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Consideration for Establishing a National System for Ensuring Radiation Protection and Safety in Diagnostic Radiology

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1. Introduction

Computed tomography(CT) is a powerful clinical tool for the diagnosis and management of patient, and its ability to provide high quality three-dimensional data has resulted in significant benefits to medical management, enabling faster and more accurate diagnosis and the avoidance of interventional surgical techniques. However, CT is associated with relatively high radiation doses, with corresponding increased risk of carcinogenesis. Therefore, sensible use of the modality requires strict adherence to the tenets of radiation protection - justification, optimization and minimization - to ensure that the risk to patients does not outweigh the benefit gained from the technique.

In the field of medical imaging, the radiation protection of the patients based on the basic principles of practice justification and dose optimization. Once an examination is justified, it must be performed with the most efficient balance between dose reduction and image quality upholding.

Diagnostic reference levels (DRLs) for imaging procedures was originally introduced by the International Commission of Radiation Protection (ICRP) in 1990 and further developed the concept with the guidelines in publication 73, 105 and ICRP Supporting Guideline 2; which is an important factor in dose optimization and radiation protection for patient. DRLs provide numerical values that act as a threshold that can readily be used to identify excessive radiation doses and prompt quality improvement. These levels, which are a form of investigation level, apply to an easily measured quantity, usually the absorbed dose in air, or in a tissue equivalent material at the surface of a simple standard phantom or representative patient. The DRL will be intended for use a simple test for identifying situation where the level of patient dose or administered activity is unusually high. If it is found that procedures are consistently causing the relevant DRL to be exceeded, there should be a local review of procedures and the equipment in order to determine whether the protection has been adequately optimized. If not, measure aimed at reduction of doses should be taken. DRLs are supplements to professional judgement and do not provide a dividing line between good and bad medicine. It is inappropriate to use them for regulatory or commercial purposes. DRLs apply to medical exposure, not to occupational and public exposure. Thus they have no link to dose limits or constraints.

The value should be selected by professional medical bodies and reviewed at intervals that represent a compromise between the necessary stability and the long-term changes in the observed dose distributions. The selected values will be specific to a county or region. DRLs are not the suggested or ideal dose for a particular procedure or an absolute upper limit for dose. Rather, they represent the dose level at which an investigation of the appropriateness of the dose should be initiated. In conjunction, with an image quality assessment, a qualified medical physicist should work with the radiologist and technologist to determine whether or not the required level of image quality could be attended at lower dose levels.

The use of CT for medical diagnosis has substantially increasing last 10 years in Mongolia. The objective of this study is consideration of establishing a national system for ensuring radiation protection and safety in diagnostic CT under the “Radiation Protection and Safety in Medical Uses of Ionizing Radiation” IAEA safety standards. In order to consider and establishing a national system at first, we were investigate and to analyze the system of DRLs from CT examination in United Kingdom, Japan, USA and Germany.

2. Diagnostic reference level

The DRL process is an effective tool for optimization of the protection in the medical exposure of patients. The DRL is used in various terms such as reference dose value, guidance level and patient dose recommendation. The DRL setting is based on the measurement and investigation of large-scale exposed doses such as the country and specific areas within the country. The DRL setting does not end with one-time period but needs to be periodically measured and investigated to update its value. Various radiation doses or related quantities have been used in the amount of reference levels. Details of the level, level and performance of reference levels are determined by the competent authorities of each country. Generally, considering the easiness of measurement of radiation dose, the absorbed dose for air kerma or tissue equivalents measured on the dose evaluation simulator or the patient's surface is used as the reference level.

In CT, published DRLs use CT dose index (CTDI)-based metrics such as weighed CTDI ($CTDI_w$), volume CTDI ($CTDI_{vol}$) and dose-length product (DLP). Published, normalized(eg, per 100mAs) CTDI values for different scanners may be used with typical technique factors (eg, tube current-time product, pitch), or CTDI value can be directly measured at typical technique factors to determine a site’s typical scanner output. For adult head examinations, sites were to calculate $CTDI_w$ and $CTDI_{vol}$, using the standard 16cm diameter poly-methal--methacrylate(PMMA) phantom placed in head holder. For adult abdominal examinations, $CTDI_w$ and $CTDI_{vol}$ were determined using the standard 32cm diameter PMMA phantom placed on the tabletop. For pediatric abdominal scans, $CTDI_w$ and $CTDI_{vol}$ were determined using the standard 16cm diameter PMMA phantom placed on the tabletop. For a single axial scan at the center of the phantom, exposure or air kerma measurements were recorded using a calibrated 100mm ionization chamber and electrometer.

The $CTDI_{100}$ at isocenter in milligrays was calculated for both center and edge position using previously described techniques.

The $CTDI_w$ was calculated in the spreadsheet using the equation.

$$CTDI_w = (1/3) \times CTDI_{100,center} + (2/3) \times CTDI_{100,edge}$$

Although $CTDI_w$ is an easily measured dose metric, it does not account for pitch, (ie, "gap or overlaps" in a helical scan). Volume $CTDI_{vol}$ quantifies scanner output for a specific scan protocol, taking into account pitch, which quantifies the table increment per consecutive rotation of the x-ray source. Volume CTDI was calculated in the spreadsheet using the equation.

$$CTDI_{vol} = CTDI_w/pitch$$

where, pitch is the ratio of the table increment per gantry rotation to the total nominal beam width.

The dose-length product (DLP) is used as a numerical value to represent the total energy given in the scan protocol. DLP refers to the total energy absorbed by the scan length, and DLP is different depending on the scan length even in the case of the same $CTDI_{vol}$. DLP calculation formula is as follows.

$$DLP = CTDI_{vol} \times L$$

2.1 United Kingdom

The United Kingdom is an developed country in the field of radiation health and has been conducting national surveys of radiation doses from patients in the 1980s. The UK first introduced guideline doses(precursors of DRLs) in 1989, and has developed the application of concept over the last 25 years(ICRP Publication 135). In 1992, a national protocol was set up to measure the patient's exposure dose and a national patient's dose database was established for systematic data collection. The UK Department of Health(HPA) is periodically recommending national patient dose recommendations by collecting patient dose information and analyzing the distribution. HPA is currently(now) part of the UK Public Health(PHE) and PHE is playing a role. In the UK, as a result of nationally administered patient dose control, the dose of patient radiation has been steady decreasing over the time(HPA 2012).

In the UK, the age of the patient and the type of CT scan were used as the reference level for diagnosis in 2003. For some test, the recommended dose for single detector CT and multiple detector CT was individually presented and the exposure level by multi-detector CT was more higher(NRPB 2005). After that, the DRL was reset by examining the radiation dose information of about 47000 patients based on 2011, and only the DRL by the multi-detector CT was presented(PHE2014). Patient radiation dose data collection was performed by using a questionnaires on standard protocols for the enemy. In the UK, DRL were set for children with high radiation sensitivity as well as for adults, the patients were classified as 0-1years old, 1-5 years old, 5years old or older because of their large changes in height and weight, respectively. In the table-1 and table-2 show the adults and pediatric DRL of UK in 2011, respectively.

Table-1 DRLs for adult CT examinations in the UK (2011)

Exam	$CTDI_{vol}$ (mGy)	DLP (mGy·cm)
Head(brain)	60	-
Cervical spine	28	600
Chest	12	610
Chest-high resolution	4	140
Chest/Abdomen/Pelvis	-	1000
CT Angiography(CTA)	15	1040
CT Pulmonary Angiography(CTPA)	13	440
Abdomen	14	910
Abdomen/Pelvis	15	745
Virtual colonoscopy	11	950
Kidney-ureters-bladder	10	460
Urogram	13	1150

Table-1 DRLs for pediatric CT examinations in the UK (2011)

Exam	Age	$CTDI_{vol}$ (mGy)	DLP (mGy·cm)
Head	<1y	25	350
	1-5y	40	650
	>5y	60	860

2.2 USA

Beginning in 2002, the American College of Radiology(ACR) CT Accreditation Program has required sites undergoing the accreditation process to measure and report $CTDI_w$ and $CTDI_{vol}$ for head and body CTDI phantoms. The typical acquisition parameters for site's adult head, pediatric abdoman and adult abdomen examinations were used to calculate $CTDI_w$ and $CTDI_{vol}$(McCollough et al 2010). Based on the results of actual patients surveyed nationwide in 2016, DRLs for 10 types of CT scans of adults were presented by patients size (Kanal et al 2017). Table-3 shows the DRLs for medium sized patients of United States in 2016.

Table-3 DRLs for adult CT examinations in the US (2016)

Exam	$CTDI_{vol}$ (mGy)	DLP (mGy·cm)
Head/Brain(no contrast)	56	962
Neck(contrast)	19	563
C-spine(contrast)	28	562
Chest(no contrast)	12	443
Chest(contrast)	13	469
Chest pulmonary arteries(contrast)	14	445
Abdomen/Pelvis(no contrast)	16	781

Abdomen/Pelvis(contrast)	15	755
Abdomen/Pelvis/Kidney(no contrast)	15	705
Chest/Abdomen/Pelvis (contrast)	15	947

2.3 Japan

The Japan Network for Research and Information on Medical Exposures (J-RIME) was established in 2010 with the cooperation of related academic societies. The purpose of the J-RIME is to collect data related to medical exposure (radiation dose and risk received by radiological procedures), to address the actual state of medical exposure in Japan and to construct a framework within Japan for appropriate protection from medical exposure based on international trends. The J-RIME has established the first DRLs of Japan in 2015 as a result of discussions with various experts, including physicians, radiological technologists and medical physicists, based on the results of the latest nationwide surveys conducted by liaison organizations of the J-RIME and advice from expert belonging to international bodies. Table-4 and table-5 show the CT DRLs for adults and children of Japan in 2015(Yoshiharu Yonekura et al 2015).

Table-4 DRLs for adult CT examinations in Japan (2015)

Exam	$CTDI_{vol}$ (mGy)	DLP (mGy·cm)
Brain	85	1350
Chest	15	550
Chest/Abdomen/Pelvis	18	1300
Abdomen/Pelvis	20	1000
Liver(multi-phase)	15	1800
Coronary CTA	90	1400

Table-5 DRLs for pediatric CT examinations in Japan (2015)

Exam	Age	$CTDI_{vol}$ (mGy)	DLP (mGy·cm)
Head	<1y 1-5y 6-10y	38 47 60	500 660 850
Chest	<1y 1-5y 6-10y	11(5.5) 14(7) 15(7.5)	210(105) 300(150) 410(205)
Abdomen	<1y 1-5y 6-10y	11(5.5) 16(8) 17(8.5)	220(110) 400(200) 530(265)

2.4 Germany

The initial values of the German DRLs in diagnostic radiology were proposed by an expert group of physicians and medical physicists chaired by Federal Office for Radiation Protection(BfS), including representatives of the professional medical societies. The DRLs were first published in August 2003. Since then, it has been recommended to establish the DRL for CT by revising the radiation regulations (DRLs in Europe 2007).

In Germany, 72 major hospitals surveyed patients for radiation doses in 2006. The based on findings, DRLs for 7 CT scans of adult patients were established (BfS2010). The pediatric DRL by CT was set through a national survey in 2005-2006(Galanski et al 2006). The survey was divided into 6 age groups (newborn, under 1 year old, 2-5 years old, 6-10 years old, 11-15 years old and 16 years old). Based on the survey data, the German real reference level was set in 2010. The CT DRL for 2016 was set based on the radiation dose information of CT surveyed nationwide in 2013 and 2014(BfS 2016). Table-6 and table-7 show the CT DRL for adults and children of Germany in 2016.

Table-6 DRLs for adult CT examinations in the Germany (2016)

Exam	$CTDI_{vol}$ (mGy)	DLP (mGy·cm)
Head	60	850
Sinus	8	90
Neck	15	330
C-spine	20	300
Chest	10	350
Chest/Upper abdomen	10	450
Upper abdomen	15	360
Abdomen/Pelvis	15	700
Chest/Abdomen/Pelvis	13	1000
Pelvis	10	260
L-spine	10	180

Table-7 DRLs for pediatric CT examinations in the Germany (2016)

Exam	Age	$CTDI_{vol}$ (mGy)	DLP (mGy·cm)
Head	3-12m 1-5y 5-10y 10-15y	30 35 50 55	300 450 650 800
Chest	0-3m <1y 1-5y 5-10y 10-15y	1 1.7 2.6 4 6.5	15 25 55 110 200
Abdomen	5-10y 10-15y	5 7	185 310

2.5 In Mongolia

This is the case of CT diagnostic examinations for which the DRL values proposed at the Australian and Korean levels are adopted in Department of Radiation Oncology, National Cancer Center of Mongolia.

Table-8 DRLs for adult CT examinations in the Department of Radiation Oncology, NCCM.

Exam	$CTDI_{vol}$ (mGy)	DLP (mGy·cm)
Head	42.97	173.16
Head/neck	38.73	1039.77
Chest	56.37	56.37
Breast	56.37	56.37
Abdomen	56.37	56.37
Pelvis	56.37	56.37
Upper limb	9.03	151.02
Lower limb	9.03	151.02

3. Discussion

The International Commission on Radiological Protection(ICRP) recommends the use of DRLs. The ICRP also recommends that the values should be selected by professional medical bodies, be reviewed at suitable intervals and be specific to a country or region. DRLs have proven to be a useful and valuable tool for optimisation of radiological protection in medical exposures of patients.

The use of CT scans increases worldwide and results in higher exposure to radiation than other tests. In order to manage the radiation dose of the patient by the diagnostic radiation test, each country sets the diagnostic reference level to reflect the medical condition.

The purpose of this study to establish national system for ensuring radiation protection and safety in diagnostic CT of Mongolia based on Department of Radiation Oncology, National Cancer Center of Mongolia. In order to achieve the our purpose we have to investigate and analyze the current status of diagnostic reference levels first.

Many developments and concepts to collect and use DRLs have already introduced in United Kingdom, Germany, USA and Japan. Diagnostic reference levels are set in each country various ways by depending on county condition such as country development, medical condition, age etc. The methods used to implement the DRLs, to inform and train the medical conditions are different for each country. Countries should try to develop concepts in order to implement and use DRLs to ensure patient doses are reduced as much as possible.

Mongolia is the relatively the small population and low number of hospitals compared to other developed countries. The small amount of CT using for diagnostic radiology, but nowadays it is increasing rapidly so we need to concern DRLs as soon as possible. This study is the first step to establishing national DRLs based one Department of Radiation Oncology, National Cancer Center of Mongolia.

3. Conclusions

The establishment of national or ragional DRL values requires surveys or registries of patients across a whole country or region, and should be co-ordinated by a national or regional organisation with support from national governments. This will require the provision of necessary resources. (ICRP publication 135, 2006).

DRLs that have been established in certain countries or regions are also periodically reviewed in accordance with changes in clinical and equipment. DRLs are a valuable tool to achieve patient dose reduction. However, the different approaches met in practice clearly include a need for harmonization.

In the recent years Mongolia is also facing a situation, the use of radiological examination is rapidly increasing. Because of this we need to set up national DRLs based on country conditions. DRLs give a direct link to patient doses and are an important tool to perform efficient dose management and optimize patient doses. In the future work, we will try to establish national system for ensuring radiation protection and safety in diagnostic CT and develop concepts in order to implement and use diagnostic reference level to ensure patient doses are reduced as much as possible.

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