Establishment of multi-slice computed tomography (MSCT) reference level in Johor, Malaysia

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Abstract. Radiation doses from computed tomography (CT) are the highest and most hazardous compared to other imaging modalities. This study aimed to evaluate radiation dose in Johor, Malaysia to patients during computed tomography examinations of the brain, chest and abdomen and to establish the local diagnostic reference levels (DRLs) as are present with the current, state-of-art, multi-slice CT scanners. Survey forms were sent to five centres performing CT to obtain data regarding acquisition parameters as well as the dose information from CT consoles. CT-EXPO (Version 2.3.1, Germany) was used to validate the dose information. The proposed DRLs were indicated by rounding the third quartiles of whole dose distributions where mean values of CTDI\(_w\) (mGy), CTDI\(_{vol}\) (mGy) and DLP (mGy.cm) were comparable with other reference levels; 63, 63, and 1015 respectively for CT Brain; 15, 14, and 450 respectively for CT thorax and 16, 17, and 590 respectively for CT abdomen. The study revealed that the CT practice and dose output were revolutionised, and must keep up with the pace of introductory technology. We suggest that CTDI\(_{vol}\) should be included in current national DRLs, as modern CTs are configured with a higher number of detectors and are independent of pitch factors.

1. Introduction

Computed tomography (CT) scan are well known for their contribution to high doses of radiation, with a resultant increased risk of cancer [1]. Although, CT examination has been acknowledged as the preferred method for diagnosis compared to other imaging modality. In 2008, according to the United Nations Scientific Committee’s effect of Atomic Radiation (UNSCEAR) report that the total effective dose from CT examinations of whole populations have increased slightly, from 41% of the total annual population dose in the period 1991–1996, to 43% in the period 1997 – 2007 [2]. The contribution of CT examinations towards the population dose has steadily increased since its inception in 1974, where the organ absorbed dose from CT was conveyed approaching levels of cancer probability, with some reports on the deterministic effects on the skin [3–5].

To date, the number of CT scan installed showing the inclining trend as well as dose exposure [2]. These trends are due to the introduction of spiral CT technology which its capability to shorten the time of image acquisition and solved some of the limitation scopes in diagnosis. Although CT images are known to have a higher spatial resolution, misdiagnosis and unjustified requests from physicians still occurs [6]. As reported elsewhere, there are wide variations in CT doses between different facilities for
similar procedures, although they used similar scanners [7, 8]. This information allows for the understanding of dose reduction activities and changes in the parameters and protocols that could be used without affecting the quality of the images. Consequently, there should be an encouragement in ensuring the principles of radiation protection, justification, and optimisation is continuously applied, in order to enhance the safety of the provided service. A simple principal of optimisation is the establishment of diagnostic reference levels (DRLs), which were first proposed by the International Commission on Radiation Protection (ICRP) in 1996, and which was initially implemented in Europe [9] and later in Malaysian regulation in 2013 [10].

Multi-slice CT (MSCT) scanner was only recently introduced to many developing countries and developed countries. Developed countries have well experienced in CT technology while most of the public hospitals in developing countries have started acquiring the latest technology MSCT scanners only later. Therefore, the purpose of this study was to evaluate patient dose and establishing local DRLs which focusing MSCT scanner in Johor, Malaysia.

2. Methodology

The survey was performed on five CT scanners from five different public hospitals in four regional cities in Johor, by means of adapted questionnaires during August 2014 to December 2014. The hospitals included were: Department of Radiology of Hospital Sultanah Aminah Johor Bahru (HSAJB); Permai Psychiatric Hospital (HPER); Hospital Enche’ Hajah Besar Kalthom (HEBHK), Hospital Pakar Sultanah Fatimah Muar (HPSF), and Hospital Segamat (HSEG). Details of the scanners are summarized in table 1.

| Hospital        | CT scanner          | Year installation | Cities         |
|-----------------|---------------------|-------------------|----------------|
| HSAJB           | Siemens Definition AS | 2010              | Johor Bahru   |
| HPER            | Siemens Somatom Emotion 16 | 2010              | Johor Bahru   |
| HEBHK           | Siemens Somatom Emotion 16 | 2013              | Kluang         |
| HPSF            | Toshiba Activion 16  | 2010              | Muar           |
| HSEG            | Siemens Somatom Emotion 16 | 2014              | Segamat       |

In accordance with the approach used elsewhere, the questionnaires were completed by radiographers who had direct contact with the CT operations of each facility. The following information was obtained from CT consoles: tube potential (kV), tube current (mA), time (s), effective tube current (mAs), nominal collimation beam width (N*hcol), table feed, slice thickness, scan range and dose output. It is noted that all the CT scanners included in table 1 are subjected to Planned and Preventive Maintenance (PPM) and have all passed the annual quality assurance (QA) carried out by consultant physicists. It can, therefore, be assumed that all of the scanners were performing optimally.

Patient radiation doses from CT were calculated using the formalism implemented in the program CT-EXPO (Version 2.3.1, Germany), which is described in detail elsewhere [7, 8, 11]. This software provides the automatic calculation of organ doses, by specifying the scanner model, scanner manufacturer, and scanning parameters as input. All scanning parameters, including patient characteristics and calculated results, were collected and registered in a Microsoft Excel spreadsheet before being transferred to the statistical package SPSS (version 17) for performing the analysis.

3. Results

The region of scanning, as well important technical factors pertaining to the patient characteristics’ data in this present study, are summarized in table 2. A total of 614 CT examinations’ data were collected from the 262, 163, and 189 patients who underwent routine CT brain, thorax, and abdomen examinations, respectively. Patient characteristics, especially body mass index (BMI), will serve as the
factors determining the CT doses in further analysis of this work. As can be observed from table 2, the weight of the patients in this study ranged from 40 kg to 87 kg, with the highest weight of a patient observed in CT abdomen. Parameter settings for different CT protocols obtained in the survey is presented in table 3. It is observed that the acquisition parameters used in this survey are widely diversified.

### Table 2. Patient characteristics in this study.

| Region of examination | Patient characteristics | n   | Weight (kg) | Height (m) | BMI (kg.m\(^{-2}\)) |
|-----------------------|-------------------------|-----|-------------|------------|---------------------|
| Brain                 |                         | 262 |             |            |                     |
| Thorax                |                         | 163 | 40.0 - 80.0 | 1.55 - 1.75| 16.6 - 31.2         |
| Abdomen               |                         | 189 | 48.0 - 87.0 | 1.52 - 1.78| 18.3 - 28.4         |

### Table 3. Range of CT scan parameters performed in this study.

| Region of examination | Parameter                      | n   | Tube output (kV) | Tube current (mAs) | Pitch | Scan range (cm) |
|-----------------------|--------------------------------|-----|------------------|-------------------|-------|-----------------|
| Brain                 |                                | 262 | 110 - 130        | 270 - 420         | 0.6 - 1.0 | 8.3 - 20.1     |
| Thorax                |                                | 163 | 40.0 - 80.0      | 57 - 262          | 0.8 - 1.2 | 24.0 - 53.4    |
| Abdomen               |                                | 189 | 48.0 - 87.0      | 54 - 328          | 0.8 - 1.0 | 15.3 - 41.9    |

Table 4 provides the details of the descriptive statistics for patient dose for CTDI\(_w\), CTDI\(_\text{vol}\) and DLP. CT brain has the highest value in mean CTDI\(_w\) value, ranging from 31.1 to 70.8 mGy, whereas the lowest values ranging from 4.3 to 31.1 mGy were noted for CT thorax examinations.

### Table 4. Statistics value of radiation doses from CT examinations in this study.

| Region of body | CTDI\(_w\) (mGy) | CTDI\(_\text{vol}\) (mGy) | DLP (mGy.cm) |
|----------------|------------------|---------------------------|--------------|
|                | Mean ± SD (Min - Max) | Mean ± SD (Min - Max) | Mean ± SD (Min - Max) |
| Brain          | 58.2 ± 9.8 (31.1 – 70.8) | 59.1 ± 10.2 (31.1 – 70.8) | 841.7 ± 179.8 (426.4 – 1167.5) |
| Thorax         | 12.0 ± 4.2 (4.3 – 31.1) | 10.9 ± 5.2 (3.2 – 31.2) | 401.3 ± 196.4 (167.9 – 902.6) |
| Abdomen        | 12.4 ± 6.1 (3.6 – 33.4) | 12.2 ± 4.6 (4.0 – 34.6) | 497.6 ± 186.0 (210.9 – 892.9) |

The proposed local DRLs are compared with current national diagnostic reference levels (NDRLs) and other references in table 5. It is observed that the third-quartile (Q3) values of CTDI\(_w\) for CT brain and CT abdomen exceed the NDRLs but Q3 values of CTDI\(_\text{vol}\) were comparable to MSCT reference level; EC2004 and UK2005.

### Table 5. Comparison of third-quartile values of this study with other reference levels.

| Region | Dose descriptors | This study\(^a\) | EU1999[9] | EU2004 | UK2005[12] | Malaysia 2013[10] |
|--------|------------------|-----------------|-----------|--------|------------|------------------|
| Brain  | CTDI\(_w\)       | 63              | 60        | 57     | 46.8       |                   |
|        | CTDI\(_\text{vol}\) | 63              | -         | 56     | -          |                   |
|        | DLP              | 1015            | 1050      | 990    | 690        | 1050             |
| Thorax | CTDI\(_w\)       | 15              | 30        | 14     | 19.9       |                   |
|        | CTDI\(_\text{vol}\) | 14              | -         | 12     | 10         | -                |

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\(^a\)This study refers to the study conducted in this particular region.
4. Discussion

The radiation dose from CT mostly depends on the CT acquisition parameters, including tube potential (kVp), tube current (mAs), shift per rotation ratio (pitch), and the scan length (L). The modern CT scanners are usually equipped with ATCM technology that aids in reducing the mAs per rotation through angular and longitudinal modulation during scanning [7, 13]. This study revealed a significant variation in acquisition parameters among the radiology departments of each site and the scanners. Furthermore, the mean values of the dose quantities and CT acquisition parameters obtained are in agreement with other findings from previous researchers.

As shown in table 3 and 4, CT acquisition settings and radiation doses received for the same examination and patient type were varied. The highest value of cumulative CTDI was noted in the CT brain examinations, with a value of about 70.8 mGy, whereas the lowest value of 4.3 mGy was recorded for the CT thorax. These variations may be due to the use of non-optimised imaging protocols, even when using a scanner from the same manufacturer, and different practices, especially in the case of CT brain examinations, with or without the use of contrast enhancement. The exposure parameters that depend on ATCM thus need to be reconsidered for reference noise, or reference mAs for adjusting, and hence would reduce the doses significantly, rather than relying on the standard protocols only.

It has been noted that current Malaysian DRLs are based on a survey taken from 2007 to 2009; this being data obtained mostly from SSCT. Merely through monitoring and survey studies of CT doses, the influencing features that affect patient doses in CT can be identified and it is usually the first step in optimisation strategies. The health care level I countries are usually consistent in providing the needed information, such as numbers of CT examinations, dosage levels from scanners, and their optimisation strategies, particularly for MSCT scanners. However, such information, in the majority of developing countries, is uncommon. Therefore, this has allowed us to propose local DRLs, as well as national DRLs, for different types of scanners, whether they are multi-slice or single-slice CT (SSCT). As a result, radiation dose surveys have been suggested in order to constantly monitor CT examinations on a national or local basis, and that the practise undergoes regular reviewing.

There are two limitations in this study: the first is the small sample size, and the second the protocols practice not being standardised. The diverse of the data because of the different used of practices where for example, in CT thorax examination, some centres include part of the liver, whereas, in the usual diagnostic CT thorax, the posterior costophrenic of the lung is usually the lower limit of the scan volume. However, this study is considered as the first step in the optimisation techniques which focusing on current, state-of-art, MSCT scanners.

5. Conclusion

In this study, patient CT doses, from four regional cities, involving five CT scanners, have been presented in terms of CTDIₘₜ, CTDIᵥ, and DLP and effective dose values. Proposed local DRLs of routine examination were highlighted with the purpose of presenting current CT practice, which were assumed to be ensembles for multi-slice CT reference levels in accordance with EU 2004. Within this same report, CTDIᵥ was mentioned and found to be comparable with all other literature focusing on MSCT. The establishment of CTDIᵥ as part of DRLs is vital in order to cope with current practice and changes of CT protocols, especially with the involvement of modern CT scanners.

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