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A SURVEY OF COMPUTED TOMOGRAPHY IMAGING TECHNIQUES AND PATIENT DOSE IN KENYA
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J. S. WAMBANI, G. K. KORIR, E. G. ONDITI and I. K.KORIR

ABSTRACT

***Objectives*: To assess the level of patient dose in Computed Tomography examination in Kenya, compare with the international diagnostic reference levels and establish the initial national diagnostic reference levels.**
***Design*: The patient doses for brain, chest, abdomen and pelvis examinations were assessed using typical exposure factors on head and body dosimetry phantoms. A log normal graphical method was developed and used in deriving the initial national diagnostic reference levels for the two dose quantities.**
***Setting*: Twenty one representative Computed Tomography facilities at different hospitals and clinics.**
***Subjects*: A questionnaire method was developed and used in recording the scanning parameters for head, chest, abdomen and pelvis adult examinations at each facility.**
***Results*: The radiation exposure from Computed Tomography examinations was determined to be below the weighted Computed Tomography Dose Index (CTDIw) and Dose Length Product (DLP) reference levels by 90% and 62% respectively.**
***Conclusion*: The mean CTDIw measurements for the adult patients were below Diagnostic Reference levels (DRLs). The mean DLP values for adult patients in some examination were above DRLs, with large variations of up to a factor of eleven. This indicates the need for local optimised scanning protocols and use of local diagnostic reference level in order to reduce patient doses without affecting diagnostic image quality.**

INTRODUCTION

The advances in medical imaging technology and applications, has revolutionised medical care provision. Clinicians are relying more on radiation imaging for disease/pathology diagnosis and treatment follow up. In the United Kingdom, a more advanced country compared to Kenya, Computed Tomography (CT) scanners constitute 4% of medical devices and deliver more than 47% of the collective effective dose (1) from medical procedures. In the United States, 11 % of diagnostic radiological procedures are CT, contribute approximately 67% of the collective effective radiation dose from medical x-ray examinations (2). The first CT scanner for medical usage was installed in Kenya in 1986. The number has increased over the years to about thirty CT scanners recorded in 2009. These constituted 2% of all irradiating medical equipments in Kenya. Although, there has been an increase in the use of CT in medical diagnosis, Kenya has not generated patient dose data for patient protection hence the concern and initiation of this study. Additionally, there was unease from healthcare providers as well as imaging professionals on the lack of such crucial data towards patient radiation safety, adequacy of prevailing quality assurance and equipment performance. The Radiation Protection Act Cap 243 law of Kenya (3), unlike the International Basic Safety Standards, is not specific on how hospitals are to comply with the required quality and safety management programme.

Dose variation in CT examination is associated with the diverse manufacturers' protocols, different examination techniques, device performance versus aging and maintenance, not excluding the human factor. These factors have presented a daunting challenge to the optimisation of patient protection throughout the world. To address these issues, diverse initiatives from the International Commission on Radiological Protection (ICRP), the International Atomic Energy Agency (IAEA), United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) the European Commission (EC) and the International Electrotechnical Commission (IEC), have all recommended relevant initiatives aimed at promoting safety in medical exposures. Kenya participates in the IAEA Technical Cooperation project RAF/9/033: Strengthening Radiological Protection of Patients and Medical Exposure Control. The project main objective was to develop a national radiological quality control programme for patient safety in diagnostic and therapeutic procedures (4). The aim was to achieve a significant, sustainable and measurable radiation safety in the country. The Kenyatta National Hospital (KNH) which was the coordinating institution in the project was developing radiation safety management programme involving quality and safety improvement, standardised operating protocols, proper equipment performance assessment and local diagnostic reference levels (LDRLs).

The EC report 16262 recommends that DRLs be expressed in terms of quantities that are clearly defined, simple to measure and provide a meaningful indication of patient exposure and a consideration of the scanning protocols (5). These DRLs are not regulatory and their use should not inhibit the development of sound clinical practice (6). The professional use of DRLs, imaging guidelines and quality control programme has been demonstrated in developed countries (7). Imaging guidelines and radiation safety control programmes are in the development phase in Kenya. This study therefore forms the basis towards CT imaging guidelines and establishment of LDRLs.

The level of doses from CT examinations depends on the technique, equipment in use, clinical and physical characteristics of the patient. This study reports the first typical patient dose assessment in CT examination and a comparison with the international DRLs. The measurement of several CT -specific dose descriptors was performed. An effort was also made to derive the initial national diagnostic reference levels (NDRLs).

MATERIALS AND METHODS

A structured questionnaire-type form was used to record standard CT examination protocols for the four anatomical body regions: head, chest, abdomen and pelvis. The parameters of interest included scanner manufacturer and model, scan length, slice thickness/beam collimation, operating conditions, and exposure factors. In our next study, the typical imaging protocols at each facility will be subjected to objective image quality assessment pending the availability of relevant phantoms.

The frequency of a particular CT examination was determined as a percentage of the annual number of that examination and the total annual number of all CT examination. The manufacturers of the twenty one representative CT scanners were; Philips (19%), Siemens (48%), General Electric (29%) and Shimadzu (4%). They are located across the country and were installed between 1986 and 2007. Although axial scanning was the prevalent imaging technique, the technological capabilities of the CT scanners involved in the study were twelve single slice, two dual slice, six helical and one multislice. The patient dose was measured in accordance with EC guidelines using 16 cm diameter (head) phantom Model 76-414 or 32 cm diameter (body) phantom Model 76-414. At intervals, each phantom was strapped in place and moved into the scanning position following the laser light guides. The CT probe (model 6000-100) consisting of a pencil type ionisation chamber with sensitive length of 100 mm with calibration reference to the National Institute of Standards and Technology in the United States, was positioned at the central axis for the in-air measurements and inserted into each of the five cavities for phantom measurements. A connection was provided via a 2.5 meter cable to a Victoreen 4000M+ detector inside a lead shielded box. Three axial scans were made with the CT probe in each of the five cavities using the specific clinical exposure factors and the respective phantom. The normalised weighted Computerised Tomography Dose Index (nCTD1w) in mGy/mAs for each examination considered was estimated from CT Dose Index ($CTDI_{100}$) calculated from equation 1.

$$CTDI_{100} = \frac{1}{NT} \int_{-50}^{+50} D(Z)\, dz.. \quad \text{.....1}$$

where N is the number of tomographic sections, T is the nominal slice thickness. D (z) is the dose profile on the axis of rotation (z) multiplied by a conversion factor of 0.87 rad/R for exposure to a dose in air and the correction factor for the CT probe.

The normalised weighted CTDI ($_nCTDI_w$) in mGy/mAs was obtained using equation 2 for each examination.

$$ {}_{n}CTDI_{w} = \frac{1}{C}\left[\frac{1}{3}CTDI_{100c} + \frac{2}{3}CTDI_{100p}\right] \quad \text{.....2} $$

where C is mAs for a particular sequence, $CTDI_{100c}$ and $CTDI_{100p}$ are derived from equation 1, and D(z) is the average dose in the central cavity and peripheral cavities, respectively.

The weighted $CTDI_w$ was obtained for the four examinations using the following equations.

$$ CTDI_w = {}_{n}CTDI_w \times C \quad \text{.....3} $$

The DLP for axial and spiral scanning, were estimated using equation 4 and 5 respectively.

$$ DLP = \sum_{i}({}_{n}CTDI_w * T * N * C)_1 \quad \text{.....4} $$

$$ DLP = \sum_{i}({}_{n}CTDI_w * T * A * t)_1 \quad \text{.....5} $$

where i represents each scan sequence forming part of an examination, T is the nominal irradiated slice thickness (cm), A is the tube current (rmA) and t is the total acquisition time (s) for the sequence.

Effective dose (E) was estimated using equation 6.

$$ E = E_{DLP} \times DLP \quad \text{.....6} $$

where E_{DLP} are appropriate region-specific normalised effective dose coefficients in $mSv.mGy^{-1}.cm^{-1}$(5).

The measured $CTDI_w$ and DLP values per facility were compared to the EC and IAEA DRLs (5, 8) and the effective dose values compared with the published values in the literature (7). The collective effective dose (S) from the CT scanner patient population in one year was determined using equation 7.

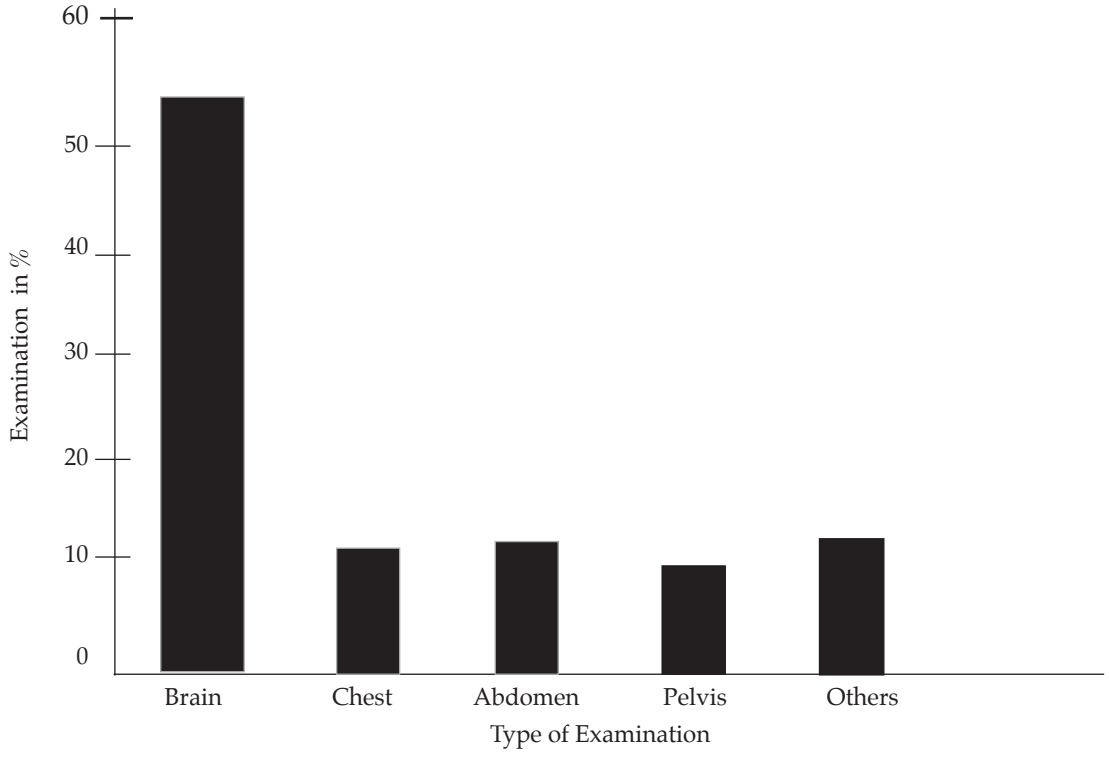
$$ S = \int^{1} \sum \bar{N}_i \times E_i \quad \text{.....7} $$

where N_i is the number of the individuals in a population subgroup i receiving mean effective dose of E_i within a period of one year (9). The third quartile values from the log normal curves (Figure 1) were considered as the initial NDRLs.

RESULTS

The scanner workload distribution from this study measured a first quartile of approximately 1900, a mean of 2600 and a third quartile of approximately 2900. Table 1 summarises techniques for the four CT examinations on representative adult patients. Table 2 indicates the CTDIw values for the CT procedures considered. The values were mostly below the DRLs, but with wide variation by factors as high as seven and eight for head and body examinations respectively. This indicates a need to review the

Figure 1
The percentage distribution of the year 2007 examination performed in Kenya



scanning parameters. A wide variation by factors of 11 and 9 is also observed for DLP values for head and body examinations respectively. These DLP variations indicate a need for optimization in accordance with the ALARA principle. Effective dose range estimates from this study are provided in Table 2. The range is approximately 0.2 mSv for brain to 29 mSv for an abdomen/pelvis examination. The reasons for DLP and effective dose variations were mainly due to differences in the CT scanning techniques and device performance. The scan lengths in Table 3 indicate diverse distribution of examination scan lengths associated to patient parameters.

Table 1

Clinically used exposure factors, and collimation for brain, chest, abdomen and pelvis examinations

	Tube Voltage (kVp)		Tube Current-time product (mAs)		Total Slices		Slice Thickness (mm)		Table Increment (mm)	
	Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*
Brain	130	110-250	249	100-405	43	30-64	7.5	2-10	7.5	2.5-10
Chest	125	110-140	181	80-392	55	40-84	8	2-10	8	2-10
Abdomen	130	110-250	209	100-495	61	40-80	9	5-10	9	5-15
Pelvis	125	110-140	225	100-496	42	25-80	9	5-10	9	5-12

Table 2

The measured dosimetric values for the examinations considered

Examination	CT Scan	*CTDIw(mGy)*	*DLP (mGy.cm)*	E(mSv)
Brain	Range	12-88	222-2470	0.2-5.5
	Mean	41	*1059*	2.5
Chest	Range	5-38	208-1500	3.5-25.5
	Mean	14	654	11.1
Abdomen	Range	6-38	218-1821	3.2-27.3
	Mean	18	843	12.6
Pelvis	Range	8-39	231-1237	4.4-23.5
	Mean	21	*702*	13.2
Abdomen/pelvis	Range	9-24	450-1950	6.8-29.2
	Mean	18	1182	18

The line-column in Figure 2 illustrates our graphical method of deriving NDRLs with respect to the distribution of CTDIw for the chest examination. The distribution is described typically log-normal, with few scanners having much greater CTDIw than others. The first quartile, the median, and the third quartile values of this distribution are 10 mGy, 14 mGy and 21 mGy respectively. Similar plots of the surveyed results showed the same log-normal distribution which was used to derive the specific NDRLs tabulated in Table 4.

Table 4 compares the initial NDRLs values from this survey, with values reported in the literature. The CTDIw results from this study are lower while DLP values are higher. The reason for this difference may in part be explained by the different methods used. Our results were calculated using measured dose values from dosimetry phantom and the average number of slices done for an average adult patient at each facility. Most of the values reported in the literature were derived from exposure parameters with an estimated scan length taken from the start and stop anatomical positions marked on the supplied survey forms.

Figure 2

The plot of the distribution of $CTDI_w$ for the chest examination, indicating long - normal distribution and the accumulating percentage of scanners with$CTDI_w$ below the DRL.

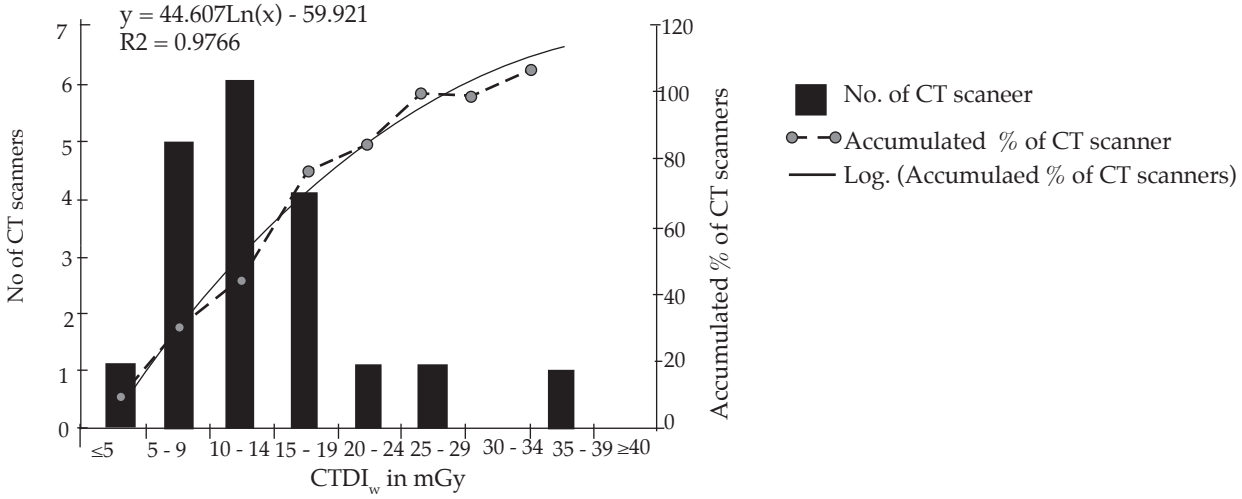


Table 3

Comparison between scan lengths cmof the four CT examinations in this study and the published values from other countries (10)

	Kenya (This study)			Tanzania			Greece			Italy		
Examination	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Head	7	48	31.4	13	28.4	21.1	13	15	14.3	8.9	18.6	12.9
Chest	10	84	49.1	31	97.5	55.8	17	25	20.7	12	31.9	23.3
Abdomen	24	80	57.0	40.7	12.9	70.4	8	25	22	12	31.4	22.7
Pelvis	20	80	50.0	38.5	86.4	61.4	15	23	20.4	9.9	23.5	16.9

Table 4

Diagnostic Reference Levels from Kenya as compared with other international values reported for single slice examinations

Procedure	This Study		IAEA CRP (11)		New Zealand 1992(12)		European Union 1999 (5)		UK 2003 (7)	
	$CTDI_w$	DLP	$CTDI_w$	DLP	$CTDI_w$	DLP	$CTDI_w$	DLP	$CTDI_w$	DLP
Head	51	1,364	47	527	-	1,050	60	1,050	55	760
Chest	21	745	9.5	447	-	700	30	650	13	430
Abdomen	21	1,143	10.9	696	-	-	**35**	**780**	**20**	**460**
Pelvis	24	943	-	-	-	-	**35**	**570**	-	-
Abdomen and pelvis	18^	1,1821^	-	-	-	1,470	25*	-	20	510

Dash (–) indicates values not available. ^Mean values *Reference 7

DISCUSSION

Number of CT Examinations in Kenya: Figure 1 indicates the distribution per examination as compared with the prevalent head examination. The 11 % other examinations consist of face and sinuses, chest high resolution computed tomography (HRCT), liver, spleen, and osseous pelvis. In consideration of the national population of about 40 million, the annual frequency in Kenya is estimated at two (2) per 1000 person population. In comparison, this rate is lower than the global rate of 16 persons per 1000 population and 57 persons per 1000 population in developed countries as presented in the ICRP 2000 report (13). However, the Kenya's rate is five times higher than Tanzania (10). This may be associated

with the relative availability or prevalence of the CT scanner services.

In this study, the average collective dose per scanner was determined as 19 man Sv per year. This value is lower than the 1994 regional survey result obtained for Wales (30 man Sv) and the 1989 national survey result (23 man Sv) for the U.K. (14). The measured collective dose per CT scanner is generally high due to the age of equipment and the use of inbuilt scanning protocols arbitrarily without taking into consideration the patient characteristics such as size or height. It may be indicative of the unavailability of alternative imaging modalities such as Magnetic Resonance Imaging (MRl) which numbers only eight in Kenya. Overall it is an indication of the lack of awareness of radiation safety in CT examinations, limited experience in justifying CT procedures among the clinicians and the need for training on customising imaging protocols. The CT scanner facilities involved in the study were informed about these findings.

Patient Doses

Imaging Techniques: Table 1 summarises techniques for the four CT examinations on representative adult patients. The prevalent kVp was 120 (49%) followed by 130 (41 %). A few facilities employed the use of less than 120 kVp or above 140 kVp. The lowest mAs values from the mean were 60 % for brain, 56 % for chest, 52 % for abdomen and 56 % for pelvis. The CTDIw measurements were generally consistent but the measured values obtained when using 130 kVp exhibited a broader range as compared to the values obtained using 120 kVp. The CTDIw consistency observed in the head phantom dose measurements when using 130 kVp makes it convenient for small body sizes characteristic of children. The majority of the CT scanners used the exposure factors reported by Huda *et aI*, in abdominal and chest examination (15). The display of high kVp and mAs values by the old CT scanners required a root cause analysis on the accuracy of the displayed exposure factors which was not possible at the time due to lack of quality control testing equipments.

Most of the CT facilities (79%) used slice thickness of (7-10) mm, similar to the European Guidelines values (4). A few facilities (16%) used 5 mm while the remainder of the facilities (5%) used less than 5 mm slice thickness. The CT scanners that applied thin slice thickness used expanded scan length combining abdomen and pelvis. The use of thin millimeter slice thickness improves the spatial resolution and permit high quality images due to low noise level but increased patient radiation dose. It allows three dimensional and multi planar reconstructions, which are used by orthodontists and orthopaedic surgeons in cases of skeletal trauma. The impact of the high radiation doses associated with expanded scan length imaging techniques was brought to the attention of the imaging professionals who were advised to optimise their protocols with the use of LDRLs. In developed countries, for example, the trends of dose following the introduction of multislice CT scanners has been reported to result in an average increase in effective dose to patients as compared with the currently prevalent single slice CT scanners (16). The introduction of multi detector CT (MDCT) in the country therefore opens the ground for superior CT applications and a concern for high patient doses. The CT scan manufacturers have introduced dose display on the control monitor and this auger well with our proposed recording and use of LDRLs for quality-assurance purposes and patient dose monitoring. The displayed patient dose together with the use of dosimetry phantom measurements will further enhance patient dose control, development of diagnostic imaging protocols and quality management systems. The optimisation strategies within each CT facility can therefore be comprehensive.

Table 3 indicates diverse distribution of the scan lengths in comparison to those in the literature. Although the pre-contrast number of slices was comparable with the reported values from Romania and Vietnam (7), the average scan lengths were higher than the IAEA reported values obtained from Greece and Italy (11) but lower than those reported for Tanzania. This difference could be due to the advanced pathology found in Kenya.

Dose Measurements: Table 3 summarises the measured dosimetric results with respect to a representative adult patient. The respective CT scanners that operated below the international CTDIw DRLs were as follows: brain 90%, chest 95%, abdomen 95%, and pelvis 89% . The respective lowest CTDIw values were 70% for brain, 64% for chest, 65% for abdomen and 60% for pelvis. The pattern is suggestive of the choice of mAs values used, generally distributed about the mean (Figure 2) but higher than the values reported in the literature (17). These differences are attributed to the technological difference between the CT scanners that participated in the study. However, the results support the potential optimisation due to standardisation of imaging protocols and use of LDRLs (18).

The respective DLP consistency with international DRLs was as follows: brain 85%, chest 94%, abdomen 30%, and pelvis 16%. Except for the chest examination, the measured ranges for all the examinations were broad even when compared with the results in the literature (19 - 21). The DLP results for the facilities that used the combined abdomen and pelvis scanning protocol (29%) were also higher than those reported in Canada by centers that used the same examination protocol (8). Overall, the high DLP values obtained need to be optimised with respect to the scanning

protocols, irradiated length, operator training and the pathological state of patients.

The effective dose assessment indicated the following number of facilities operating below the third quartile effective dose values in the study; brain 67%, chest 74%, abdomen 50% and pelvis 53%. The mean effective doses for this study were higher than the published values (22 - 24) but comparable with UNSCEAR results for the equivalent systems of healthcare (25). However, it is worthwhile noting that any multiple studies involving the same imaging protocol as well as expanding scanning region results in a higher radiation exposure.

Comparison with the Diagnostic Reference Levels: The dose variations in the measured values are associated with diverse device protocols, different standard examination techniques, device performance, equipment age and also maintenance and service conditions. The adoption of LDRLs can result in the optimisation of patient dose and image quality caused by the variations in imaging techniques. It will also promote comparison of patient dose and imaging technique between diagnostic CT facilities as shown in this study.

Table 4 consists of the initial CTDIw NDRLs as compared with those available in the literature. The derived values represent the measurements from the most used imaging protocols at each facility and were lower when compared with the respective international DRLs values. The larger international diagnostic reference levels will mean more CT scanners operating within the diagnostic reference level. Since the derived DRLs resulted from the imaging protocols used in local practice, they are suggestive of the state of the available CT scanners. Additionally the slope of the curve in (Figure 2) represents the relative number of scanners per unit interval of a diagnostic quantity considered. Although this study initiated an extensive data collection covering all examinations, these initial DRLs derived are restrictive indicating the possible optimisation. The derived DLP DRLs values (Table 4) were exception due to the post contrast sequence and axial scanning being the most prevalent imaging technique. It was also attributed to advanced pathology which requires post contrast scanning. An effort to lower these radiation exposure levels therefore must take into consideration the diagnostic information within the image quality. The European Guidelines has ideally demonstrated this goal by developing both anatomical image quality criteria and DRLs (4). If individual CT facilities follow such guideline, optimization of patient dose is inevitable. The four old generation CT scanners equipped with high pressure xenon detectors that performed poorly when this survey / study was being carried out have since been replaced by the much more efficient Multi-detector row (MDCT) with solid state detectors. Under these technologically emerging medical imaging practices, the optimisation of radiation protection is also catered for. The medical practitioners who are legally responsible for the imaging referrals must justify the practice to ensure that the vital diagnostic information is not compromised during the required optimisation process.

In conclusion a national survey of patient dose measurements was conducted to establish the initial national diagnostic reference levels and the state of CT practice in Kenya. The measured patient dose, couched in terms of the CTDIwand DLP are comparable with but generally higher than the reported values found in the literature. The radiation dose surveys have indicated that there is a large variation in the technical factors employed at different facilities subsequently resulting in large variation in the radiation doses to patients. A considerable optimisation potential of CT practice through the standardisation of imaging protocols was brought to the attention of each participating CT facility in the study. Although the high DLP and effective dose obtained in this study may be justified by the advanced pathological state of the patients, a recommendation was made to explore possible dose reduction measures; from the imaging techniques to manufacturer-provided dose reduction features as well as patient factors.

The derived DRLs are practical and useful indicators for promoting radiation protection in medical practice. The CT practice and patients safety can be assessed through the measurement or use of displayed CTDIw and DLP values for each examination. Extensive research into the complex relationship between radiation exposure, and diagnostic accuracy, at each facility can be initiated following our baseline data and the initial NDRLs. Adequate validation at the facility level can result in optimised protocols, establishing LDRLs and development of automatic exposure controls while collaborating with the CT scanner manufacturers and other stake holders.

The initiated optimisation process can be enhanced through a combination of training of imaging personnel, and the inclusion of patient dose criteria in the quality assurance standards to be developed. A coordinated effort and team-work between the few radiologists, imaging technologists, biomedical engineers and medical physicists must also be enhanced. When established, the use of LDRLs will become handy especially to the imaging professionals who will be able to maintain high standards of healthcare provision through compliance with imaging guidelines. These new guidelines will not be limited to specifying the quality control tests, frequencies, but will include Standards that consist

of patient dose forming an integral part of public health and safety.

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