Optimization of Patient Dose in Abdominal Computerized Tomography

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ABSTRACT: Abdominal computed tomography (CT) scan have contributed greatly to diagnose abdomen diseases. However the radiation exposure to the patient is significantly higher in respect to other radiological examinations. While the benefits of CT exceed the potential effects of radiation exposure to patients, increasing radiation doses to the population have raised a compelling case for reduction of radiation exposure from CT. In Sudan, there was a remarkable increase of CT examinations being performed. Therefore, radiation dose optimization is mandatory because of the risks associated with exposure to radiation. The purpose of this study was to optimize the radiation dose, estimate the effective dose and radiation risk during adult computed tomographic (CT) for abdomen. A total of 83 patients referred to The National Ribat University Hospital (NRUH) in the period of the study with abdominal disturbances. Data of the technical parameters used in CT procedures was taken during May - October, 2009. The patients were divided into two groups: Control group (53 patients) were examined with the own department protocol using multislice CT (MSCT) 16 slice (Siemens Sensation); and optimization group (30 patients). Optimization was achieved through; the design of dose efficient equipment, the optimization of scan protocol and improvement of referring criteria. Organ and surface dose to specific radiosensitive organs was estimated by using software from National Radiological Protection Board (NRPB). The mean age was 45.4±18 years while the mean weight was 67±14Kg. The DLP was 288.25 mGy.cm and CTDIvol was 9.7 mGy. Patient effective doses were 13.5 mSv before the optimization. Conversely, this was reduced to 4.3 mSv after dose optimization. Estimated radiation risk is 742 x10⁻⁶ conversely the risk was reduced to 237 x10⁻⁶. Dose optimized protocol lowered the effective doses to 31.9%.

KEYWORDS: Radiation risk, Radiation dosimetry

INTRODUCTION
Computed tomography (CT) has rapidly evolved in terms of both technical performance and clinical use and become one of the most important of all X ray procedures worldwide. Spiral CT and in particular the latest generation of scanners with multi-slice capability in subsecond time frames have allowed improvements in speed of acquisition and image quality. This has resulted in highly reliable information about every part of the body, without motion artifacts from peristalsis and breathing. Thus, completely new indications for CT are being reported, as well as completely new methods for performing and reading the studies. Twenty years ago, a standard CT examination of the thorax took several minutes to conduct, while today similar information can be accumulated within a single breath hold period. This makes it more comfortable for patients and also easier for physicians to refer patients for examination, since the investigation is fast, well tolerated, accessible and, last but not least, regarded as highly reliable in its outcome (1, 2)

The individual risk from the radiation associated with a CT scan is quite small compared to the benefits that accurate diagnosis and treatment can provide. Still, unnecessary radiation exposure during medical procedures should be avoided. Unnecessary radiation may be delivered when CT scanner parameters are not appropriately adjusted for patient size (3). In conventional x-ray procedures, medical
personnel can tell if the patient was overexposed because the resulting film is overexposed, producing a dark image (2). However with CT, there is no obvious evidence that the patient was overexposed because the quality of the image may not be compromised. Several recent articles (4,5,6) stress that it is important to use the lowest radiation dose necessary to provide an image from which an accurate diagnosis can be made, and that significant dose reductions can be achieved without compromising clinical efficacy. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (7) has highlighted that worldwide there were about 93 million CT examinations performed annually at a rate of about 57 examinations per 1000 persons. UNSCEAR also estimated that CT constitutes about 5% of all X-ray examinations worldwide while accounting for about 34% of the resultant collective dose. In the countries that were identified as having the highest levels of healthcare, the corresponding figures were 6% and 41% respectively. Absorbed dose in tissues from CT are among the highest observed from diagnostic radiology (i.e. 10-100 mGy). These doses can often approach or exceed levels known to increase the probability of cancer. The main tools generally to achieve this aim are justification of practices optimization of protection. Optimization is even more important than in other practices using ionizing radiation (1). Optimization means keeping the dose “As low as reasonably achievable, economic and social factors being taken into account”, for diagnostic medical exposures this is interpreted as being a dose as low as possible, which is consistent with the required image gratuity and necessary for obtaining the desired diagnostic information (8). It is inevitable that some complex cases will require a larger number of CT sections and multiple phases, but the disparity occurring between apparently similar applications is of serious concern. It is now widely accepted that un-optimized CT examination protocols are a significant contributor of unnecessary radiation dose. There appears to be much scope for dose optimization through use of appropriate protocols.

The objectives of this study were to: (i) reduce patient’s radiation dose without affecting image quality during abdominal CT, (ii) estimate the effective dose for the patients undergoing CT exam (iii) design a proper requesting form for CT examination and (iv) propose a local diagnostic reference level for abdominal CT.

MATERIALS and METHODS
The data used in this study were collected from Department of Radiology, National Ribat University Hospital-Khartoum. Data of the technical parameters used in CT procedures was taken during May - October, 2009. An informed consent was obtained from all patients prior to the procedure.

CT Machine
Multislice CT Scanner (MSCT) 16 slice (Siemens Sensation) a Sensation 16 scanner installed in 2004. (Siemens Medical Solutions, Forchheim, Germany). All quality control tests were performed to the machine prior any data collection. The tests were carried out by experts from Sudan Atomic Energy Commission (SAEC). All the data were within acceptable range.

Patient Data
A total of 83 patients were referred to National Ribat University Hospital (NRUH) in the period of study with abdominal disturbances. The patients were divided into two groups: Control group (53 patients) were performed with the own department protocol and optimization group (30 patients). Patient-related parameters (e.g., age, gender, diagnostic purpose of examination,
body region, and use of contrast media) and patient dose were collected. In addition to that, Exposure-related parameters (gantry tilt, kilovoltage (kV), tube current (mA), exposure time, slice thickness, table increment, number of slices, and start and end positions of scans) on patient dose.

CT dose measurements
CT dose index (CTDI), which is a measure of the dose from single-slice irradiation, is defined as the integral along a line parallel to the axis of rotation (z) of the dose profile, D(z), divided by the nominal slice thickness, t.(1,1–5,41) In this study, CTDI was obtained from a measurement of dose, D(z), along the z-axis made in air using a special pencil-shaped ionization chamber (Diados, type M30009, PTW-Freiburg) connected to an electrometer (Diados, type 11003, PTW-Freiburg). The calibration of the ion chamber is traceable to the standards of the German National Laboratory and was calibrated according to the International Electrical Commission standards (9). The overall accuracy of ionization chamber measurements was estimated to be ±5%. Measurements of CTDI in air (CTDI100, air) were made as recommended by the EUR 16262EN based on each combination of typical scanning parameters obtained from the machine (9).

Organ dose determinations
The organ dose conversion factor f (organ, z) was obtained from the NRPB datasets (NRPB-SR250) based on the Monte Carlo simulations (9). The CTDOSE software supplied by the ImPACT group (10) was used. CTDIair normalized to 100 mAs (nCTDIair), CT scanner manufacturer and model, and typical scanning parameters such as kV, mA, exposure time, pitch, slice thickness, gender, and start and end positions of each scan were used as input data to the CTDOSE spreadsheet in organ dose estimations (9).

Cancer risk estimation
The risk (R_r) of developing cancer in a particular organ (T) following ERCP after irradiation was estimated by multiplying the mean organ equivalent (H_T) dose with the risk coefficients (f_r) obtained from ICRP (11,12).

\[ R_r = H_r \cdot f_r \] (1)

The overall lifetime mortality risk (R) per procedure resulting from cancer/heritable was determined by multiplying the effective dose (E) by the risk factor (f). The risk of genetic effects in future generations was obtained by multiplying the mean dose to the ovaries by the risk factor (11,12).

\[ R = E \cdot f = \sum R_r \] (2)

Radiation dose optimization technique
Optimization was based on reduction of the number of multiple scans with contrast material during and after injection of intravenous contrast material and elimination of inappropriate referrals for CT. In some cases, conventional radiography, sonography, or magnetic resonance imaging (MRI) can be just as effective as CT, and with lower or no radiation exposure.

RESULTS
A total of 83 CT abdomen procedures were performed over 5 months. Patients were divided into two groups: Routine and optimized. Clinical indications, dosemetric data and patients body characteristics are presented in table 1. Considerable variations were observed among patient populations in terms of radiation dose, and demographic data. Although the vast majority of patients were elderly, it is interesting to note that 50% of patients in this study were below 45 years. Radiation risk might be potential for this entire age group. The clinical indications showed that 45.7% of the performed procedures were CT scan for renal problems, 19.2% for
liver, and 12.0% for uterine, 13.2% for stomach and bowel and 9.6% for urinary bladder. The mean kV for Control and Optimisation group were 118.5 (120-140) and 101 (80-120), respectively. While the mean and range for mA were 100 (50-140) and 66 (31-130) and number of scans were 130 and 50 in that order.

**Table 1. Clinical indications for patients groups**

<table>
<thead>
<tr>
<th>Clinical Indication</th>
<th>Control group</th>
<th>Optimized group</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renal disease</td>
<td>28</td>
<td>10</td>
<td>45.7</td>
</tr>
<tr>
<td>Liver pancreas</td>
<td>11</td>
<td>5</td>
<td>19.2</td>
</tr>
<tr>
<td>Uterine+ cervix</td>
<td>5</td>
<td>5</td>
<td>12.0</td>
</tr>
<tr>
<td>bowel</td>
<td>4</td>
<td>7</td>
<td>13.2</td>
</tr>
<tr>
<td>KUB*</td>
<td>5</td>
<td>3</td>
<td>9.6</td>
</tr>
</tbody>
</table>

*KUB= Kidney urinary bladder.

The patient characteristics and exposure factors were comparable for both groups (age (years): 41 and 45 for control and optimized group, respectively; weight (Kg 60 and 67 correspondingly. Table 2 presents the CTDI (mGy), DLP (mGy. cm) and effective dose (mSv) values for both patients groups. This data shows asymmetry in dose distribution. A reduction of 30% was achieved by using optimized techniques.

**Table 2. Patients radiation dose values**

<table>
<thead>
<tr>
<th>Group</th>
<th>DLP Values(mGy. cm)</th>
<th>CTDI (mGy)</th>
<th>Effective dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>865.26</td>
<td>18.87</td>
<td>13.58</td>
</tr>
<tr>
<td>Optimized</td>
<td>288.9</td>
<td>9.73</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Table 3 Shows the estimated organ dose using the conversion factors from NRPB, risk factors from ICRP and the estimated risk values. The table also provides an estimation of the cancer risks associated with the organ dose. Not surprisingly, the pancreas and adrenals had the highest dose due to its position always inside the radiation field. The risk of radiation-induced cancer for different organs was in the magnitude of $10^{-4}$ and $10^{-5}$ per procedure.

**Table 3. Patient risk estimation for routine group**

<table>
<thead>
<tr>
<th>Organ</th>
<th>Organ equivalent dose (mSv)</th>
<th>Risk factor ($10^{-4}$Sv$^{-1}$)</th>
<th>Cancer probability ($10^{-6}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liver</td>
<td>18.4</td>
<td>30</td>
<td>55.2</td>
</tr>
<tr>
<td>Stomach</td>
<td>18.3</td>
<td>79</td>
<td>144.6</td>
</tr>
<tr>
<td>Pancreas</td>
<td>18.2</td>
<td>144</td>
<td>262.1</td>
</tr>
<tr>
<td>Spleen</td>
<td>18.4</td>
<td>30</td>
<td>55.2</td>
</tr>
<tr>
<td>Kidney</td>
<td>15.1</td>
<td>144</td>
<td>217.4</td>
</tr>
<tr>
<td>Adrenal</td>
<td>18.2</td>
<td>144</td>
<td>262.1</td>
</tr>
<tr>
<td>Ovaries</td>
<td>15.4</td>
<td>21</td>
<td>32.3</td>
</tr>
<tr>
<td>Uterus</td>
<td>17.1</td>
<td>131</td>
<td>224.0</td>
</tr>
<tr>
<td>Testicles</td>
<td>8.1</td>
<td>20</td>
<td>16.6</td>
</tr>
</tbody>
</table>

**DISCUSSION**

There were large variations in the radiation dose to the patients. In general these variations of doses due to differences in, tube voltages, number of scan, tube current and repeated scans. There may be justifiable reasons for some variability in practice, of which the most important one is the difference in clinical indication. This difference is greater if operators and practitioners are insufficiently educated in newly emerging technology. Further, increasing demand in radiology may induce radiologists to use over-intense protocols for CT, for viability to supervise the examination directly while engaged in other work. It is perceived that this is more likely to occur with relatively inexperienced workers and it is also possible that some examinations are carried out more intensively than needed as a means of clinical risk limitations.
These factors indicate strongly against measures to provide effective radiation protection. It is necessary to establish the minimum exposure threshold that will deliver adequate image quality in each application, preferably expressed in terms of clinical effectiveness.

The mean and range values of radiation dose were presented in different expressions: DLP (865.27 mGy.cm (150-3215 mGy). CTDI$_{vol}$ 18.87 mGy (3.69-70.4 mGy) and effective dose 13.58 mSv (2.25-48.22 mSv). This wide range of variation could be attributed to scan repetition and patients weight. According to the values obtained after optimization protocol was applied, a reduction in these values was achieved up to 31.9% in effective dose, 33.4% reduction in DLP & 51.6% reduction in CTDI.

CT abdomen involves direct irradiation of the abdominal and pelvic organs; therefore organ doses were estimated for the liver, pancreas, spleen, kidneys, bladder gonads and uterus (Table 3). These values are significantly higher than in previous studies (11,12). Estimation of ovarian dose is very important because most of patients are in childbearing age. The mean ovarian dose was estimated at 15.4±0.2 mGy. Comparing the results of this study with the previous data, it is clear that this study reports the successful reduction of the radiation dose to the ovaries as well as all other dose values. However, the ovarian equivalent dose estimation, which is a good indicator for the expected stochastic risk of the CT abdomen procedure, might contain some uncertainties. These uncertainties are related to the ovaries position, which varied in different patients and in the same patients at different times (13).

Radiation risk estimation for fatal cancer and hereditary effects per procedure was found to be 7.4 x10^{-4} while the hereditary risk is estimated to be 32 x 10^{-6}. To obtain a reasonable assessment of radiological risk for the patient, account should be taken of the irradiation of all the radiosensitive organs of the body. The estimated risk values for the uterus offer a better understanding of the radiation dose for the fetus and associated risks due to unexpected.

Despite these problems and the uncertainties involved, the estimation of the probability of radiation-induced cancers is needed for use in radiation protection to increase the awareness of medical personnel for further dose optimization. Both the hereditary and somatic risks of CT radiation exposure are enhanced when the average patient age is lower, i.e. the younger the patient the higher child expectancy and a longer subsequent life expectancy (11,12). The study protocol of optimization was designed using machine parameters for optimization of image quality to meet clinical requirements allow patient dose reduction without the loss of diagnostic accuracy, and are therefore of great interest.

The advantage of these techniques is the dose reduction up to 30% less than routine group and some of the previous studies. This reduction also reduces the risk of the tissue reactions and offers further margins for further investigations and follows up. The disadvantage of this technique is that it needs a good level of clinical experience. Nevertheless, it is still advisable to avoid radiation exposure where possible by other alternatives, i.e., sonography and magnetic resonance imaging (MRI) when equivalent information can be obtained.

DRLs can be used to verify the practices for typical examinations for groups of standardized patients in order to ensure that the dose should not be exceeded in normal practice without adequate justification (11,14-17). However, the available data is still not enough to establish national reference levels, but this could be a baseline for further studies.
concerning dose optimization. To the best of our knowledge, no values have been proposed to date for DLP during CT abdomen procedure. Therefore, a third quartile value of 170 mGy.cm can be used as DRL in a local basis for CT abdomen procedure for adults.

CONCLUSIONS
This study revealed large variations in radiation dose to various organs. Different data in request form were responsible for these variations. The mean organ doses in this study were mostly comparable (optimized group) to and slightly higher (control group) than reported values from the developed countries. The use of imaging protocol for abdomen and pelvis increases the radiation dose than that used in some of these countries (either abdomen or pelvis).

Organ doses and the probability of cancer induction were relatively high which justify the need to optimize CT scanning protocols. This can be achieved through optimal selection of scanning parameters based on indication of study, body region of interest being scanned, and patient size.

REFERENCES


