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# Establishing institutional adult computed tomography diagnostic reference levels at a public tertiary hospital in Singapore

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## INTRODUCTION

The utilisation of radiation for medical diagnosis, treatment and management has been rapidly increasing in the last two decades. This is particularly evident in the use of Computed Tomography (CT) as it rapidly expands in the last two decades where 62 million CT scans are performed annually in the United States. Advancements in its availability and systems play an increasingly indispensable role in the diagnosis and treatment of patients.(1,2) This increase in CT utilisation can be attributed to its widespread availability and technological advancement in 3D imaging that enable faster, more accurate diagnosis and the prevention of certain invasive surgical procedures. Furthermore, CT has been proven to be an integral part of emergency medicine due to its capability in improving diagnostic confidence and admission decisions.

As CT imaging continues to gain a foothold globally, since 1996, The International Commission on Radiological Protection (IRCP) has used the concept of Dose Reference Levels (DRLs) in an effort to monitor medical radiation dose. The adoption of DRLs in imaging facilities will serve to improve radiographic practices and the optimization of radiation protection for the patient.(3-5)

This study aims to establish institutional DRLs for the four most common adult CT examinations in Department of Radiology (DoR) in Sengkang General Hospital (SKH), namely CT Brain (non-contrast), CT Chest (contrast, single phase), CT Abdomen-Pelvis (contrast, portal venous phase), and CT Kidney-Ureter-Bladder (KUB) (non-contrast). The primary purpose of this study is to determine our facility's median ($50^{th}$ percentile) DRL, in line with ICRP recommendations. Our secondary aim is to compare our obtained institutional DRLs with that of other facilities, both at a local as well as at an international level.

## METHODS

The SingHealth Centralised Institutional Review (CIRB) Board and Singapore Institute of Technology Institutional Review Board approved the ethics submission for the retrospective review of data records.

Data was extracted from the DoR's Radiology Information System (RIS) and Picture Archiving and Communication System (PACS) for the common CT examinations performed on three different clinical CT scanners between July 2018 and October 2018 in SKH. All three clinical CT scanners have been commissioned in 2018 and are equipped with the latest iterative reconstruction (IR) software algorithms. Current CT scanners at SKH are one 512-slice General Electric (GE) Revolution, equipped with Adaptive Statistical Iterative Reconstruction - V (ASiR-V) and two 384-slice Siemens SOMATOM Force scanners equipped with Advanced Modeled Iterative Reconstruction (ADMIRE). The CT scanners had undergone daily quality control tests and quarterly preventive maintenance checks to ensure that $CTDI_{vol}$ and DLP values are verified, against the use of an ionisation chamber. With the exception of brain scans, most of the body CT scans were acquired in dual energy protocols recommended by the respective scanner vendors.

As CT imaging is tailored to individual patients with varying pathologies, the study only analyses single-phase scans. Scan coverage are as follows CT Brain: base of skull to vertex; CT Chest: apex to base of lungs; CT Abdomen-Pelvis: diaphragm to symphysis pubis; CT KUB: kidney to symphysis pubis.

All collected data included patient age and gender, CT manufacturer, study description, scan phases, Computed Tomography Dose Index ($CTDI_{vol}$), Dose Length Product (DLP), tube current (mA), and tube potential (kVp), was encrypted in a password encoded hard disk. The data was then sorted using Microsoft Excel (Version 16.33) according to scanned anatomic region. As a final step, the data was exported to SPSS software (IBM SPSS Statistics version 26.0.0 2019) for statistical analysis.

A total of 2976 CT scan orders were performed from the opening of SKH (July 2018) till October 2018. 37% involves CT Brain, 11% involves CT Chest, 24% CT Abdomen Pelvis orders and 9% CT KUB. There were 552 males and 540 females for CT Brain; 178 males and 163 females for CT Chest; 300 males and 401 females for Abdomen Pelvis; and 161 males and 103 females for CT KUB.

The age group of the analysed data set ranged from 18 years old to 98 years old. The breakdown on the number of clinical CT scans analysed for each examination on each scanner is shown in Table 1. Median (50th percentile), mean (average) and 75th percentile CTDIvol (mGy) and DLP (mGy.cm) values were calculated and determined for each CT protocol, according to ICRP recommendations.[(5)] The medians were taken as the institution DRLs and were compared with the other established countries' DRLs.

## RESULTS

The DRL for each examination are calculated and tabulated in Table 2. The mean, median ($50^{th}$ percentile) and $75^{th}$ percentile of the $CTDI_{vol}$ and DLP are also shown in Table 2. The obtained median DLPs for this study for CT Brain, CT Chest, CT Abdomen-Pelvis and CT KUB scans are 713 mGy.cm, 190 mGy.cm, 385 mGy.cm and 398 mGy.cm respectively. Expressed within the $75^{th}$ percentile, the obtained DRLs for this study for CT Brain, CT Chest, CT Abdomen-Pelvis and CT KUB scans are 803 mGy.cm, 301 mGy.cm, 551 mGy.cm and 535 mGy.cm respectively.

## DISCUSSION

While there is a lack of consistency in data collection across the CT DRL literature in terms of methodology, scan coverage, and image reconstruction algorithms, our obtained DLPs at the

75th percentile for head and body CT are notably lower than Japan, indicating differences in radiologists' preferences and the preferred scanning protocol in Japan based on clinical indications. For chest and abdomen-pelvis CT, SKH DLPs are approximately half of those of the United Kingdom and United States. This may be attributed to smaller patient habitus requiring shorter scan lengths in Singapore compared to the western countries The caveat when comparing our institutional local DRLs with that of any country-specific nationally established DRLs, is that differences in CT scanner tube age, clinical indication for the imaging examination and a diverse patient cohort across different states within any specific country is bound to affect the obtained DRL. Within the local Singaporean context, the results of this study in establishing institutional SKH CT DRL is comparable with the established institutional CT DRLs conducted by National University Hospital (NUH)[(6)] (Table 3).

Other than scan coverage, the use of image reconstruction algorithm may play a part in the overall lower CT DRL in SKH. Studies investigating dose reduction in CT examinations have largely agreed that IR algorithm has the ability to reduce image noise and enhance general image quality, indicating potential for dose reduction while preserving image quality. However, methodologies of these studies range from simulations in phantom studies to clinical studies using patient-based dosimetry which have discrepancies in sample sizes and hence contributing to differing extents of dose savings reported. Current literature also suggests dissimilar dose reduction for different anatomical region examined. This appears to be true when we compare the SKH institutional CT DRLs with the published CT DRLs, on the assumption where not all scanners involved in the published literature are equipped with IR algorithms.

During analysis, it was observed that the $CTDI_{vol}$ and DLP for CT KUB was marginally higher than that of CT Abdomen-Pelvis in SKH, which is unusual given the shorter scan length in CT KUB acquisition. Although the CT KUB DRL is comparable with international DRLs, this finding was communicated to the respective vendor application specialists, radiographer in-charge and the consultant radiologist.

The CT KUB protocol was later amended to a low-dose protocol to better tailor for its common indications which were mostly for urolithiasis, where high image noise will not obscure urinary stones that have high intrinsic contrast. The revised CT DRL for CT KUB will be reported in future publication during the next institutional CT DRL review. This further highlights the importance of CT DRL as an important quality improvement tool in radiology departments and its role in optimisation of radiation dose in the initial set up.

Although data on patients' height and weight were not available, we believe that the use of the relatively large sample size of 1706 examinations in this study is an accurate representation of average patient size corresponding to the median population dose within our demographic cohort analysed in this study. In future work, we will include data on patients' height and weight in order to better account for data outliers in the study.

This study has excluded the paediatric patient population, as we currently do not have a sufficiently large population size to conduct a similar study.

In conclusion, as a newly built hospital equipped with new CT scanners and the latest CT technology, SKH DoR requires a baseline CT DRL to provide a reference for radiology staff. CT protocols are regularly updated to improve both diagnostic quality of CT images and radiation dose reduction to patient as these are important factors to consider when changes are made to the scan parameters. This is especially critical since there is no national DRL at the point of writing in Singapore, with solely NUH's institutional CT DRL publication in local context.

Future research can attempt to establish DRLs specific to clinical indications, instead of broad anatomical classifications. This is crucial because heterogeneous examinations of the same anatomical region require varying image quality or coverage area specific to the clinical objective, affecting the resultant DRL values.[11,12] Hence, differentiating clinical indications can improve interpretability of results and facilitate specific comparisons across DRLs, benefitting follow-up improvements in optimising scan parameters.

Establishing institutional CT DRL values is a significant step to provide a platform for radiographers and radiologists to fine-tune their CT scan protocols. Initial SKH institutional DRLs for its four common CT examinations, established at the $50^{th}$ percentile, shall provide a benchmark for future institutional CT protocol optimization. The $75^{th}$ percentiles of the study were compared to the international DRLs demonstrates that the scan protocols are set up in line with international standards.

In this ever-changing time with constant technological advancements, it is essential to conduct a periodic review of our institutional DRLs in line with ALARA practices, while being aware of updates in practice standards. SKH DoR shall continue its current effort in routine equipment quality control, periodic review of imaging scan protocols and techniques to ensure ongoing CT dose management within the department.

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**Table 1. Number of clinical CT scans performed in each CT scanner.**

| CT Examination | Number of clinical CT scans | | | |
|---|---|---|---|---|
| | **Scanner A** | **Scanner B** | **Scanner C** | **Total** |
| Brain (Non-Contrast) | 70 | 195 | 135 | 400 |
| Chest (Contrast) | 83 | 33 | 225 | 341 |
| Abdomen-Pelvis (Contrast) | 109 | 244 | 348 | 701 |
| KUB (Non-Contrast) | 55 | 17 | 195 | 264 |
| **Total** | **317** | **489** | **903** | **1706** |

CT: computed tomography; KUB: kidney-ureter-bladder

**Table 2. Mean, median (50th percentile) and 75th percentile of $CTDI_{vol}$ and DLP for each examination.**

| CT Examination | Cases Collected | $CTDI_{vol}$ (mGy) | | | DLP (mGy.cm) | | |
|---|---|---|---|---|---|---|---|
| | | **Mean** | **Median ($50^{th}$)** | **$75^{th}$** | **Mean** | **Median ($50^{th}$)** | **$75^{th}$** |
| Brain | 400 | 38 | 39 | 41 | 718 | 713 | 803 |
| Chest | 341 | 6 | 5 | 9 | 226 | 190 | 301 |
| Abdomen- Pelvis | 701 | 9 | 8 | 11 | 437 | 385 | 551 |
| KUB | 264 | 9 | 9 | 12 | 420 | 398 | 535 |

CT: computed tomography; $CTDI_{vol}$: computed tomography dose index (volume); DLP: dose-length product; KUB: kidney-ureter-bladder

**Table 3. Local institutional Sengkang General Hospital (SKH) CT DRL compared to local institutional National University Hospital (NUH) DRL study and international DRLs (values are rounded off to the nearest whole number), at the $75^{th}$ percentile.**

| CT | DRLs | SKH | NUH(6) (2016) | Australia(7) (2018) | Japan(8) (2020) | Ireland(4) (2012) | UK(9) (2011) | USA (UCMC)(10) (2015) |
|---|---|---|---|---|---|---|---|---|
| Brain | $CTDI_{vol}$ (mGy) | 41 | 51 | 52 | 77 | 66/58 | 60/80 | 56 |
| | DLP (mGy.cm) | 803 | 1057 | 880 | 1350 | 940 | 970 | 962 |
| Chest | $CTDI_{vol}$ (mGy) | 9 | 7 | 10 | 16 | 9 | 12 | 17 |
| | DLP (mGy.cm) | 301 | 295 | 390 | 1200 | 390 | 610 | 610 |
| Abdomen-Pelvis | $CTDI_{vol}$ (mGy) | 11 | 12 | 13 | 18 | 12 | 15 | 17 |
| | DLP (mGy.cm) | 551 | 643 | 600 | 880 | 600 | 745 | 860 |
| KUB | $CTDI_{vol}$ (mGy) | 12 | - | 13 | - | - | 10 | 15 |
| | DLP (mGy.cm) | 535 | - | 600 | - | - | 460 | 705 |

CT: computed tomography; $CTDI_{vol}$: computed tomography dose index (volume); DLP: dose-length product; DRL: dose reference levels; KUB: kidney-ureter-bladder