Establishment of institutional diagnostic reference level for CT imaging associated with multiple anatomical regions

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Abstract. Advancement of CT technology has increased the frequency of CT scanning in diagnosis. However, the concern on dose increment that related to radiation-associated health risk from CT also improved. The aim of this study was to establish an institutional diagnostic reference level (DRL) for computed tomography (CT) imaging associated with multiple or combined anatomical regions and compared with other international DRLs. CT dose data of 705 subjects were collected retrospectively from January 2015 until December 2017 at AMDI, USM, Malaysia. The most common CT examination of combined anatomical regions were neck-thorax-abdomen-pelvis (NTAP), thorax-abdomen (TA), thorax-abdomen-pelvis (TAP), and abdomen-pelvis (AP). CT dose data such as CTDIvol, CTDIw and dose-length product (DLP) were collected including contrast, non-contrast, single-phasic, and multiphasic examinations. The 50th and 75th percentile of dose distribution were calculated and compared with other established DRLs. TAP CT was the most frequently performed examination at AMDI (73%). The local dose values of multiphasic and non-contrast examination were higher compared to single phasic and contrast study. The results show a weak correlation between different CT sequences and DRLs for AP examination. Local dose values reported for all CT examinations were below any international DRLs except for CT TAP (multiphasic) study. The institutional DRL for combined anatomical regions was established using the third quartile values of dose distribution and is categorized based on CT sequences.

1. Introduction

Along with the growing number of computed tomography (CT) scanners and frequency of usage, concerns on radiation dose and its associated-health effects were also expanding [1]. Thus, diagnostic reference level (DRL) was introduced in early 1990s by the International Commission on Radiological Protection (ICRP) as a crucial element for dose optimisation [2,3]. DRL has been established in medical imaging to assess the patient dose received from specific imaging procedure by comparing with the reference guideline [4]. DRLs are usually set at the 75th percentile of dose distribution from survey conducted across various facilities using a specified dose measurement protocol. DRL should be established at both regional and national level, and huge variations have been seen across regions and countries [5].
Establishment of local DRL for each CT protocols are recommended as an optimisation tool to ensure the doses received by the patients are appropriate with the clinical purpose [8]. The limitation with current national DRL recommended by Ministry of Health (MOH) Malaysia was only cover CT examinations for single part or specific anatomical region. This study aims to establish a local DRL for CT examination associated with combined or multiple anatomical regions. The study also compared two methods for DRL establishment associated with multiple anatomical regions which were summation of DRL of single body region and calculation of third quartile value of the study population dose.

Recent studies utilised the third quartile (75th percentile) of dose distribution for national DRL and the median (50th percentile) for local DRL (LDRL) intended for CT examinations of combined parts or multiple anatomical regions rather than using summation of DRLs for each region [5,7]. The aim of the third quartile calculation is to alert professionals on dose metric that exceeding the reference guideline while the 50th percentile is to reassure professionals sustain the dose optimisation even if their practice is below DRL [9]. In this study, utilising a standard method for establishment of DRL for multiple anatomical can lead to comparable results to international DRL and it will act as a guidance in routine CT practice at institution and national level [7].

2. Methodology

Institutional committee review for ethical approval on clinical data study was obtained (study protocol code: USM/JEPeM/16040164). A retrospective survey on the local dose data for all CT examinations performed at Imaging Unit, Advanced Medical and Dental Institute (AMDI), Universiti Sains Malaysia (USM), Malaysia was performed. Data were collected from Siemens SOMATOM Definition AS+ CT scanner (Siemens Healthcare, Germany). Only four most common local CT examinations from January 2015 until December 2017 involving multiple anatomical regions were observed. The inclusion criteria for recruiting the subjects is patients aged 15 years old and above.

The CT examinations were categorised based on CT sequences such as single phasic, multiphasic, non-contrast and contrast CT examinations. Single phasic scan is a single acquisition CT examination while multiphasic scan comprises more than one acquisition of CT examinations [7]. Non-contrast scan is a CT sequence without intravenous injection of contrast media while contrast CT scan involves intravenous contrast media injection.

All related data including exposure settings such as tube potential (kV), tube current (mA), pitch, slice thickness, scan range, and patient information such as patient’s gender, and age were obtained for all examination. The displayed dose output such as volume CT dose index (CTDIvol), and DLP were collected. The national DRLs suggested the use of CT dose indices of weighted CT dose index (CTDIw) (in mGy) and DLP (in mGy.cm). The weighted CT dose index (CTDIw) was calculated based on the formula:

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CTDIw = CTDI_{vol} \times pitch
\]  

The mean, min, median, the first and third quartile values for each CTDIw, CTDIvol and DLP of all selected CT protocol were calculated respectively. The dose values were then analysed and compared with the national and international DRLs. The institutional DRLs were established from the calculated third quartile values of mean patient dose for each examination type. In accordance with the regulations, the institutional DRL is established from three years period of data collection or minimum of 10 cases [11]. Median values were used for comparison with other countries as recommended by International Commission of Radiological Protection (ICRP) [5]. All dose data were compared with the reference guidelines which were national DRLs [6] and other international DRLs [5,7]. All the collected dose data were then documented for further evaluation on the current local practices in CT procedure.
3. Results
A total of 705 CT examinations involving combined anatomical regions from overall 1146 CT examinations were collected. The most frequently performed examinations at AMDI were thorax-abdomen-pelvis, TAP (73%), followed by abdomen-pelvis, AP (18%), neck-thorax-abdomen-pelvis, NTAP (6%), and thorax-abdomen, TA (3%). From the results, it shows that more female patients underwent CT examinations than male patients, as shown in Figure 1.

![Figure 1](image)

Figure 1. Demographic distribution of study population of most frequent CT protocols performed based on gender.

The dose data collected were categorised according to CT sequences; contrast, non-contrast, single-phasic, and multiphasic examinations. Table 1 shows the local dose distribution for most frequent CT examination performed at AMDI. It reported the median and 75th percentile of CT dose values for singlephasic and multiphasic CT studies. CTDI\(_{vol}\) values for multiphasic examinations were higher than single phasic examinations. For multiphasic CT NTAP, the DLP was slightly double the dose values for single phasic. The DLP for single phasic CT AP was slightly equal than multiphasic. Table 2 summarises the 50th and 75th percentile values of dose distribution for non-contrast and contrast CT studies of the most frequent CT examination involving multiple anatomical regions. The dose values (CTDI\(_{vol}\), CTDI\(_{w}\), and DLP) for non-contrast examinations of CT NTAP, TA, and TAP were slightly higher than contrast examinations, but the doses for non-contrast examinations of CT AP were slightly lower than contrast examination.

From the dose surveys, the collected CTDI\(_{w}\) values were ranged between 3.47 mGy to 98.75 mGy for each CT protocols. The highest value of CTDI\(_{w}\) was noted in the CT NTAP examinations, with a maximum value of 98.75 mGy, whereas the lowest value of 3.47 mGy was recorded for the CT AP study. For range of collected CTDI\(_{vol}\) was between 4.45 mGy to 98.75 mGy per procedure. The highest CTDI\(_{vol}\) value was noted in the CT NTAP, with a maximum value of 164.58 mGy, whereas the lowest value of 4.45 mGy was CT AP study. CT TAP study gave the highest DLP value of maximum 6849 mGy.cm. These variations may be due to exposure protocols selection that markedly attributable to selected mAs, and multiple exposures of contrast monitoring scan.
Table 1. Dose values for most common examinations of combined anatomical regions based on phase study.

| CT protocols | Sample number | CTDI$_{vol}$ (mGy) | CTDI$_{w}$ (mGy) | DLP (mGy.cm) |
|--------------|---------------|---------------------|------------------|--------------|
|              |               | Median 75th percentile | Median 75th percentile | Median 75th percentile |
| NTAP         | Single Phasic | 1                   | 8.88 8.88         | 5.33 5.33     | 706 706 |
|              | Multiphasic   | 44                  | 35.77 51.14       | 21.46 30.69   | 1276 1724 |
| TA           | Single Phasic | 4                   | 10.73 15.47       | 6.44 9.28     | 485 615 |
|              | Multiphasic   | 15                  | 37.05 46.84       | 22.23 37.89   | 707 977 |
| TAP          | Single Phasic | 17                  | 6.25 8.26         | 3.75 4.96     | 376 491 |
|              | Multiphasic   | 499                 | 38.15 45.22       | 22.89 27.13   | 1124 1416 |
| AP           | Single Phasic | 3                   | 11.30 11.87       | 6.78 7.12     | 519 545 |
|              | Multiphasic   | 142                 | 10.66 14.56       | 10.40 14.00   | 487 643 |

Table 2. Dose values for most common examinations of combined anatomical regions based on contrast and non-contrast study.

| CT protocols | Sample number | CTDI$_{vol}$ (mGy) | CTDI$_{w}$ (mGy) | DLP (mGy.cm) |
|--------------|---------------|---------------------|------------------|--------------|
|              |               | Median 75th percentile | Median 75th percentile | Median 75th percentile |
| NTAP         | Non-Contrast  | 45                  | 8.32 10.29       | 4.99 6.17     | 645 782 |
|              | Contrast      | 44                  | 6.95 9.01        | 4.17 5.41     | 520 700 |
| TA           | Non-Contrast  | 18                  | 8.60 11.47       | 5.33 9.15     | 402 515 |
|              | Contrast      | 16                  | 7.36 11.51       | 4.97 9.45     | 383 492 |
| TAP          | Non-Contrast  | 503                 | 8.94 10.92       | 5.36 6.55     | 565 695 |
|              | Contrast      | 514                 | 7.46 9.42        | 4.49 5.65     | 466 594 |
| AP           | Non-Contrast  | 120                 | 5.36 6.89        | 4.55 6.34     | 241 309 |
|              | Contrast      | 19                  | 6.80 10.91       | 4.08 6.54     | 402 524 |

Table 3 shows the comparison of local dose data (based on third quartile values) with the standard Malaysian NDRL (based on dose summation of single region). From the findings, it shows that local dose values were lower than the summed values of NDRL. However, CT TA study exceeded the NDRL by 10% and thorough evaluation is required to assess the higher radiation dose and the correction procedure strategy should be proposed. Table 4 shows the comparison of local dose data with the selected DRLs established by several countries such as Ireland, Greece, Japan, and international agencies such as American College of Radiology (ACR), and University of California Medical Centre (UCMC) in United States. The dose values were only compared for CT TA, TAP and AP studies as international DRL for NTAP was not yet established. Local dose values reported for all CT examinations were below any international DRLs except for multiphasic studies for all CT procedures that exceed the DRLs of UCMC.
Table 3. Local dose values (CTDI\textsubscript{w} and DLP) and comparison with national DRLs.

| CT Procedure | CTDI\textsubscript{w} (mGy) | MOH\textsuperscript{*}Sum | % difference | DLP (mGy.cm) | MOH\textsuperscript{*}Sum | % difference |
|--------------|---------------------------|---------------------------|--------------|--------------|---------------------------|--------------|
| NTAP         | 30.64                     | N/A                       | N/A          | 1705         | N/A                       | N/A          |
| TA           | 37.89                     | 34.1                      | 0.1          | 977          | 870                       | 0.11         |
| TAP          | 27.12                     | 73.2                      | 0.63         | 1412.5       | 1600                      | 0.12         |
| AP           | 14.52                     | 51.9                      | 0.72         | 637          | 1180                      | 0.46         |

Institutional = Local dose data in this study were set at the level of third quartile value for CTDI\textsubscript{w} and DLP.
MOH\textsuperscript{*}Sum = NDRL values are based on reference standard established by Ministry of Health Malaysia (summation NDRL values for combined anatomical parts).

Table 4. Local dose values (CTDI\textsubscript{vol} and DLP) and comparison with international DRLs.

| Countries | Dose values | 1P | MP | NC | C | 1P | MP | NC | C | 1P | MP | NC | C |
|-----------|-------------|----|----|----|---|----|----|----|---|----|----|----|---|
| Ireland\textsuperscript{[12]} | CTDI\textsubscript{vol} | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
|             | DLP         | 850 | 850 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| Greece\textsuperscript{[13]} | CTDI\textsubscript{vol} | 17 | 17 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
|             | DLP         | 1020 | 1020 | 760 | 760 | 760 | 760 | 760 | 760 | 760 | 760 | 760 | 760 |
| Japan\textsuperscript{[14]} | CTDI\textsubscript{vol} | 18 | 18 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
|             | DLP         | 1300 | 1300 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 |
| ACR        | CTDI\textsubscript{vol} | 17 | 17 | 16 | 15 | 16 | 15 | 16 | 15 | 16 | 15 | 16 | 15 |
|             | DLP         | 2020 | 781 | 755 | 781 | 755 | 781 | 755 | 781 | 755 | 781 | 755 | 781 |
| UCMC\textsuperscript{[7]} | CTDI\textsubscript{vol} | 18 | 17 | 12 | 13 | 15 | 12 | 12 | 16 | 15 | 16 | 15 | 16 |
|             | DLP         | 1800 | 2160 | 823 | 1349 | 947 | 643 | 1406 | 781 | 755 | 781 | 755 | 781 |
| Institution| CTDI\textsubscript{vol} | 15 | 47 | 11 | 12 | 8 | 45 | 11 | 9 | 12 | 15 | 7 | 11 |
|             | DLP         | 615 | 977 | 515 | 492 | 491 | 1416 | 695 | 594 | 545 | 643 | 309 | 524 |

1P = Single Phasic = Single acquisition CT examination
MP = Multiphasic = More than one acquisition CT examination.
NC = Non-Contrast = CT examination sequence without contrast media intravenous injection.
C = Contrast = CT examination sequence with contrast media intravenous injection.

4. Discussion

The higher dose values observed in certain CT examinations performed at AMDI USM were possibly due to multiple acquisitions of pre- and monitoring contrast scans. Thus, improvement for local radiation protection for the patient at AMDI should be promoted and sustained. Besides, the number of scan for multiphasic examination should be reduced and properly justified.

The summation method of NDRL values for each single region used for dose comparison resulted in higher values as compared to third quartile value of local dose for combined anatomical regions. For determination of local DRLs, the calculation of third quartile values for multiple anatomical regions doses are suggested because more reliable than the summation method of DRL values for each region.

The comparative study was limited due to the current NDRLs provided by MOH\textsuperscript{[6]} only implies for CT examinations involving single anatomical region instead of multiple anatomical regions. Besides, the comparative study was performed only for selected CT examinations that has available DRL values for both
national and international DRLs. Thus, examination-specific DRLs for the unavailable CT protocols should be proposed in current NDRLs.

5. Conclusion
The local DRLs for combined anatomical regions were established using the third quartile values of dose distribution. For higher dose studies that exceeded the established DRLs, further evaluation is critical to ensure the dose optimisation for patients and to reduce the occurrence of excessive radiation exposure. A corrective strategy for dose reduction should be proposed to improve the local radiation protection program. Future work will involve establishment of local DRL based on the standard regulations as the first step in dose optimisation strategies at AMDI.

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