the brain had CTA of the neck for preoperative assessment of cervical carotid arteries and internal jugular veins. His follow-up examination was requested by the radiologist to be MRI but the patient had a CT of the head and neck to avoid the long MRI procedure and cost.

The final case was a 17.6 year old female who underwent 3 procedures, the first procedure, CT head in May 2009 involved 1 helical scan, the second procedure, CT Urogram in September 2009 involved 5 helical scans and the third procedure, CT pelvis involved 3 helical scans. Her resulting cumulative effective dose was estimated to be 69mSv.

This patient presented to the ER with severe headache, CT of the brain was done which showed abnormalities, further assessment was done by MRI. She had cerebral sinus thrombosis so, as diagnostic work-up CT of the abdomen and pelvis was done to exclude malignancy, it showed ovarian mass which was operated upon, her follow-up CT examination revealed, contralateral ovarian mass, all her follow-up examinations are now MRI and US.

Recommendations; reduce the scan range, reduce the number of phases, avoid un-enhanced and venous phases if possible and promote an awareness to the physician, radiologist and technologist about which procedures require high dose protocols. Record the estimated effective dose of the procedures in the patient's health records to avoid or minimize future CT imaging and follow up using Ultrasound and MRI.

Before this study was undertaken these figures were untracked and unmonitored. These results have helped to look at ways to implement guidelines for utilizing CT whilst balancing the risks of CT imaging with the clinical benefits.

Pediatric radiologists are best able to appreciate the challenges of imaging a child's small anatomy, faster breathing and heartbeat and the challenges of minimizing radiation dose to these patients. The challenge starts with the proper order of test, minimizing the area exposed, proper use of child settings, weight dependent to avoid over exposure, the use of special protocols for children and a full understanding of the childhood disorder.

The Image Gently campaign is an effort to ensure that medical protocols for imaging children keep pace with technological advances. It focuses on reducing CT dose for individual protocols and procedures, but a bigger concern is raised here about the use of CT diagnostic imaging and the consequence in cumulative effective dose to pediatric patients. Efforts to reduce the radiation effective dose to children if and when they need a CT scan must always be made. Any measure taken and every effort made for each individual child has a collective effect on the whole population.

Some of the steps that can be taken to reduce cumulative effective dose to children include applying measures to reduce, or child-size, the amount of radiation used for imaging children. Scanning only when necessary, ensuring that the risk benefit ratio is in favor of the exam ensuring that all previous and possible future exams are considered.

Only scanning the indicated region and only scanning once. Reducing the scan length and multiphase imaging can significantly reduce effective dose. Due to their smaller body size, organs are much closer and likely to receive greater levels of scattered radiation, reducing the scan region can help to reduce the amount of scattered radiation reaching critical organs not required in the image. Multiphase imaging significantly increases the effective dose of a procedure, it should rarely be used in children and each phase should be justified.

The Image Gently campaign also urges providers who perform imaging exams on children to work with medical physicists in order to monitor pediatric CT techniques, and to involve the radiology technologists to optimize scanning. The Image Gently website (www.imagegently.org) provides information describing how to achieve these goals. Achieving CT dose optimization and utilization is a team effort that will ensure that the radiation safety of the patient is considered and balanced with the clinical needs of the patient. A system of monitoring needs to be established in order to track dose, procedures and associated risks for individuals.

5. Conclusions

The likely effective doses received have been estimated with an acceptable level of accuracy for the purposes of risk assessment. The effective doses estimated support the conclusion that the level of exposure is high from CT and monitoring CT procedures performed on individuals certainly needs to be established. At the very minimum an easy to obtain dose metric such as the dose length product from a procedure should be considered for record in the patient file. Ideally effective dose, calculated for the individual undergoing the procedure to better estimate the risk estimates could be determined for that individual. These conclusions reflect the difference in the magnitude and circumstances of an individual's exposure.

Publication of the dose assessment, either the total dose length product or the effective dose of the procedure on the final CT report will benefit the physician and radiologist in providing quantitative information to the extent of doses received by the individual to enable appropriate risk benefit and justification of future procedures involving ionising radiation to the individual.
However without prior knowledge of the extent of an individual patient's exposure to ionizing radiation, or the number of previous CT procedures performed, as was the current situation, the number of patients exceeding a high level of radiation effective dose can be much higher than expected.
This study shows that unless precautions are taken to control the use of CT, pediatric patients have the potential to receive doses in excess of 50mSv very easily and very quickly during a hospital stay.
Although doses to patients undergoing CT procedures will be of low radiological significance in the majority of circumstances, the potential for the numbers of these procedures to increase for an individual is there which can mean that for a small proportion of patient's very high cumulative radiation doses can be reached, increasing their personal stochastic risks to a significant level.
Children are at a greater risk of receiving higher doses over their lifetime. With a proportion already exceeding 50mSv by the age of 18, what lies ahead………

6. Recommendations

Physicians need to be aware of estimates of the effective doses of procedures requested; this can be achieved by providing reference levels for commonly performed procedures and training programs.
Alternative modalities either not involving ionizing radiation such as MRI and Ultrasound or procedures involving less ionizing radiation such as certain nuclear medicine or general radiology procedures should be considered by physicians and radiologists.
Patient radiation exposure history needs to be included in the patient file and be reviewable by the physician and radiologist to help in the management of further imaging.
Patients undergoing CT should have the patient protocol of the procedure archived along with the images. The dose length product and scanned range should be included in the final CT report by the radiologist.
Precautions in over utilization of CT need to be established.
Optimized, appropriately used procedures performed with full justification and consideration of the risk benefit for the individual patients' circumstances prior to a procedure being performed do not pose concern, but it should be borne in mind that a CT procedure is always associated with a radiation effective dose to the patient which can increase their risk of a future cancer or other genetic or hereditary detriment and every effort should be made to reduce that risk. The control of CT exposure and associated issues should be under an organization management policy of dose reduction, particularly in consideration to pediatric CT imaging.

7. References

Berrington, A., González, D., Mahesh, M., et al., (2009). Projected Cancer Risks From Computed Tomographic Scans Performed in the United States in 2007. Archives of Internal Medicine Vol. 169 (22) (2009), 2071-2077.

Bongartz, G., Golding, S.J., Jurik, A.G. et al., (2004). European Guidelines for Multislice Computed Tomography. European Commission. URL:www.msct.eu/CT_Quality_Criteria.

Brody, A.S., Frush, D.P., Huda, W., et al. (2007). Radiation Risk to Children from Computed Tomography. Pediatrics Vol. 120 No. 3 (Sep 2007), 677-682.

Fazel, R., Krumholz, H.M., Wang, Y., et al., (2009). Exposure to Low-Dose Ionizing Radiation from Medical Imaging Procedures. The New England Journal of Medicine Vol. 361 No. 9 (Aug 2009),849-857.

Fujii, K., Aoyama, S. & Kawaura, C., (2007). Comparative evaluation of organ and effective doses for pediatric patients with those for adults in chest and abdominal CT examinations. The British Journal of Radiology, 80 (2007), 657-667.

ICRP (1991). 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Oxford: Pergamon Press, 1990.

ICRP (2007). Managing Patient Dose in Multi-Detector Computed Tomography (MDCT). ICRP Publication 102. Volume 37 No. 1 2007. Elsevier.

ImPACT: Imaging Performance Assessment of CT Scanners, ImPACT CT Patient Dosimetry Calculator. (2009), version 1.0.2 12/11/2009. URL:www.impactscan.org

Jones, D.J. & Shrimpton, P.C., (1993). Survey of CT Practice in the UK Part 3: Normalised Organ Doses Calculated using Monte Carlo Techniques. NRPB-R250 and associated Software NRPB-SR250. National Radiological Protection Board, Oxon.

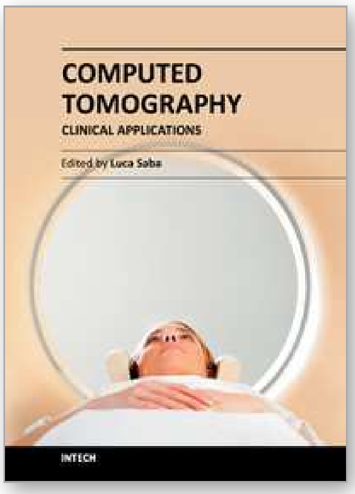
Khursheed, A., Hillier, M.C., Shrimpton, P.C. et al. (2002). Influence of patient age on normalized effective doses calculated for CT examinations. The British Journal of Radiology; 75 (2002), 819-830.

Mettler, F.A., Wiest, P.W., Locken, J.A., et al., (2000). Radiation Risks to Children from Computed Tomography. Journal of Radiological Protection; 20 (2000), 353-359.

Shrimpton, P.C., Hillier, M.C., Lewis, M.A., et al., (2005). Doses from Computed Tomography (CT) Examinations in the UK – 2003 Review. NRPB-W67. National Radiological Protection Board, Oxon.

Stecker, M.S., Balter S., Towbin, R., et al., (2009). Guidelines for patient radiation dose management. Journal of Vascular and Interventional Radiology, 20 (2009), s263-s273.

Wall, B.F., Kedall. G.M., Edwards, A.A. et al., (2006),What are the risks from medical X-rays and other low dose radiation? The British Journal of Radiology, 79 (2006), 285-294.



Computed Tomography - Clinical Applications
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Computed Tomography (CT), and in particular multi-detector-row computed tomography (MDCT), is a powerful non-invasive imaging tool with a number of advantages over the others non- invasive imaging techniques. CT has evolved into an indispensable imaging method in clinical routine. It was the first method to non-invasively acquire images of the inside of the human body that were not biased by superimposition of distinct anatomical structures. The first generation of CT scanners developed in the 1970s and numerous innovations have improved the utility and application field of the CT, such as the introduction of helical systems that allowed the development of the "volumetric CT" concept. In this book we want to explore the applications of CT from medical imaging to other fields like physics, archeology and computer aided diagnosis. Recently interesting technical, anthropomorphic, forensic and archeological as well as paleontological applications of computed tomography have been developed. These applications further strengthen the method as a generic diagnostic tool for non- destructive material testing and three-dimensional visualization beyond its medical use.