CLINICAL INDICATIONS FOR DIAGNOSTIC REFERENCE LEVEL IN COMPUTED TOMOGRAPHY PROCEDURES

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Abstract— **Diagnostic reference level (DRL) is the investigation level used for optimization of protection in the medical exposure of patients. The DRL quantity is the value commonly and easily measured or determined radiation metric that assesses the amount of ionizing radiation used to perform a medical imaging task. The purpose of this study is to establish the local clinical indication based Diagnostic Reference Levels (LcDRLs) for the Computed Tomography (CT) procedures. Twelve CT procedures for 50 adult patients per procedure were acquired by 5 CT scanners. Both male and female patients age were 18 years old and over with the body weight ranged from 45 to 75 kg or the body mass index (BMI) ranged from 19 to 29 kg.m^{-2}. The twelve clinical indications selected were: 1. Head-trauma, stroke, infarction; 2. Head - tumor, infection, metastasis; 3. Sinus- sinusitis and polyps; 4. Cervical spine-trauma, herniation, degenerative disease; 5. Chest – unclear chest symptom; 6. Chest - follow up-metastasis, staging, tumor evaluation, dyspnea; 7. Chest -metastasis, staging, tumor evaluation, dyspnea, unclear symptom, first exam; 8. Chest CTPA - thrombus detection; 9. Chest HRCT – interstitial lung disease, bronchiectasis; 10. Cardiac – detection of calcified plaques and coronary vessels, calcium score non-contrast acquisitions; 11. Abdomen–detection, follow up of hepatocellular carcinoma, cholangio-carcinoma; 12. Abdomen/pelvis – detection of stone. The radiation metric, volume computed tomography dose index ($CTDI_{vol}$), dose–length product (DLP), total DLP, and scan length are recorded. The LcDRLs is set at the median values of the distribution of the data and 75th percentile of the distribution of the median quantity for national clinical indication diagnostic reference levels, NcDRLs. If the regional cDRLs are available, they should be set as the median values of the NDRLs values for the countries in the region. The LcDRLs of the CT procedures were established and compared to the NDRLs, and the gold standard of RDRLs, European Study on Clinical Diagnostic Reference Levels for X-ray Medical Imaging (EUCLID).**

Keywords— **clinical indications DRL, median, third quartile, optimization, CT procedures**

I. INTRODUCTION

Use of Computed Tomography (CT) scans has increased significantly due to their speed and accuracy in diagnosis, crucial for timely patient treatment [1-9]. However, the cost-effectiveness and appropriateness of the radiation exposure associated with CT scans, which tends to be higher than conventional X-ray examinations are questionable. Reports also highlight potential risks and hazards associated with the cumulative radiation exposure from all medical imaging procedures, which induce to cancer development in patients [10-15].

In the past, each medical institution has emphasized the importance of providing radiation doses with CT scans by setting dose levels according to anatomical-based diagnostic reference levels (DRLs), without considering individual patient conditions [16-20]. However, nowadays, several institutions recognize the significance of tailoring radiation doses according to specific clinical indications [21-24]. This approach leads to better outcomes for patients, as it ensures appropriate radiation doses while maintaining diagnostic efficacy. For instance, the urinary tract stones may necessitate focusing on specific disease areas that do not require higher radiation doses for accurate diagnosis. However, with advancements in technology and more sophisticated equipment, it is feasible to reduce radiation doses and compensate for examinations in certain disease areas, thus lowering patients' radiation exposure risk. It is worth noting that besides considering anatomical-based DRLs, determining radiation doses tailored to specific disease areas can maximize patient benefits and appropriateness of care.

DRLs are originally defined [18] for an anatomical location, with lacking information on the clinical indication and on the procedure. Such the information strengthens the significance of DRLs, as they correspond to a better specified setting and would ultimately provide a stronger tool for optimization and comparisons between centers or countries. Therefore, the definition of clinical indication-based diagnostic reference levels, cDRLs, should be a combination of disease and symptoms, anatomical location and of the used technique. The concept is applicable for CT examinations in Thailand. Twelve clinical indications were proposed according to the concepts. Identified parameters including the number of phases, scan and reconstruction techniques, protocol details, reference phantom size etc. were reported. The facility with radiation dose monitoring software collect the data of $CTDI_{vol}$, DLP per phase, total DLP and the scan length in order to establish cDRLs for those clinical indications. Patient size is selected from the body weight, 45-75 kg, or BMI, 19-29 kg.m^{-2} that is the standard size for Thai people. Optimization should be performed after the radiation dose reduction and the image quality assessment. The second clinical indication DRLs after the anatomical DRLs should be obtained and led to the establishment of the LcDRLs in Thailand.

II. MATERIALS AND METHODS

Study design and setting

The analytical, observational, retrospective study is conducted at Department of Radiology, King Chulalongkorn Memorial Hospital. The Institutional Review Board, Faculty of Medicine Chulalongkorn University approved the IRB No. 0891/65 COA No.0247/2023 title "Local and Clinical DRLs of Computed Tomography procedures at King Chulalongkorn Memorial Hospital". The data were included for diagnostic CT examinations from five CT scanners of adult patients aged 18 years and older between January 1, 2021 and December 31, 2022. The body sizes ranged from 45 to 75 kilograms (60±15 kg) or body mass index (BMI) 19-29 $kg.m^{-2}$. The examinations for research, surgical or interventional procedures, the hybrid systems i.e. PET/CT, SPECT/CT and for radiation oncology guidance were excluded.

Data from fifty adult patients were collected for each CT protocol. Total number of patients were 600. The radiation metric of volumetric computed tomography dose index, CTDIvol, in the unit of mGy, dose length product, DLP per phase (mGy.cm), total DLP (mGy.cm), and the scan length (cm) are collected to estimate the local cDRLs using the radiation dose monitoring software, Radimetrics™ Enterprise Platform (Bayer HealthCare, Whippany, NJ, USA) installed in 2017, current version 3.4.2. The anatomical-clinical indication based protocols are shown in Table 1.

Table 1 Twelve anatomical-clinical indication protocols with/without contrast and number of phases

Anatomy	NC/C	Clinical Indication	Phases
1. HEAD	NC	Trauma, Stroke, Infarction	1
2. HEAD	NC+C	Tumor, Infection, Metastasis	2
3. SINUS	NC	Sinusitis and polyps (Screening)	1
4. CERVICAL SPINE	NC	Trauma, herniation, degenerative disease	1
5. CHEST	NC	Unclear chest symptoms	1
6. CHEST	+C	Metastasis, tumor evaluation, Dyspnea, Unclear symptom) F/U	1
7. CHEST	NC+C	Metastasis, Staging, tumor evaluation, Dyspnea, Unclear chest symptom, 1st Exam	2
8. CHEST CTPA	+C	Thrombus detection	1
9. CHEST HRCT	NC	Interstitial lung disease, bronchiectasis	max 3
10. CARDIAC	NC	Detect calcified plaques and coronary vessels (Calcium score)	1
11. ABDOMEN	NC+C	Detection, F/U of HCC, Cholangio Carcinoma	max 4
12. ABDOMEN/ PELVIS	NC	Detection of stones	1

The national diagnostic reference levels, NDRLs Thailand, in diagnostic imaging-anatomical based, was established in 2021 by the Department of Medical Science, Ministry of Public Health, Thailand. The NDRLs of CT procedures –anatomical based, 75th percentile of CTDIvol and DLP is shown in table 2. In 2023, the updated NDRLs Thailand of CT procedures is shown in table 3.

Table 2 National Diagnostic Reference Level of CT procedures, 75th percentiles of CTDIvol and DLP, established in 2021 in Thailand

CT Procedures	CTDIvol (mGy)	DLP (mGy.cm)
Brain without contrast media	62	1028
Brain with contrast media	52	935
Chest without contrast media	18	417
Chest with contrast media	18	665
Whole abdomen without contrast media	18	717
Whole abdomen with contrast media	20	717

Table 3 National Diagnostic Reference Level of CT procedures, 75th percentiles of CTDIvol and DLP, established in 2023 in Thailand.

CT Procedures	CTDIvol (mGy)	DLP (mGy.cm)
Chest and whole abdomen, venous phase *	14.4	1001
Pulmonary artery (CTPA), arterial phase	12.7	495
Angiography of the whole aorta, arterial phase	12.2	860
Angiography of the thoracic aorta, arterial phase	12.2	490
Angiography of the abdominal aorta, arterial phase	13.8	667
Angiography for stroke fast track, arterial phase	26.2	1095
Urinary stone, non-contrast phase *RCRT	13.6	625
Angiography of coronary artery, arterial phase - Prospective gating	18.7	233
- Retrospective gating	60.2	976
Coronary artery, calcium scoring	6.2	85
Neck, venous phase	16.1	504
Upper abdomen, venous phase	34.3	548

III. RESULTS

In order to establish the local clinical indication diagnostic reference level, LcDRLs, the radiation metric data is statistical analyzed to obtain the 50th percentile (median) of CTDIvol (mGy), DLP (mGy.cm), total DLP (mGy.cm) and scan length (cm) from twelve CT anatomy (clinical indication) protocols with three hundred patient data as shown in Table 4.

Table 4 Establishment of the Local Clinical Indication DRL (KCMH) with 12 CT clinical protocols.

CT procedures: Anatomy (Clinical Indications)		CTDI (mGy)	DLP (mGy.cm)	Total DLP (mGy.cm)	Scan length (cm)
1.	HEAD (Trauma, Stroke, Infarction)	47	1011	1011	22
2.	HEAD (Tumors, Infection, Metastasis)	47	1033	2066	22
3.	SINUS (Sinusitis and polyps)	30	457	457	16
4.	CERVICAL SPINE (Trauma)	18	496	496	27
5.	CHEST (Interstitial Lung disease, Bronchiectasis)	9	373	373	40
6.	CHEST F/U exam (Metastasis, Staging)	9	381	381	41
7.	CHEST (Metastasis, Staging,1st Exam)	9	367	745	40
8.	CHEST (Thrombus detection)	12	389	389	34
9.	CHEST (Interstitial lung disease)			307	
	Axial Inspiration HRCT	1	29	-	30
	Helical Inspiration Chest	7	259	-	40
	Axial Expiration HRCT	0.6	17	-	28
10.	CARDIAC (Calcium score NC)	3	43	43	16
11.	ABDOMEN (Detection, F/U of HCC)	11	333	1325	31
12.	ABDOMEN/ PELVIS (Detection of Stones)	7	359	359	49

IV. DISCUSSION

The European Union, EU, has formally introduced the concept and the mandatory use of DRLs in every Member State since 1997. Most of the existing DRLs (independently of the imaging modality) have been established based on anatomical locations. However, some limitations of this approach were pointed out for computed tomography (CT) as, for the same anatomical location, one could have several clinical indications with consequently different protocols corresponding to different exposure levels. For example, chest CT could correspond to the work-up for pulmonary embolism, lung cancer, or even coronary calcium scoring, each of which requires corresponding image quality parameters and scan length, and hence should have different DRLs [5]. The concept was introduced to Thailand by the International Atomic Energy Agency Expert of the RAS 6088 in 2022. The project title is “Strengthening Education & Clinical Training Programmes for Medical Physicists” The local diagnostic reference level was established at King Chulalongkorn Memorial Hospital in 2023. (Table 4)

The European Study on Clinical Diagnostic Reference Levels for X-ray Medical Imaging, EUCLID, identified ten common clinical indications for undergoing CT protocols [3]. EUCLID category of “stroke” most closely aligns with a routine head CT performed to exclude hemorrhage, so brain perfusion scans and cerebrovascular CT angiograms were excluded.

Table 5 EUCLID: CT DRLs for ten clinical indications investigated in the survey. (2014)

Body region	EUCLID Clinical Indication	CTDIvol EUCLID	DLP (mGy.cm)	Total DLP (mGy.cm)	Scan Length (cm)
Head	Chronic sinusitis	11	188	211	16
	Stroke	48	807	1386	18
Neck	Cervical spine trauma	17	455	495	23
Chest	Coronary calcium scoring	4	72	81	17
	Lung cancer	8	348	628	47
	Pulmonary embolism	9	307	364	35
	Coronary CT angiography	25	415	459	17
Abdomen	Hepatocellular carcinoma	9	354	1273	37
	Colic/abdominal pain	8	436	480	48
	Appendicitis	9	498	874	49

The LcDRLs of King Chulalongkorn Memorial Hospital, KCMH, in table 4 is compared to the NDRL United States [24], which the 75th percentile of the distribution of the median has been used**.** In order to compare to the EU of regional, RcDRLs, the median values of the NDRLs values for the countries in the region has been used. [24]

Table 6 Median doses (50th percentile) for $CTDI_{vol}$ (mGy) and DLP (mGy.cm) in the EU and KCMH and (75th percentile) for United States (US), for $CTDI_{vol}$ (mGy) and DLP (mGy.cm)

Body region	EUCLID category	US (75th) $CTDI_{vol}$	EU (50th) $CTDI_{vol}$	KCMH (50th) $CTDI_{vol}$	US (75th) DLP	EU (50th) DLP	KCMH (50th) DLP
Head	Chronic sinusitis	26.9	17.6	30.1	446	265	457
	Stroke	56.2	37.8	46.9	1072	691	1011
Neck	Cervical spine trauma	24.1	11.3	18.1	609	256	496
Chest	Coronary calcium scoring	8.0	1.6	2.7	125	34	43
	Lung cancer	11.9	3.5	9.3	478	130	373
	Pulmonary embolism	14.9	3.7	12.2	594	138	389
	Coronary CT angiography	26.5	5.5	-	914	180	-
Abdomen	Hepatocellular carcinoma	12.5	6.9	10.9	1773	683	1325
	Colic/abdominal pain	12.6	6.9	-	645	325	-
	Appendicitis	14.5	8.9	-	880	433	-

$CTDI_{vol}$ and DLP of KCMH were highest for sinusitis. The rest of KCMH radiation metric were in between EU and US. The discrepancy among both DRL are according to the scan length, number of phase and CT parameters and this study was pilot study without optimization. In order to optimize the CT patient dose, the radiology team should plan to include the image quality to adjust the mentioned parameters to obtain the appropriate image quality with patient dose reduction.

Clinical indication of Diagnostic Reference Level is influenced by several factors such as image quality, scan length/collimation, number of phases/projections/images that affect patient dose. Different image quality is needed for different clinical indications of the same anatomical location. Kidney stone (high-contrast structures) evaluation, using lower radiation doses than appendicitis (low-contrast structures, high image noise).

In addition, the new technologies of CT machine have featured that aid in adjusting protocols to suit clinical conditions. For instance, in some diagnostic procedures, the dual energy technique can be utilized to generate Virtual Non-Contrast images instead of performing a true non-contrast phase. This approach can significantly reduce radiation exposure and enhance contrast enhancement at various energy levels, thus minimizing the need for repeated scans in cases where the scan does not align with the contrast phase or when patients have compromised kidney function and can only tolerate limited contrast injection. Moreover, these technologies can assist in diagnosing underlying conditions.

V. CONCLUSION

The established anatomical based of NDRL Thailand on CT protocols was in 2021 and 2023. The local clinical indication diagnostic reference level of 12 CT procedures has been introduced in 2022 and established in 2023 at King Chulalongkorn Memorial Hospital, Bangkok, Thailand. The median values of $CTDI_{vol}$, DLP per phase, total DLP and the scan length were calculated. Our results showed the highest $CTDI_{vol}$ and DLP for chronic sinusitis. The large number of phases and extensive scan lengths result in high total DLP values, Head 2066 mGy.cm. The comparison of our results to NDRLs US of 75th percentile and EUCLID RDRLs at 50th percentiles of similar categories shows that our results are lower than NDRL US but higher than EU except sinusitis. Three procedures of our results are not available – CTA, colic/abdominal pain and appendicitis. The factors influenced the radiation metric were the scan length, collimation, the number of phases, and CT parameters including the image quality. The optimization of radiation protection is planned for the patient dose reduction by adjustment of the CT protocols, and then revised the LcDRLs. The patient clinical indication is one of the most important factors for the dose optimization in CT procedures. There is a need to develop knowledge, skills and competences of health professionals involved on the use of CT equipment to improve the use of available dose reduction tools. More efforts are needed towards end user training on dose optimization.

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