NATIONAL DIAGNOSTIC REFERENCE LEVEL INITIATIVE FOR COMPUTED TOMOGRAPHY EXAMINATIONS IN KENYA

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Received 7 December 2014; revised 7 February 2015; accepted 18 February 2015

The purpose of this study was to estimate the computed tomography (CT) examination frequency, patient radiation exposure, effective doses and national diagnostic reference levels (NDRLs) associated with CT examinations in clinical practice. A structured questionnaire-type form was developed for recording examination frequency, scanning protocols and patient radiation exposure during CT procedures in fully equipped medical facilities across the country. The national annual number of CT examinations per 1000 people was estimated to be 3 procedures. The volume-weighted CT dose index, dose length product, effective dose and NDRLs were determined for 20 types of adult and paediatric CT examinations. Additionally, the CT annual collective effective dose and effective dose per capita were approximated. The radiation exposure during CT examinations was broadly distributed between the facilities that took part in the study. This calls for a need to develop and implement diagnostic reference levels as a standardisation and optimisation tool for the radiological protection of patients at all the CT facilities nationwide.

INTRODUCTION

The technological advances in computed tomography (CT) scanners have resulted in its recognition as a valuable diagnostic tool by many medical practitioners. Unlike conventional radiography, CT scanning leads to greater radiation exposure to patients resulting in it being the single imaging modality that contributes significantly to the collective effective dose⁽¹⁾. This radiation exposure to patients from CT examinations may in the long-term cause cancer^(2–6). The pervasiveness of CT as well as the emergence of new scanning techniques ranging from diagnostic to guided therapeutic procedures (drainage of fluid collections, pain therapy and embolisation) raises health concerns that require adequate justification and optimisation strategies⁽⁷⁾ especially for the developing world.

In Kenya, the number of CT scanners in direct medical use increased by over 80 % in the past decade⁽⁸⁾. Previous studies have shown that CT examinations were performed using manufacturer-prescribed protocols, resulting in multiphase protocols and inadequate professional effort geared towards developing local optimal conditions commensurate to specific patient needs and indication⁽⁹⁾. Because the country does not have well-established national radiation dose management strategies, the radiation exposure to patients is not adequately managed, creating a need for optimisation and patient dose monitoring, record keeping, analysis as well as tracking of the exposed individuals. The

dose quantities that characterise CT patient radiation exposure like volume CT dose index (mGy) and dose length product (mGy cm) that are currently displayed by CT scanners are not always recorded nor utilised to monitor optimisation of CT practice. This study was undertaken to demonstrate how operational data collection could be used to achieve a comprehensive review of CT imaging protocols that is both efficient and effective in the radiological protection of CT patients.

METHODOLOGY

CT examination frequency

In 2012, 30 CT facilities operating in the country were requested to participate on a voluntary basis in this study and in addition to fill an annual CT examination survey form supplied to all of them by the Department of Radiology at the Kenyatta National Hospital (A national referral, teaching and research hospital in Nairobi, Kenya). The survey data were received from 15 of the CT facilities representing 50 % coverage of all facilities in the country with respect to the 20 identified types of CT scanning procedures that were performed and are considered in the study.

Patient dose survey and assessment

A structured questionnaire (Table 1) was used to record both the patient information and the CT

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Table 1. Questionnaire for CT patient parameters and exposure factors.

Hospital/ClinicRoom No. /X-Ray TubeDate.....Form No.....

Patient Details				Please fill in as many of these columns as possible that are displayed on the CT scanner console. Total mAs recorded <i>includes</i> / <i>excludes</i> scanogram (delete as appropriate)												Scanner displayed values	
Exam type	DOB(d-mm-yy)	Height (cm)	Weight (kg)	kV	mA	mAs per rotation	Effective mAs	Rotation time (s)	Total mAs	Total scan time (s)	Dose modulation used Y/N	Scan length (Range) mm	Filter mode (Head, Body, S, M, L)	Acquisition slice setting (e.g. 4x5mm)	Pitch or increment	Total DLP (mGy.cm)	Mean CTDI (mGy)

Scanogram / topogram information for average protocol. If two projections are done routinely please note both sets of factors.

Projection	kV	mA	Typical Scan Length (mm)	Slice Width	Total mAs (just scanogram)	Number of scanograms / topograms per examination
A.P	120	50	240	2x1	240	

scanner radiation exposure parameters. Out of the 15 CT facilities (50 %) that participated and provided annual CT examination frequency, only 10 facilities (33 %) provided the requisite details, namely, scanner manufacturer and model, scan length, slice thickness/beam collimation, operating conditions, exposure factors and displayed patient doses.

The CT facilities that provided patient dose survey data had the clinical protocols validated for displayed dose measurements using T40027 CT head (16 cm diameter) and body (32 cm diameter) phantoms (PTW-Freiburg, Germany) with a calibrated Unfors Xi CTexternal detector instrument.

The validation of the routinely displayed dose measurements was calculated using Equations 1–4. The CT air kerma index ($CTDI_{100}$) in mGy mAs^{-1} for the head and body phantoms was estimated from Equation 1:

$$CTDI_{100} = \frac{1}{NT} \int_{-50 \text{ mm}}^{50 \text{ mm}} D(z) dz \quad (1)$$

where N is the number of the simultaneously acquired slices of nominal slice thickness T . $D(z)$ is the dose profile on the axis of rotation (z) multiplied by a correction factor for the CT probe. The weighted CT dose index ($CTDI_w$) in mGy mAs^{-1} was obtained using Equation 2. The $CTDI_w$ combines values measured at the centre ($CTDI_{100,c}$) and periphery ($CTDI_{100,p}$) of a standard CT dosimetry phantom for a particular tube current–exposure time product (mAs):

$$CTDI_w = \frac{1}{3} CTDI_{100,c} + \frac{2}{3} CTDI_{100,p} \quad (2)$$

The volume CT dose index ($CTDI_{vol}$) was obtained using Equation 3 in mGy per volume scanned:

$$CTDI_{vol} = CTDI_w \frac{N \times T}{I} \quad (3)$$

where I is the constant slice increment in mm per gantry axial rotation.

The CT dose length product (DLP) for axial and spiral scanning for a complete CT examination was estimated using Equation 4:

$$DLP = CTDI_{vol} \times \text{scan length} \quad (4)$$

where *scan length* is the product of the total number of serial or helical scans and the slice width. Effective dose (E) is estimated using Equation 5:

$$E = E_{DLP} \times DLP \quad (5)$$

where the DLP values calculated using Equation 4 were obtained from the questionnaire records, while appropriate region-specific normalised effective dose coefficients (E_{DLP}) values in mSv $mGy^{-1} cm^{-1}$ were obtained from the age- and sex-specific conversion factors in reference⁽¹⁰⁾ compared with the values obtained from dose coefficient factors in references⁽¹¹⁾ and⁽¹²⁾ for composite scans. Effective dose coefficients

or k -factors are used to convert DLP displayed on the CT console per examination to derive patient-effective doses. These effective dose conversion factors were derived from data averaged over many models of scanners thus being non-specific to a CT scanner. The mean effective dose per examination type was used to calculate the collective effective dose in CT. The annual collective effective dose (S) from the CT scanning examination patient population was determined for each age group as a product of mean effective dose and the total patient population per examination type⁽⁹⁾. As a guideline for good practice, the third quartile patient dose values for each age group examination procedure irrespective of the hospital or CT scanner model were determined and proposed as the initial national diagnostic reference levels (NDRLs) for each CT procedure. In the study, the effective dose according to age and gender categories was reported but not considered NDRLs because it is not a measurable dosimetry parameter.

RESULTS

CT examination frequency

The sum total of CT examinations in the country was over 112 000 (about 0.3 % of the total population at the time) and distributed as shown in Figure 1: 77 % adults (40 % male, 37 % female) and 23 % children (13 % male, 11 % female). In children, 99 % of CT examinations were found to be distributed as follows: brain (82 %), sinuses (9 %), abdomen (4 %) and chest (4 %). In adults, 89 % of the CT examinations were found to be distributed as follows: brain (48 %), chest (19 %), abdomen (13 %) and spine (9 %).

The analysed patient dose sample size of 3178 patients had the anatomical distribution as shown in Figure 2. The proportion of male CT brain patients was found to be 20 % higher than that of female patients, which was associated with more susceptibility to the motor vehicle accident trauma. The average weight for adults was found to be 69 kg for males and 71 kg for females, and respective gender weights for children were found to be 31 and 26 kg.

Patient dose survey and assessment

The national quality management level or index for the CT practice was determined to be fair and the least of all the quality management performance indicators that were considered⁽¹³⁾. Most facilities used manufacturer-installed scanning protocols without any facility optimisation efforts. Table 2 contains a summary of scanning techniques for the CT examinations of representative patients from the 33 % of the hospitals that took part in the study. Complex CT angiography examinations were performed by doctors using a standard technique in all the CT facilities.

The kVp values per examination type were generally consistent, but variations were observed with respect to mAs, slice thickness and pitch.

Table 3 indicates that the measured CTDI_{vol} and DLP on a phantom for head, chest and abdomen, clinical exposure parameters and measured results were within acceptance level when compared with the values displayed on the scanner console. Table 4 is a record of measured patient dose with respect to CTDI_{vol}, DLP and E for the CT procedures reported. The values were corrected based on the measurements shown in Table 3. The CTDI_{vol} for brain examinations were below the DRLs in the literature except for 0–1-year-old children that were 10 % above. The DLP and E values for adult lumbar spine examinations were 10 % below and 20 % above the DRLs, respectively. The mean patient dose lower than the DRLs was 50 % for CTDI_{vol}, 27 % for DLP and 11 % for effective dose. The CTDI_{vol} variations were attributed to the slice thickness in the scanning protocols employed, while for DLP, it was associated to the patient body region and scan length. The suboptimal protocols were associated with the operator errors (wrong protocol selection), acquisition errors and patient induced errors resulting in additional scanning as well as express use of manufacturer-provided CT protocols. In children, the DRLs in the literature covered 55 % of the procedures considered in this study, whereas for adults, the coverage was 26 %. In children, the results showed that 60, 40 and 20 % were below the DRLs for CTDI_{vol}, DLP and E , respectively. The figures for adults were 60, 20 and 20 %, respectively. In the study, the average collective dose per scanner was estimated to be 21 person-Sievert per year, which was larger than the 19 person-Sievert per year obtained in a previous study⁽⁸⁾. For the CT scanner, three examinations that delivered the largest collective effective dose to adults in decreasing order were abdomen, chest and brain. The corresponding examinations in children were brain, abdomen and chest.

DISCUSSION

Imaging techniques and patient doses

A CT image produces detailed clinical anatomical display of disease pathology or altered anatomy features but contributes significantly to radiation exposure to the patients. To achieve patient radiation protection in these examinations, it is essential to analyse the scanning protocols, optimise the exposure factors, assess patient dose and compare with other studies as well as reference levels^(14, 23, 24, 29, 33–36). Although the CT patient exposure factors in this study (Table 2) were similar to the European recommendations⁽²²⁾, large and varying radiation doses were observed in the examinations involving brain, chest and lumbar spine in adults performed with the default manufacturer-

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setting scanning protocols. The use of thin slices may have produced high-resolution images but at a cost of higher radiation dose to the patients (Table 4). Axial

scanning was the most frequently used method in adult brain scans. The tilted gantry was used by some facilities to reduce radiation dose to the radiosensitive lens

Figure 1. The frequency distribution of the year 2012 CT examinations and the total population in the country according to age and gender.

Figure 2. The distribution of CT examinations samples for patient dose assessment (the other examinations are neck and lumbar spine for children and pelvis, computed tomography angiograph aorta, cerebral angiography, liver, temporal bones, orbits, pulmonary angiography and coronary angiography for adults).

Table 2. Mean (range) clinically used exposure factors in the CT examinations.

Examination	N (age—y)	kVp		mAs		Rotation time		Slice thickness (mm)		Pitch	
		Mode	Range	Mode	Range	Mean	Range	Mode	Range	Mode	Range
Child											
Brain	120 (0–1)	120	100–130	200	110–415	0.8	0.4–1.5	5	2.5–5	0.44	0.44–2
	140 (2–5)	120	90–130	250	155–600	0.7	0.4–1.5	3	1–5	0.44	0.44–0.69
	254 (6–15)	120	80–130	155	155–500	0.8	0.3–1.5	5	1–5	0.52	0.44–0.69
Chest	10 (2–5)	120	120–130	170	29–177	1.1	0.7–1.5	5	1–5	1	0.78–1.5
	17 (6–15)	120	120–131	170	60–250	1	0.4–1.5	5	2–5	2	0.56–2
Abdomen	28 (3–15)	120	110–120	160	70–313	0.8	0.4–1	5	1–5	1	0.94–2
Sinuses	56 (2–15)	120	120–130	250	60–300	0.6	0.5–0.8	1	1–3	0.64	0.44–0.94
Lumbar spine	2 (0.5–11)	120	120–130	130	80–212	1	0.4–1.5	5	2–5	0.96	0.42–1.5
Neck	3 (3–12)	130	130–140	103	60–70	1	0.5–1.5	5	1–5	0.42	0.42
Adult											
Brain	1234 (16–100)	120	90–140	360	60–600	1.5	0.5–1.5	5	1–10	0.44	0.44–1.5
Chest	328 (16–97)	120	100–140	250	40–342	0.75	0.4–1.5	3	1.5–6	1	0.8–2.0
Abdomen	486 (16–100)	120	80–140	100	61–415	0.75	0.4–1.5	3	0.5–8	0.9	0.43–2.0
CTA renal	32 (20–79)	120	120	250	158–500	0.75	0.4–0.75	2	1–3	0.94	0.35–1.28
CT pyelogram	55 (24–84)	120	120	245	134–359	0.75	0.4–0.75	0.5	0.5–3	1	0.81–1.18
Facial bones	26 (16–49)	120	120	300	250–500	0.5	0.5–0.75	1	1	0.64	0.56–0.69
Sinuses	191 (16–84)	120	120–130	250	60–300	0.75	0.4–1	1	0.8–1	0.44	0.44–1
Lumbar spine	48 (23–79)	130	100–140	120	77–351	1	0.5–1.5	2	2–10	1.5	0.42–2.0
Neck	33 (23–70)	120	120–130	100	18–290	0.75	0.4–1.5	5	0.5–5	0.94	0.94–1.5
Pelvis	15 (22–83)	120	120–130	250	110–335	0.75	0.75–1	2	1–3	0.69	0.61–1.17
Cervical spine	37 (17–73)	120	120–140	235	90–462	0.75	0.5–1	2	1–2	0.42	0.42–1
Cerebral angio	10 (19–67)	120	120	300	300–569	0.75	0.75	0.5	0.3–2	0.92	0.2–0.92
Pulmonary angio	2 (33–38)	120	120	194	178–211	0.75	0.75	1	1	1.1	1.1
CTA entire aorta	11 (22–78)	120	120	230	174–287	0.75	0.75	1	1	1.1	1–1.1
BMD	23 (29–88)	120	120	200	200–250	0.75	0.75	0.5	0.5	0.64	0.64
Coronary angio	2 (78–80)	120	120	276	100–451	0.4	0.4	1	1	0.2	0.2
Liver	6 (37–63)	120	120	218	125–288	0.75	0.75	3	1.5–3	1	1–1.14
Orbits	4 (39–49)	120	120	300	250–400	0.5	0.5–0.8	0.5	0.3–0.5	0.64	0.6–0.7
Temporal bones	5 (16–52)	120	120–140	349	349	0.75	0.75	0.3	0.3	0.35	0.35

N = no. of patients.

CTA, computed tomography angiograph.

of the eye⁽³⁷⁾. The majority of the adult chest, abdomen and pelvis, as well as paediatric brain scans, were performed using the helical scanning method. The study showed inadequate use of the equipment-displayed dose measurement readout during patient scan. The patient-specific information generated from the imaging equipment console display system needs to be analysed when developing optimal radiation and indication specific scanning techniques for specific CT equipment.

In the overall, 60 % of volume CT dose index and 20 % of DLP were below the diagnostic reference levels in children cases. Twenty per cent of effective dose measurements were below the reported values for children in the literature (Table 4). The respective figures for adults were similar in proportion except for the DLP, which was 40 %. The $CTDI_{vol}$ values were indicative of the slice thickness selected that resulted in larger radiation output when compared with the values reported in the literature^(17, 16). Additionally, the larger $CTDI_{vol}$ values were attributed to the tube distance, beam filtrations and patient body size. The large DLP was attributed to the high $CTDI_{vol}$, equipment efficiency performance and the CT scanner technological level, type or model. The larger DLP and E dose values were associated to the human factors like scanning of longer body size attainable due to the fast CT scanning technique and the prolific use of manufacturer-specified scanning protocols^(7, 8, 38, 39) and the unavailability of radiologists to oversee justification and optimisation (most CT facilities had only one radiologist taking care of all the clinical reports of the imaging procedures within the facility). The 25–63 % large E values in paediatric examinations were attributed to the conversion factors used that took into consideration the children being radiosensitive, with longer life expectancy and higher radiation exposure from non-optimal CT technique on a small body size. Additionally, the prescribed head CT scans due to head trauma were done from the seventh cervical vertebra to the head vertex. Abdominal examinations constituted the largest contribution of the collective effective dose (52 %) in adults despite its low frequency (13 %) when compared with other CT examination procedures. Overall, the high portion of CT collective effective dose was linked to the increasing CT examinations and contrast enhancement studies. There was new CT angiography (pulmonary, coronary, renal, abdominal aorta, peripheral, carotid arteries, Circles of Willis) examinations including the bone mineral density (BMD) associated with diagnosis and follow-up of osteoporosis in aging patients. CT angiography examinations were generally performed with multiple series scans involving use of contrast media, employing a delayed serial scanning technique to visualise the renal function for any pathology or insufficiencies during contrast excretion. In the evaluation of patients with a high likelihood of malignant disease, radiation

dose was not a limiting factor as long as the ALARA (as low as reasonably achievable) principle was applied appropriately. Consequently, a similar split-bolus two- and three-phase CT angiography at an increased radiation dose level was justifiable for such patients.

By definition, the NDRL is the third quartile value of measured national patient dose distributions for a specific procedure, while the local diagnostic reference level (LDRL) is the mean patient dose for sampled patients at a specific CT facility or hospital radiological practice⁽⁴⁰⁾. Based on the findings of this study, it is recommended that the use of LDRLs is more effective for indication-specific patient dose management in low-resource countries with no well-established quality management systems. Developing countries exhibit centralised sites with specialised imaging facilities, radiologists and clinical consultants. Nationally, development and incorporation of patient dosimetry are critical in risk assessment and radiological protection of patients. CT scanning results in larger radiation dose exposure compared with other radiological imaging modalities, and therefore, there is need for a clinical indication-specific scanning protocol for dose optimisation.

CONCLUSION

The multi-factorial nature of optimisation in CT scanning requires relevant training in patient dosimetry among medical imaging professionals, automated display of patient parameters such as weight and radiation exposure and establishment of equipment efficiency performance standards. LDRLs could help facilities to address the optimisation of patient radiation dose during the rapid expansion and increasing kinds of CT examinations that are being performed. There is a need to establish customised CT facility optimisation strategies, justification and LDRLs specific to the facility performing the procedures. The CT annual collective effective dose and effective dose per capita were determined as 86 person-Sievert and 0.002 mSv in children, respectively. The equivalent values in adults are given as 682 person-Sievert and 0.02 mSv. The large patient radiation exposure in CT procedures at 30 % of all the CT facilities revealed an inconsistent pattern for optimisation of CT imaging protocols to adequately match the prevailing clinical conditions. A more comprehensive study on CT scanners should be conducted to cover all the CT scanners in use in the country to obtain a better understanding of their safe utilisation.

This study recommends the international community to lend support to developing countries to establish their national patient dosimetry and radiobiology database centres in order to manage and maintain medical exposure surveillance programmes, national X-ray examinations trends, patient dose assessment and regular X-ray equipment performance

Table 3. Comparison of measured and displayed CTDI_{vol} and DLP per CT scanner.

	Philips Brilliance 6			Philips Brilliance 64			Philips Brilliance 16			Philips Brilliance 16		
	Clinical head phantom	Clinical chest Body phantom	Clinical abdomen Body phantom	Clinical head phantom	Clinical chest Body phantom	Clinical abdomen Body phantom	Clinical head phantom	Clinical chest Body phantom	Clinical abdomen Body phantom	Clinical head phantom	Clinical chest Body phantom	Clinical abdomen Body phantom
Scan type: axial/helical (pitch)	Axial	Axial helix	Helical	Axial	Axial	Axial/helical	Axial	Axial	Helical	Axial helical	Axial helical	Axial helical
Technical factors												
Pitch	0.65	0.8	0.9	0.67	1	1.142	1	1	0.94	1	1	0.94
kVp	120	120	120	120	120	120	120	120	120	120	120	120
Time	1.5	0.75	0.75	0.75	0.5	0.75	1.5	0.75	0.75	1.14	0.53	0.8
mAs	415	250	250	399	226	312	600	200	250	399	249	300
Display FOV	200	300	300	210	350	339	250	300	375	171	325	325
Detector size	1.5	1.5	1.5	0.625	0.625	0.625	0.75	0.6	1.5	16	16	16
No. of detector rings	6	6	6	64	2	64	16	2	16	0.75	0.75	1.5
Scan time (sec)	7.5	3.2	2.9	3.5	0.5	2.5	1.8	0.75	3	1.8	0.75	3
Scan length (mm)	30.1	30.6	31.2	125.7	1.2	81	12	1.2	94.4	12	1.2	94.4
Mean measured dose (mGy)												
Central	17.3	3.4	3.6	42	0.2	11.6	9.6	0.2	7.6	12	0.2	0.4
North	15.8	5.9	6.7	45.3	0.5	21.5	11.9	0.3	14.7	14	0.7	0.7
East	18.7	7.4	8.4	44.4	0.4	18.5	10.4	0.3	14.1	12	0.6	1.1
South	21.2	6.6	7.8	43.9	0.3	22.1	9.4	0.3	15.8	12	0.5	1
West	19	5.7	7	45.1	0.4	22.8	10.8	0.3	17.4	13	0.6	1
Results												
CTDI _{vol} (mGy)—measured	62	17.7	19.8	51.7	27.3	19.4	85.7	20.8	14.5	77.6	21	24
CTDI _{vol} —displayed on console	65.6	20	20	51.1	34.1	20.2	91.3	20	17.6	65.6	20	20
CTDI _{vol} (meas.—display)—% diff.	−5.5	−11.5	−1.0	1.2	−19.9	−4.0	−6.1	4.0	−17.6	18.3	5.0	20.0
DLP (mGy cm)—measured	186.3	53.9	61.7	649.7	3.3	157.5	102.8	2.5	137	233	64	75
DLP—displayed on console	192.7	61	62.4	715	4.1	303	109.6	2.4	156	193	61	62
DLP (meas.—display)—% diff.	−3.3	−11.6	−1.1	−9.1	−19.5	−48.0	−6.2	4.2	−12.2	20.7	4.9	21.0

	Siemens Somatom Spirit			Philips Brilliance 40			Siemens Somatom Emotion 6			Siemens Emotion Duo		
	Clinical head phantom	Clinical chest Body phantom	Clinical abdomen Body phantom	Clinical head phantom	Clinical chest Body phantom	Clinical abdomen Body phantom	Clinical head phantom	Clinical chest Body phantom	Clinical abdomen Body phantom	Clinical head phantom	Clinical chest Body phantom	Clinical abdomen Body phantom
Phantom employed	Head phantom	Body phantom	Body phantom	Head phantom	Body phantom	Body phantom	Head phantom	Body phantom	Body phantom	Head phantom	Body phantom	Body phantom
Scan type: axial/helical(pitch)	Axial	Axial helix	Axial helix	Axial helix	Axial helix	Axial helix	Axial	Axial	Helical	Axial	Axial	Helical
<hr/>												
Technical factors												
Pitch	1	1.85	1.6	0.68	0.78	1.13	1	1	1	1	1	1
kVp	130	130	130	120	120	120	130	130	130	130	130	110
Time	1.5	1	1	0.75	0.75	0.75	1.5	0.8	0.8	1.5	2.4	1.8
mAs	220	78	100	300	244	196	250	122	100	260	40	70
Display FOV	200	358	359	171	363	363	200	350	350	200	350	350
Detector size	5	5	5	0.625	0.625	0.625	2	2	2	2.5	4	4
No. of detector rings	2	2	2	40	40	40	6	6	6	2	5	5
Scan time (sec)	1.5	6	9.1	3.9	3.5	2.5	3.4	2.3	2	1.5	2.4	1.8
Scan length (mm)	10	30	45.5	44.1	91.5	95.1	12	42.8	30	5	20	20
Mean measured dose (mGy)												
Central	3.8	2.1	2.7	29.2	7.6	6.4	6.2	3.2	4.9	2.6	0.8	0.57
North	4.1	3.9	5.7	34.7	19.9	11.2	8.3	6.6	5.8	3.3	1.25	1.27
East	4	4	4.9	33.3	17.1	10.8	6.7	6.1	5.7	3.2	1.29	1.36
South	4	4.5	4.2	29.8	12.6	15.6	6	4.9	7	3.6	1.28	1.52
West	4.2	4.3	5.5	31.7	13	11.7	5.6	5.6	5.7	3.1	1.38	1.21
Results												
CTDI _{vol} (mGy)—measured	39.6	6.3	8.9	35.6	18	10.9	54.2	14.4	18.8	61.7	5.6	5.4
CTDI _{vol} —displayed on console	42.1	7.4	9.5	40.9	17.1	13.7	58.8	14	13.2	59.7	4.5	4.7
CTDI _{vol} (meas.—display)—% diff.	−5.9	−14.9	−6.3	−13.0	5.3	−20.4	−7.8	2.9	42.4	3.4	24.4	14.9
DLP (mGy cm)—measured	42.1	35.5	40.6	156.9	164.8	103.2	65	61.5	56.3	29.9	11.2	11
DLP—displayed on console	42	39	48	154	153	130	71	57	55	35	13	15
DLP (meas.—display)—% diff.	0.2	−9.0	−15.4	1.9	7.7	−20.6	−8.5	7.9	2.4	−14.6	−13.8	−26.7

FOV, field of view.

Table 4. CT mean (range) patient dose values compared with DRLs.

Exam.	Age (y)	CTDI _{vol} (mGy)	NDRL (mGy)	DRL (mGy)	DLP in (mGy cm)	NDRL (mGy cm)	DRL (mGy cm)	E (mSv)	3Q (mSv)	3Q (mSv)	E values in literature
Child											
Brain	0–1	33 (16–66)	38	33 ⁽¹⁴⁾ , 20 ⁽¹⁵⁾ , 35 ⁽¹⁶⁾ , 31 ^(17,18)	739 (163–2959)	1005	390 ⁽¹⁴⁾ , 270 ^(15,16) , 333 ^(17,18) , 300 ⁽¹⁹⁾ , 820 ⁽²⁰⁾	4 (1–15)	6	3 ⁽¹⁶⁾	2.5 (1.8–3) ⁽¹⁶⁾ , a
	2–5	41 (7–91)	50	40 ⁽¹⁴⁾ , 30 ^(15,16) , 45 ⁽¹⁶⁾ , 47 ^(17,18)	1072 (135–3146)	1395	520 ⁽¹⁴⁾ , 420 ⁽¹⁵⁾ , 470 ⁽¹⁶⁾ , 374 ^(17,18) , 650 ⁽²¹⁾ , 600 ⁽¹⁹⁾ , 1000 ⁽²⁰⁾	4 (0.5–10)	5	1.9 ⁽¹⁶⁾	1.5 (1.1–1.9) ⁽¹⁶⁾ , a
	11–15	43 (14–760)	55	50 ⁽¹⁴⁾ , 40 ⁽¹⁵⁾ , 45, 65 ⁽¹⁶⁾	1113 (190–3052)	1608	710 ⁽¹⁴⁾ , 560c, 620 ⁽¹⁶⁾ , 975 ⁽²¹⁾ , 750 ⁽¹⁹⁾ , 1040 ⁽²⁰⁾	3 (0.5–9)	4	2 ⁽¹⁶⁾	1.6 (1.3–2) ⁽¹⁶⁾ , a
Chest	2–5	11 (1–12)	11	5.5 ⁽¹⁴⁾ , 8 ⁽¹⁵⁾ , 13 ⁽¹⁶⁾ , 12 ^(17,18)	189 (53–339)	215	110 ⁽¹⁴⁾ , 200 ⁽¹⁵⁾ , 230 ⁽¹⁶⁾ , 152 ^(17,18) , 336 ⁽²¹⁾ , 400 ⁽¹⁹⁾	4 (1–7)	6	4.1 ⁽¹⁶⁾	3.6 (2.1–4.1) ⁽¹⁶⁾ , a
	11–15	8 (2–19)	11	8.5 ⁽¹⁴⁾ , 10 ⁽¹⁵⁾ , 20 ⁽¹⁶⁾	363 (72–1069)	453	210 ⁽¹⁴⁾ , 220 ⁽¹⁵⁾ , 370 ⁽¹⁶⁾ , 578 ⁽²¹⁾ , 600 ⁽¹⁹⁾ , 250 ⁽¹⁹⁾	9 (1–32)	13	4.8 ⁽¹⁶⁾	3.9 (2.3–4.8) ⁽¹⁶⁾ , a
Abdomen	3–5	11 (4–22)	11	–	554 (163–1652)	765	–	9 (2–19)	11	–	–
Sinuses	2–15	29 (12–49)	38	–	468 (56–1475)	538	–	3 (0.3–8)	3	–	–
Lumbar spine	0.5–11	11 (5–22)	14	–	326 (125–702)	426	–	7 (3–16)	10	–	–
Neck	3–12	7 (2–12)	9	–	232 (54–422)	322	–	3.8 (0.8–7)	5	–	–
Adult											
Brain	16–100	55 (7–112)	61	65*, 100 ⁽¹⁶⁾ , #, 60 ⁽²²⁾ , 69 ⁽²³⁾ , 66 ⁽²⁴⁾	1274 (112–5101)	1612	1050 ⁽²²⁾ , 760 ^(25,16) , *, 930 ⁽¹⁶⁾ , #, 1120 ⁽²⁰⁾ , 1000 ⁽²⁶⁾ , 900 ^(27,28) , 1312 ⁽²³⁾ , 940 ⁽²⁴⁾	2 (0.2–10)	3	1.7 ⁽¹⁶⁾	2 (0.9–4) ⁽²⁹⁾ , 1.5 (1.2– 1.7) ⁽¹⁶⁾ , a, 1.5 ⁽²⁸⁾ , 1.7 ⁽²⁵⁾
Chest	16–97	14 (1–40)	19	10 ^(22,16) , *, 13 ⁽¹⁶⁾ , #, 15 ⁽²³⁾ , 11 ⁽²⁴⁾	709 (39–3467)	895	430*, 580 ⁽¹⁶⁾ , #, 650 ⁽²²⁾ , 580 ⁽²⁰⁾ , 400 ⁽²⁶⁾ , 520 ⁽²⁷⁾ , 250 ⁽²⁸⁾ , 190 ⁽²⁵⁾ , 569 ⁽²³⁾ , 390 ⁽²⁴⁾	10 (0.4–54)	13	6.9 ⁽¹⁶⁾	7 (4–18) ⁽²⁹⁾ , 5.8 (3.9– 6.9) ⁽¹⁶⁾ , a, 3.3, 4 ⁽²⁸⁾ , 3.5 ⁽²⁵⁾
Abdomen	16–100	14 (2–42)	20	13*, 14 ⁽¹⁶⁾ , #, 25 ⁽²²⁾ , 18 ⁽²³⁾	1340 (114–5666)	1842	460*, 470 ⁽¹⁶⁾ , #, 300 ⁽²⁸⁾ , 580 ⁽²⁵⁾ , 555 ⁽²³⁾	21 (2–88)	28	7.1 ⁽¹⁶⁾	8 (3–25) ⁽²⁹⁾ , 5.3 (2.6– 7.1) ⁽¹⁶⁾ , a, 3.2, 3.6 ⁽²⁸⁾ , 7 ⁽²⁵⁾
CTA renal	20–79	23 (9–76)	21	–	1476 (332–3765)	2040	–	23 (5–61)	32	–	15 ⁽²⁹⁾ , 12.3, 13.3 ⁽²⁸⁾
CT pyelogram	24–84	14 (6–25)	18	–	922 (218–2941)	1287	350 ⁽²⁸⁾	14 (3–51)	18	–	15 (9–19) ⁽³⁰⁾ , (25–35) ⁽³¹⁾ , 4, 4.4, 6 ⁽²⁸⁾
Facial bones	16–49	36 (19–76)	38	–	1013 (44–2432)	1169	–	2 (0.8–4)	2	–	–
Sinuses	16–84	33 (11–75)	41	–	550 (112–1840)	700	–	1 (0.2–4)	1	–	–
Lumbar spine	23–79	17 (6–43)	20	12*, 14 ⁽¹⁶⁾ , #, 15 ⁽²²⁾ , 42 ⁽²³⁾	582 (162–2261)	712	900 ⁽²²⁾ , 650 ^(16,28) , 680 ⁽²⁰⁾ , 400 ⁽²⁶⁾ , 720 ⁽²⁷⁾ , 300 ⁽²⁵⁾ , 888 ⁽²³⁾	9 (2–30)	12	8 ⁽¹⁶⁾	6 (1.5–10) ⁽²⁹⁾ , 7.1 (5.3–8) ⁽¹⁶⁾ , a, 6.8, 7.2 ⁽²⁸⁾ , 6.4 ⁽²⁵⁾
Neck	23–70	12 (5–20)	16	–	697 (153–1572)	1010	460 ⁽²²⁾ , 520 ⁽²⁰⁾ , 500 ⁽²⁶⁾	4 (0.8–8)	5	–	3 ⁽²⁹⁾
Pelvis	22–83	18 (6–24)	21	13*, 14 ⁽¹⁶⁾ , #	1257 (153–3464)	1928	570 ⁽²²⁾ , 510*, 560 ⁽¹⁶⁾ , #, 350 ⁽²⁰⁾ , 500 ⁽²⁶⁾ , 540 ⁽²⁷⁾	18 (2–54)	25	–	6 (3–10) ⁽²⁹⁾
Cervical spine	17–73	27 (6–72)	34	–	758 (172–1503)	1015	–	4 (0.9–8)	5	–	–
Cerebral angio	19–67	43 (30–55)	50	–	4076 (2479–5657)	4324	350 ⁽²⁸⁾	8 (4–10)	8	–	–

Pulmonary angio	33–38	13 (11–14)	–	623 (334–912)	767	250 ⁽²⁸⁾	12 (6–17)	14	15 (13–40) ⁽²⁹⁾ , 2.8, 3.4 ⁽²⁸⁾
CTA entire aorta	22–78	15 (11–19)	–	1931 (1083–3412)	2495	450 ⁽²⁸⁾	30 (11–63)	44	5.2, 5.7 ⁽²⁸⁾
BMD	29–88	16 (15–32)	–	422 (200–1047)	457	–	6.7 (3–14)	7	–
Coronary angio	78–80	18 (7–29)	61 ⁽²³⁾	423 (133–714)	568	1510 ⁽²⁰⁾ , 1000 ⁽²⁶⁾ , 1208 ⁽²³⁾	6 (2–10)	6	16 (5–32) ⁽²⁹⁾ , 6.4 ^b , 11 ⁽¹²⁾ , c
Liver	37–63	14 (8–19)	–	1734 (903–2602)	2197	460, 470 ⁽¹⁶⁾	19 (13–27)	23	15 ⁽²⁹⁾ , 5.9, 7.2 ⁽²⁸⁾
Orbits	39–49	38 (32–51)	–	1943 (1146–2730)	2258	–	4 (2–5)	4	–
Temporal bones	16–52	80 (78–84)	–	732 (391–1489)	766	–	2 (0.8–3)	2	–

CTA, computed tomography angiograph.

(–) Reference level not found.

^aDose range provided as mean(2Q–3Q).^b16 Slices.^c64 Slices.^qUsed DLP conversion factors and imaging performance assessment of computed tomography scanners dose calculator, respectively.

surveillance audits under the medical professional or national regulatory authority stewardship. Such a national programme will require a concerted effort from all stakeholders in the radiological practice, with the medical physicists playing the vital role in radiation exposure quantification, calibration checks of CT scanner measured dose values and patient radiation dose optimisation. The role of medical physicists in the optimisation, quality assurance and quality control of radiological equipment, especially CT scanners, is vital and needs to be adequately supported.

ACKNOWLEDGEMENTS

We sincerely thank the management and radiology staff of the CT facilities for accepting to participate in the International Atomic Energy Agency (IAEA) Project (RAF/9/033— *Strengthening Radiological Protection of Patient and Medical Exposure Control*) and making this study possible, and the IAEA for their support.

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