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Establishment of Diagnostic Reference Levels and Evaluation of Radiation Dose in Double Phase Abdominopelvic Computed Tomography

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ABSTRACT

Introduction: The purpose of this study was to establish of diagnostic reference level (DRL) and to compare radiation dose between single phase and unjustified double phase abdominopelvic CT imaging.

Material and Methods: A total of 163 patients, 85 patients with single phase and 78 patients with unjustified double phase abdominopelvic CT scans, were included in this retrospective study. Volumetric CT dose index ($CTDI_{vol}$) and dose length product (DLP) were obtained from the CT console. The third quartile of $CTDI_{vol}$ and DLP were determined for diagnostic reference level (DRL). Effective dose (E) and organ dose were obtained using CT-Expo software (version 2.2). Single phase and double phase scans were compared in terms of $CTDI_{vol}$, DLP, size-specific dose estimate (SSDE), E and organ doses.

Results: The institutional DRLs using $CTDI_{vol}$ and DLP for abdominopelvic CT were 9.8 mGy and 571 mGy.cm, respectively. The mean value of E was 5.4 ± 1.8 and 10.3 ± 3.4 for single phase and double phase imaging, respectively, resulting in 4.9 mSv excess dose per patient. Mean value of the DLP was 396.9 ± 142.7 and 759.0 ± 250.7 for single phase and double phase imaging, respectively. E was significantly higher in female compared to male ($p < 0.05$). Bladder has a highest lifetime attributed risk of cancer incidence among other organs. Also, the cancer risk incidence was higher for female than male.

Conclusion: The awareness of physicians about the correct indications of abdominopelvic CT should be increased by using associated reliable guidelines.

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Introduction

Since the advent of computed tomography (CT) scans in medicine, the number of CT examinations in the form of various clinical applications has grown significantly [1]. Fast imaging, multiplanar reconstruction, high spatial and temporal resolution and accurate diagnosis have increased the number of CT scans per year from 1995 to 2015 by about 394% in the United States [2].

The increased number of requests CT examinations and the high radiation dose of the CT imaging has raised many concerns about the potential risk of ionizing radiation [3]. In most reports, linear no threshold (LNT) model is adopted for radiation risk due to medical imaging examinations, declaring that the risk of stochastic effects augments linearly with augmenting radiation dose, with no threshold [4].

Therefore, all CT scan examinations must be justified as one of the radiation protection principles [5]. Justification considers the benefit versus the risk of exposure to radiation. For example, if single phase CT imaging of an anatomic area provides sufficient diagnostic information, multiphase imaging is unjustifiable. A single phase CT may include either without or with a contrast agent injection. A multiphase CT can be acquired without and with contrast agent injection [6].

Abdominopelvic CT scan is one of the most frequent CT examinations in clinical applications such as in patients with abdominal pain [7], trauma [8] and so on. Guite et al. [9] showed that more than half of the abdominopelvic CT examinations performed in multiphasic scans were unnecessary which increase radiation dose to patients. This means in many cases, abdominopelvic CT in alone plain mode or contrast injection mode rather than multiphasic scans can diminish potential radiation risk to patients. For example, a study reported that among common CT examinations, multiphasic abdominopelvic had a highest effective radiation dose (31 mSv) [9]. Therefore, it is essential that the lowest possible radiation dose be delivered to the patient while maintaining sufficient and accurate image interpretation.

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Although various methods can be used to reduce radiation dose in CT imaging, such as reducing radiation factors (kVp, mAs) [10], bismuth shields [11], dedicated reconstruction software [12], etc., but it is still the best way to reduce the number of examinations [13].

The purpose of this study was to establish of diagnostic reference level (DRL) and to compare radiation dose between single phase and unjustified double phase abdominopelvic CT imaging.

Materials and Methods

Patients' data

The research ethics committee of an institution approved and waived consent form for this study. A total of 163 patients, 85 patients with single phase and 78 patients with unjustified double phase abdominopelvic CT scans, were included randomly in this retrospective study. All patients with single phase CT scans were justified and one of the phases in double phase CT scans was unjustified according to a radiologist's report.

All patients were imaged with a 16 slice Somatom Emotion CT scanner (Siemens, Germany). For all patients, the CT scanner began imaging from the diaphragm and end to the symphysis pubis. Demographic data, including gender and age were acquired from the picture archiving and communication system (PACS)system.

Dose parameters

Some dose parameters were obtained from the CT console after a CT examination including: volumetric CT dose index ($CTDI_{vol}$, mGy) and dose length product (DLP, mGy.cm). The third quartile of $CTDI_{vol}$ and DLP were determined for diagnostic reference level (DRL) [14, 15]. Furthermore, we calculated size-specific dose estimate (SSDE) manually by the following formula;

$$SSDE = CTDI_{vol} \times f$$

Where f is the conversion factor extracted from American Association of Physicists in Medicine (AAPM) report number 204 [16, 17]. It should be noted that we need an effective diameter of the imaged region to extract specific conversion factor. Effective diameter calculated as square of product of anterior-posterior (AP) and Lat lengths, where the AP and Lat are anteroposterior and lateral dimensions of the middle slice of abdominopelvic CT images, respectively [17].

Effective dose (E) and organ doses were estimated by CT dose software CT-Expo (version 2.2) for further evaluation. In CT-Expo software, after determining scanner model, patient gender and scanning range, dose quantities are calculated following specified protocol details including; tube potential (kVp), tube current (mA), rotation time and collimation. E (mSv) and organ doses (mSv) were calculated based on tissue weighting factor provided by the international commission on Radiological protection (ICRP) 103 [18].

Lifetime attributed risk (LAR) of cancer incidence for organs were calculated on the basis of the Biological Effects of Ionizing Radiation (BEIR) VII report by inputting organ dose, patient gender and age. LARs were calculated for different organs, including; liver, lung, bladder and ovaries.

Statistical analysis

All statistical analysis was performed by SPSS software (version 23). All quantities were expressed in mean and standard deviation (SD). Comparison of dose quantities in terms of gender and phases were performed with non-parametric Mann-Whitney test. P values less than 0.05 were noted statistically significant.

Results

Table 1 presents some imaging parameters and patient's age. Tube potential were constant value of 130 kVp. The mean tube current-time product was 79.00 ± 24.0 mAs. The mean patients age was 51.64 ± 20 years.

Figure 1 shows the results of $CTDI_{vol}$ (mGy), DLP (mGy.cm) and SSDE for abdominopelvic CT scanning. The mean $CTDI_{vol}$, DLP and SSDE were 8.1 ± 2.5, 426.5 ± 156.0 and 7.5 ± 1.8, respectively. The 3rd quartile of $CTDI_{vol}$ and DLP (DRL) were 9.8 and 571, respectively.

The results of $CTDI_{vol}$, DLP and SSDE of abdominopelvic CT scanning in terms of gender are represented in Figure 2. There is no statistically difference between male and female in terms of $CTDI_{vol}$, DLP and SSDE ($p > 0.05$). The mean $CTDI_{vol}$ was 8.4 ± 2.7 and 8.2 ± 2.5 for female and male, respectively. The mean SSDE was 7.9 ± 1.7 and 7.5 ± 1.8 for female and male, respectively. The mean DLP was 398.5 ± 155.6 and 395.9 ± 136.1 for female and male, respectively.

The results of $CTDI_{vol}$ and SSDE of abdominopelvic CT scanning for single phase and double phase imaging are represented in Figure 3. There is no statistically difference between single phase and double phase imaging in terms of $CTDI_{vol}$ and SSDE ($p > 0.05$). The mean $CTDI_{vol}$ was 8.3 ± 2.6 and 7.7 ± 2.2 for single phase and double phase imaging, respectively. The mean SSDE was 7.7 ± 1.7 and 7.5 ± 1.2 for single phase and double phase imaging, respectively.

Table 1. Scanner type, imaging parameters and patient's age.

CT scanner	Tube potential (kVp)	Tube current-time product (mAs)	Age (years)
16 slice Somatom Emotion, Siemens	130	79.00 ± 24.0 (46-148)	51.64 ± 20.81 (13-87)

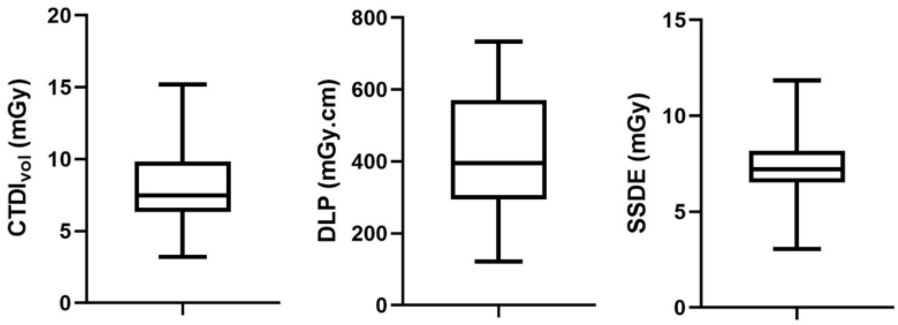

Figure 1. Box plot showing results of $CTDI_{vol}$, DLP, and SSDE for abdominopelvic CT scanning.

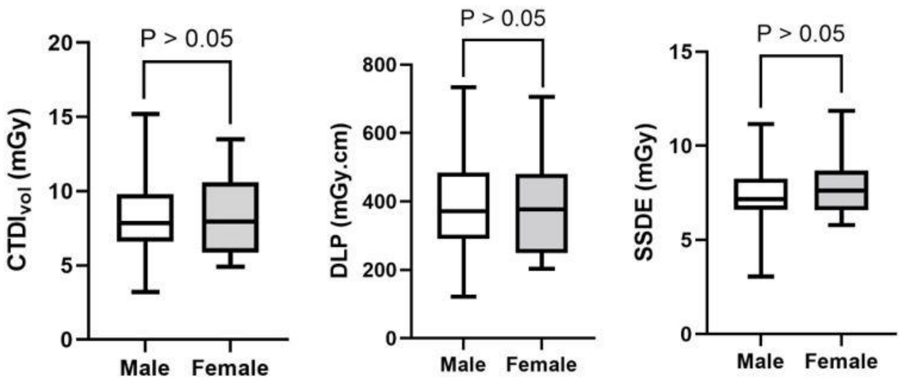

Figure 2. Box plot showing comparison of $CTDI_{vol}$, DLP and SSDE in terms of gender.

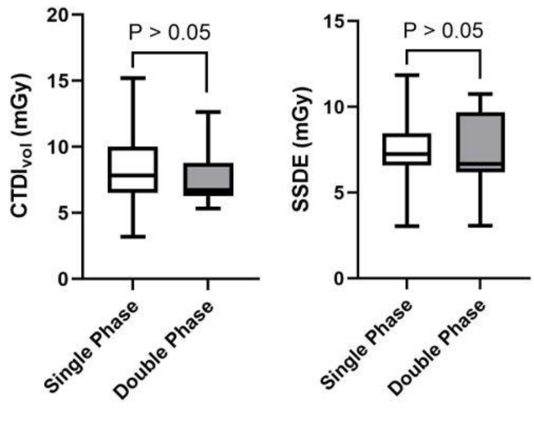

Figure 3. Box plot showing comparison of $CTDI_{vol}$ and SSDE for single phase and double phase abdominopelvic CT imaging.

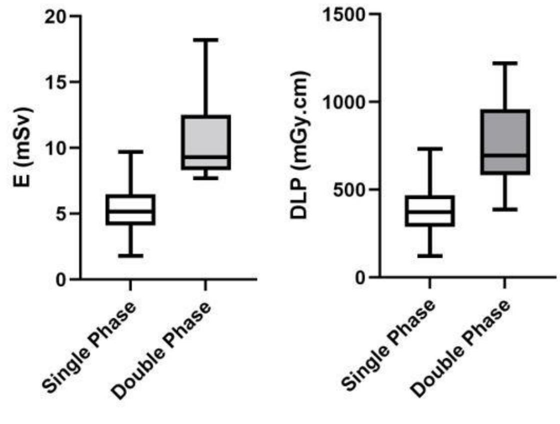

Figure 4. Box plot showing comparison of effective dose (E) and DLP for single phase and double phase abdominopelvic CT imaging.

The results of E (mSv) and DLP for single phase and double phase imaging are represented in Figure 4. Mean value of E was 5.4 ± 1.8 and 10.3 ± 3.4 for single phase and double phase imaging, respectively. Mean value of the DLP was 396.9 ± 142.7 and 759.0 ± 250.7 for single phase and double phase imaging, respectively.

The results of E (mSv) in terms of gender for single phase and double phase imaging are represented in Figure 5. Mean value of E was 5.9 ± 1.5 and 6.1 ± 1.9 for male and female in single phase imaging, respectively. The mean value of E was 8.2 ± 0.6 and 9.9 ± 2.1 for male and female in double phase imaging, respectively. There is a statistically difference between male and female in terms of E ($p < 0.05$).

Organ doses (mSv) for single phase and double phase scans are summarized in table 2 and represented in Figure 6 for better comparison.

Summary of LAR of cancer incidences associated with abdominopelvic CT imaging in single phase and double phase scans is presented in table 3.

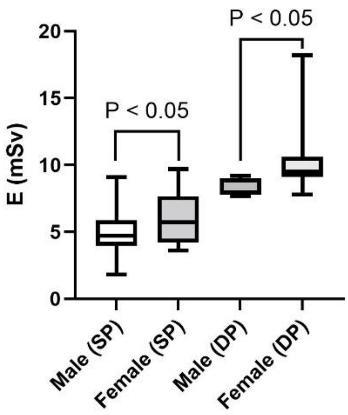

Figure 5. Box plot showing comparison of effective dose (E) in terms of gender for single phase (SP) and double phase (DP) abdominopelvic CT imaging.

Table 2. Summary of organ doses (mSv) for single phase and double phase scans.

Organs	Single phase	Double phase
Lungs	2.17 ± 0.70	4.04 ± 1.27
Liver	9.40 ± 2.93	17.31 ± 4.83
Testicles	2.56 ± 0.78	4.27 ± 0.35
Bladder	11.44 ± 3.62	21.56 ± 5.89
Bone marrow	4.84 ± 1.55	9.04 ± 3.12
Bone surfaces	7.05 ± 2.24	13.21 ± 4.33
Spleen	9.63 ± 3.01	17.80 ± 5.03
Pancreas	7.88 ± 2.45	14.69 ± 4.17
Adrenals	7.78 ± 2.57	14.01 ± 3.87
Kidneys	10.12 ± 3.14	18.73 ± 5.33
Small intestine	9.59 ± 3.08	18.73 ± 5.75
Prostate	11.09 ± 3.50	18.40 ± 1.43
Gall bladder	7.88 ± 2.45	14.70 ± 4.17
Heart	1.74 ± 0.56	3.32 ± 1.04
Stomach	9.78 ± 3.03	17.98 ± 5.06
Ovaries	10.81 ± 3.47	20.52 ± 6.36
Breast	1.35 ± 0.40	2.44 ± 0.72

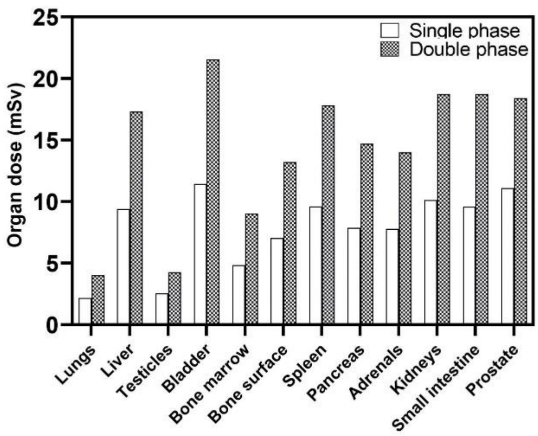

Figure 6. Results of organ doses (mSv) for single phase and double phase scans.

Table 3. LAR of organ cancer incidences (per 100,000 patients) associated with abdominopelvic CT imaging in single phase and double phase scans.

Organs	Single phase		Double phase	
	Male	Female	Male	Female
Liver	0.87 ± 0.37	1.57 ± 0.90	1.00 ± 0.65	2.60 ± 1.32
Lung	1.91 ± 0.94	5.35 ± 2.29	2.91 ± 1.13	6.66 ± 3.59
Bladder	7.42 ± 3.64	9.08 ± 3.74	9.91 ± 4.88	11.93 ± 6.04
Ovaries	-	3.34 ± 1.66	-	3.41 ± 0.84

Discussion

This study was performed because there is evidence that many numbers of abdominopelvic CT scans are performed in extra phases while have no specific clinical indication [19]. Therefore, this extra radiation dose delivered to the patient is not justified.

In the first step, DRLs were determined for this institution. Establishment of DRLs causes dose optimization in medical imaging departments while preserving acceptable image quality [20]. The institutional DRL using $CTDI_{vol}$ for abdominopelvic CT was 9.8 mGy, which is lower than national DRLs of United Arab Emirates, UK, Canada, Japan, Australia, France and Egypt [21]. Also, the institutional DRL using DLP for single phase abdominopelvic CT was 571 mGy.cm, which is lower than national DRLs of United Arab Emirates, UK, Canada, Japan, Australia, France and Egypt [21]. These discrepancies may be related to different adjusted scanning parameters, especially for relatively lower mAs (79.00 ± 24.0) used in this institution.

There was no statistically difference between male and female in terms of $CTDI_{vol}$, DLP and SSDE, which is somewhat acceptable because these dose quantities show radiation dose per slice, not personal sensitivity to radiation. The $CTDI_{vol}$ indicates the radiation output of the CT scanner and does not lonely represent the actual radiation dose received by the patient. Patient size is another important factor affecting patient dose, which AAPM report No.204 accommodate both ($CTDI_{vol}$, patient size) as SSDE. Also, Kayun et al. [22] observed no statistical difference in SSDE between genders in brain CT scans.

We also calculated E using CT-Expo software as it can be used to compare exposure between different imaging studies and appropriately estimate radiation risks [23]. E is calculated by summation of equivalent doses of organs multiplied by the tissue weighting factor as indicated in the report [18]. As expected, E (mSv) value was statistically different between single phase and double phase scans. The results of the present study showed that an extra phase scan can increase E from 5.4 ± 1.8 to 10.3 ± 3.4 mSv (almost doubled). Therefore, it seems unnecessary extra phases are one of the main sources of unacceptable radiation dose in medical imaging. This is where the importance of justification comes into play. Al Naomi et al. [24] have shown that about half of the phases in multi-phase abdomen and pelvic CT in women childbearing age have no clinical indication, increasing the radiation dose by about 65% in those who had unindicted phases compared to those had indicated phases. Giannitto et al. [25] reported that unnecessary phases in abdominopelvic CT in women with reproductive age may increase radiation dose to the uterus and ovaries about 38 and 33 mSv, respectively. Our results showed that each extra phase in abdominopelvic CT in women increases radiation dose to ovaries about 9.7 mSv.

Guite et al. [9] reported that 52.8% phases of abdomen-pelvis CT scans are not considered necessary by associated guidelines, leading to an increase in effective dose of 16.8 mSv per patient. Therefore, the awareness of physicians about the correct indications of abdominopelvic CT should be increased by using associated reliable guidelines.

E values calculated by CT-expo software were statistically different between male and female for both single phase and double phase scans, because the software in order to calculate doses, uses gender specific anthropomorphic phantoms as ADAM for male and EVA for female.

One of the strengths of this study is the calculation of organ doses. It can be observed that in abdominopelvic CT, bladder receives the highest dose followed by prostate, ovaries, kidneys and stomach. It can be seen that the double phase doubles the radiation dose to the organs compared to the single phase. These radiation levels do not appear to have deterministic effects, but stochastic effects such as the risk of cancer and hereditary effects cannot be ignored. Therefore, all institutions must prevent unnecessary exposure of patients by adopting the ALARA (As Low As Reasonably Achievable) principle.

LARs of cancer incidence for organs including liver, lung, bladder and ovaries are presented in table 3. As expected, bladder has highest LAR of cancer incidence. The mean LAR of bladder cancer in male patients in single phase was 7.42 (about 1 in 13000) and increases to 9.91 (about 1 in 10000) in double phase. Also, it can be observed that cancer risk incidence is higher for female than male, which is in consistent with other studies [23, 26].

The limitations of the present study are; (1) the study covers only one institution, (2) the patient population is relatively low, (3) not including pediatric patients (4) and most importantly not evaluates image quality due to relatively low mAs used in this institution.

Conclusion

Many numbers of abdominopelvic CT scans are performed in extra phases while they have no specific clinical indication, resulting in extra radiation dose to the patient. It seems that in abdominopelvic CT, bladder receives the highest dose followed by prostate, ovaries, kidneys and stomach. The results of the present study showed that an extra phase scan can increase E from 5.4 ± 1.8 to 10.3 ± 3.4 mSv. Therefore, the awareness of physicians about the correct indications of abdominopelvic CT should be increased by using associated reliable guidelines.

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