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Paper

Entrance surface air kerma to patients during digital radiographic examinations in Tanzania

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Abstract

The aim of this study was to determine the entrance surface air kerma (ESAK) in adult patients during digital radiography and to evaluate the optimisation potential in five common X-ray examinations in Tanzania. Based on a sample of 240–610 patients, ESAK was estimated using X-ray tube output measurements, patient information and backscatter factors. The results show that the mean ESAK values were higher or comparable to data from the literature. The diagnostic reference values of ESAK for digital radiography were 0.31 mGy (chest PA), 4 mGy (lumbar spine AP), 5.4 mGy (lumbar spine LAT), 3.8 mGy (abdomen AP) and 2.4 mGy (pelvis AP). For computed radiography, the mean ESAK ranges were 0.44–0.57 mGy (thoracic AP), 3.59–3.72 mGy (lumbar spine AP), 6.16–6.35 mGy (lumbar spine LAT), 3.89–3.44 mGy (abdominal AP) and 2.92–3.47 mGy (pelvic AP). In conclusion, high ESAK variations show the potential for optimising protection in digital radiology.

Introduction

It is generally accepted that projection radiographs are a valuable tool in the diagnosis of disease and injury. In such examinations, the individual dose to the patient is generally small; however, they contribute significantly to the collective dose because they are performed frequently. Despite the considerable benefit to the patient, exposure to X-rays can cause harm[1]. Therefore, a systematic approach should be used to ensure that there is a justifiable balance between the resulting benefits and the associated risks[1]. Because of these risks, international basic safety standards recommend that once radiographic examinations are justified, optimisation of protection and safety should be ensured[2]. Optimisation in this sense means that patient radiation exposure should be limited to the minimum necessary to achieve the desired diagnostic or interventional objective[2].

As a contribution to optimisation, patient dose monitoring is a currently recommended approach to patient dose management to ensure safety in radiology departments and to achieve good practice[3, 4]. To design patient dose monitoring programs, it is necessary to collect baseline data on patient dose and image quality by performing the related extensive surveys. In this way, diagnostic reference levels (DRLs) can be established, which are an important tool to promote optimisation. Regular comparison of median patient dose with DRL values can help identify unusually high or low radiation doses[3, 5, 6]. There is evidence that such comparison has led to significant reductions in patient doses in many countries without compromising image quality[2, 3].

In Tanzania, there have been previous efforts to initiate the promotion of optimisation in diagnostic radiology in Tanzania. The results of some studies on general examinations of adult patients have been reported[7, 8]. A review of the results of these studies showed that variations in patient dose and image quality were common and optimisation needed. To continue this effort, the present study was initiated, further motivated by

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the lack of national or local DRLs[3] and the current wave of change in medical imaging technology in this country. Most conventional X-ray equipment has been replaced by digital imaging systems, and the transition is progressing nationwide. Therefore, a survey of doses with new imaging systems in the country was imperative, taking into account ongoing developments. The objective of this study was to determine the radiation exposure of adult patients during common X-ray examinations using digital imaging technology in Tanzania in terms of entry surface air kerma (ESAK).

Materials and methods

Hospital information

The study was conducted from July 2021 to August 2022 in nine hospitals in six different regions of Tanzania, inhabited by ~21% of the national population[9]. Information on the hospitals, all of which have referral status, is summarised in Tables 1 and 2. The hospitals were Aga Khan Medical Centre, Muhimbili National Hospital and TM Jafferji Hospital in Dar es Salaam region; Bugando Medical Centre in Mwanza region; and Mbeya Zonal Referral Hospital in Mbeya region. Other hospitals included Arusha Lutheran Medical Centre and Mount Meru Regional Referral Hospital in Arusha Region, Mnazi Mmoja Hospital in Mjini Magharibi Region and Ligula Regional Referral Hospital in Mtwara Region. With the exception of the Aga Khan, TMJ and Arusha Lutheran, which are private hospitals, and Bugando Hospital, which is a private hospital in partnership with the government, the remaining hospitals are public. The hospitals are hereafter referred to as Aga Khan, Muhimbili, TMJ, Bugando, Mbeya, Arusha, Mount Meru, Mnazi Mmoja and Ligula, respectively. Aga Khan, Muhimbili, Bugando and Mbeya hospitals serve ~0.24, 0.35, 0.65 and 1% of their regional distribution, respectively. The other hospitals, Ligula, Mount Meru, Mnazi Mmoja, Arusha and TMJ, serve 0.67, 0.5, 1.8, 0.39 and 0.08%, respectively (Tables 1 and 2). With a current national population of 61 741 120, the nine hospital radiology departments together serve ~0.15% of the population[9].

All clinical uses of the radiographic equipment were registered and approved by the relevant national authorities. The survey was approved by the ethics committee, and a quasi-experimental study design was used, allowing nonrandom sampling and data comparison, as has been applied elsewhere[10]. A total of 610 patients in digital radiography and 240 patients in computed radiography were recruited in the study. Twenty patients limited in size to 80 ± 10 kg weight for each radiographic projection at each hospital in six different regions participated in the study. The total number of patients varied from 99 to 135 per each X-ray projection for seven hospitals using digital radiography (DR) systems, while 20 patients were recruited in two hospitals using computed radiography (CR) system. Patients were recruited to the study when they consecutively appeared for radiographic examinations. In this way, the study design allowed application of the nonprobability sampling method to the selected population of patients of similar size at each hospital during the data collection period.

Two types of digital imaging systems (DR and CR) were used in this study. The performance of the exposure parameters of the devices was verified using the Raysafe x2 R/F solid-state dosemeter (serial number 290211) before the start of the study. The dosimetry equipment was manufactured by Ray Safe of Sweden and calibrated by Unifors Ray Safe AB laboratory of Sweden in April 2021. The expanded uncertainty determined by Raysafe x2 R/F with respect to air kerma, tube potential and time is 1.4%, 0.9% and 0.2%, respectively, with a coverage factor of 2, i.e. $k = 2$. The calibration is traceable to the Physikalisch-Technische Bundesanstalt in Germany. Parameters tested included tube potential accuracy, tube potential reproducibility, tube current and timer. The results of quality control in the range of 50–125 kV_p showed that the values of tube potential accuracy were ≤5% and the values of X-ray tube output linearity were ≤10%, and thus satisfactory performance[11]. All X-ray equipment, including CR, systems were operated with automatic exposure control (AEC), the function of which was subjectively tested as working or not working with or without a 4-cm-thick and 30 cm × 30 cm polymethylmethacrylate plate. The supplier thoroughly tested the performance of the AEC devices during equipment commissioning, which included brief user training for radiologists, radiographers and maintenance engineers.

X-Ray tube output measurements

The X-ray tube output values were obtained from air kerma measurements at constant focus detector distance (FDD) using the Raysafe x2 R/F solid-state dosemeter (serial number 290211) at specified tube potential (50–125 kV_p range) and constant tube current-time product (tube load). During measurements, the dosimetry equipment also generates half-value layer (HVL) and total filtration values for specified X-ray exposure parameters. Each X-ray tube output in mGy $mA.s^{-1}$, normalised to 1 m, was determined from the ratio of the measured dose to the applied tube load. The X-ray tube output, HVL and total filtration were later used to determine entrance surface air kerma (ESAK).

Table 1. Information of digital radiography and image detectors at hospitals.

Item	Hospitals						
	Aga Khan	**Bugando**	**Muhimbili**	**Mbeya**	**Ligula**	**Mount Meru**	**Mnazi Mmoja**
Regional population	5 383 728	3 699 872	5 383 728	2 343 754	1 634 947	2 356 255	272 091
Number of beds	172	1080	1500	860	200	371	712
Annual number of patients	13 000	24 000	19 000	24 000	11 000	12 000	5000
Manufacturer	Siemens	General Electric	Philips	Carestream	SITEC	Nanjing Perlove	Mindray
Model	Multifix Fusion Max	SVP-1	Philips 50	Ascend Carestream	Digi Rad-FP	PLX 6800 B	Dig Eye 760
Year of manufacturing	2019	2021	2018	2018	2020	2019	2015
Year of installation	2020	2022	2019	2019	2021	2019	2016
Detector details	Pixium 3543E2H, 160 μm pixel	iDR3543, 139 μm pixel	PaxScan 4336Wv, 139 μm pixel	DRXPlus 3543, 139 × 139 μm pixel	EVS 4343A/3643A, 140 μm pixel	DFP Mars1417V-TSI, 150 μm pixel	Fujifilm DR-ID 802SE, 150 μm pixel

Table 2. Information of computed radiography (CR) equipment and image detectors at hospitals.

Item	Hospital	
	Arusha	**TMJ**
Regional population	2 356 255	5 383 728
Number of beds	120	80
Annual number of X-ray patients	9151	4500
Manufacturer	Fujifilm Corporation	Siemens
Model	CR-IR 392	Multix Swing
Year of manufacturing	2018	2012
Year of installation	2019	2012
Detector details	FujiFilm ST-VI, 35 cm × 43 cm, 10 pixels/mm reading	Fujifilm A54224315C ST-VI, 35 cm × 43 cm, 10 pixels/mm reading

Patient and exposure information

A worksheet adapted from the International Code of practice in Diagnostic Radiology[12] was used to collect information for each patient and each type of radiographic projection. Information collected and recorded in the worksheet included patient weight, patient height and patient thickness. Other information included tube potential, tube current-time product, focus-skin distance (FSD) and focus-image-detector distance (FDS), which corresponds to focus-film distance. Patient thickness and FSD were measured at the examination position immediately before an X-ray exposure was activated. The radiographic projections considered in this study were chest posteroanterior (PA), lumbar spine anteroposterior (AP), lumbar spine lateral (LAT), abdomen AP and pelvis AP. Twenty patients were recruited for each of the radiographic projections studied. All patients recruited for this study were at least 18 years old and therefore adults. The weight range of the patients was limited to 60–90 kg. Patient and exposure data were recorded by radiographers; data are presented in Tables 3 and 4.

Radiation dose assessment

X-Ray output data were used to determine ESAK from collected patient exposure data. Interpolated values of the radiographic output data were performed when the selected clinical tube potential for the patient's radiographic examination did not match the measured values. ESAK values were determined from the tube output values and the collected patient exposure data using Equation 1.

$$ESAK = Tube\ output \times tube\ load \times \left(\frac{FDD}{FSD}\right)^2 \times BSF \quad (1)$$

Table 3. Patient and exposure information during digital radiography of adult patients.

Hospital	Examination	Weight		Height (cm)		Tube potential (kV)		Tube load (mA.s)		FSD (cm)		Patient thickness (cm)		FDD (cm)
		Med	Range	Med	Range	Med	Range	Med	Range	Med	Range	Med	Range	
Aga Khan	Chest PA	85	60–90	163	143–178	125	0	2.9	1–5.5	155.5	147–161	20	14–28	92
	LS AP	77	72–89	162	150–175	75	0	25.3	15–65	76.5	69–81	19	14–26	92
	LS LAT	80	61–89	162	147–175	81	75–90	27.9	22–65	72	68–78	24	17–27	92
	ABD AP	80	69–87	162	150–170	81	0	15.5	6–65	73	69–79	22	16–26	92
	Pelvis AP	73	60–84	164	147–170	75	0	15.1	3.8–29	77	70–80	18	15–25	92
Bugando	Chest PA	74	60–86	168	150–180	120	0	4	3.2–5	155.5	150–161	20	14–25	160
	ABD AP	73.5	61–87	167	162–179	80	70–85	53	45–63	76.5	74–79	19	16–21	94
	Pelvis AP	73.5	62–86	166	150–181	80	65–85	32	25–40	78.6	69–80	16	15–18	94
Muhimbili	Chest PA	70	60–89	152	120–180	125	0	1.63	1.2–2.5	120	115–129	25	16–30	130
	LS AP	65	60–78	152	122–180	77	77–95	14	8.9–30	56.5	48–62	24	18–32	100
	ABD AP	78	60–90	144	119–180	85	0	8.9	6.1–33	59.2	54–80	23	18–26	100
	Pelvis AP	82	60–90	150	120–180	80	77–80	11.7	7.2–29	57	52–62	24	18–28	100
Mbeya	Chest PA	70	61–94	167	151–182	110	0	1.7	1.4–4	122	105–130	23	15–40	150
	LS AP	69.8	60–85	166	162–175	80	80–85	16.4	8.8–21	73	66–79	22	16–29	100
	LS LAT	67.4	60–80	166	160–175	85	80–85	11	8–19.9	76	71–82	27	21–32	100
	ABD AP	71.2	60–84	166	135–160	80	70–80	12	14–20	75	63–77	24	18–32	100
	Pelvis AP	71.3	60–80	165	149–162	80	71–82	9.4	12–20	75	60–77	20	16–28	100
	Chest PA	66.9	60–73	155	110–165	73	0	5	3.2–8	126	129–149	21	15–22	60
	LS AP	62.8	60–74	164	150–170	80	70–80	58.5	34–80	75	77–85	19	15–23	60
	LS LAT	62.1	60–74	161	150–169	90	0	70	31–87	64	72–82	21	18–28	60
	ABD AP	63.7	60–70	160	151–188	76	0	25	10–80	75	79–82	19	18–21	60
	Pelvis AP	63.5	60–74	162	150–166	80	75–85	48	19–78	81.5	73–89	19	14–21	60
	Chest PA	65	60–90	157	100–172	73	65–0	10	8–12	126	119–145	19	17–26	80
	LS AP	61	60–85	157	140–173	85.4	70–115	23.5	19–28	72.7	67–76	20	19–28	80
	LS LAT	61	61–89	159	149–173	92.6	68–125	25	20–40	75	55–67	31	28–30	80
	ABD AP	60	62–90	154	140–170	79.5	65–125	22	18–30	64	69–78	22	17–26	80
	Pelvis AP	62	60–86	166	150–181	76.5	65–85	32	25–40	75	69–80	16	15–18	80
Ligula	Chest PA	67	60–78	162	144–176	105	105–120	0.6	0.4–2	122	105–130	23	15–32	80
	LS AP	75	60–80	157	153–162	72	70–85	23.5	20–28	73	66–79	22	16–29	80
	LS LAT	75	69–80	157	153–160	76	70–80	20	15–30	65	54–70	30	25–32	80
	ABD AP	70	60–84	154	135–160	77	70–80	16	14–20	72	63–77	23	18–32	80
	Pelvis AP	72	60–80	158	149–162	77	71–82	17.5	12–20	75	60–77	20	16–28	80

The examinations are indicated as chest PA, lumbar spine AP (LS AP), lumbar spine LAT (LS LAT), abdomen AP (ABD AP) and pelvis AP. FSD and FDD refer to focus to skin distance and focus to detector distance, respectively. Median is indicated as Med.

Table 4. Patient and exposure information during computed radiography of adult patients.

Hospital	Examination	Weight		Height (cm)		Tube potential (kV)		Tube load (mA.s)		FSD (cm)		Patient thickness (cm)		FDD (cm)
		Med	Range	Med	Range	Med	Range	Med	Range	Med	Range	Med	Range	
Arusha	Chest PA	70	60–90	172	150–180	77	70–88	10	5–12	125	129–145	20	16–26	70
	LS AP	77	60–90	175	100–187	76	70–80	25	16–30	83	65–75	24	20–30	70
	LS LAT	73	61–90	174	130–180	78	70–90	42	20–50	64	55–71	31	24–40	70
	ABD AP	77	89–90	171	160–192	75	65–82	23	12–40	72	63–77	23	18–32	70
	Pelvis AP	74	60–89	174	150–189	75	65–80	25	16–32	66.5	55–76	28	19–36	70
TMJ	Chest PA	67	61–80	154	137–183	79	75–83	10	6–20	119	114–131	22	13–27	70
	LS AP	74	62–80	159	148–179	77	70–81	35	22–73	83	80–89	22	16–25	70
	LS LAT	77	62–80	163	148–179	85	70–85	42	35–71	77.5	74–81	28	24–31	103
	ABD AP	70	62–80	160	149–171	81	77–85	33.5	27–40	84.5	69–88	21	17–36	103
	Pelvis AP	71	60–80	158	149–187	79	77–81	33.3	25–38	83.5	77–105	23	18–28	103

The examinations are indicated as chest PA, lumbar spine AP (LS AP), lumbar spine LAT (LS LAT), abdomen AP (ABD AP) and pelvis AP. FSD and FDD refer to focus to skin distance and focus to detector distance, respectively. Median is indicated as Med.

Here, *Tube output* is the normalised X-ray tube output at 1 m in mGy $mA.s^{-1}$, *tube load* is the tube current-time product in mA.s, FDD is the focus detector distance in cm, *FSD* is the focus-skin distance in cm and *BSF* is the backscatter factor determined in the literature[11]. The BSF depends on the size of the radiation field and the HVL and thus on the total filtration. The BSF used were 1.49 for the chest PA and 1.36 for the abdomen PA, lumbar spine AP or LAT, and pelvis AP, as used elsewhere[13].

Image quality assessment

Image quality was assessed by an experienced radiologist at each hospital based on the clinical image quality criteria for digital imaging systems established in Europe[14]. Radiologists did not evaluate each radiograph against each criterion but used their experience to assess whether the image was clearly accepted without remarks, accepted with some remarks but still useful for diagnosis, or should be rejected without providing further details. Thus, image quality was not assessed according to quantitative criteria, which is consistent with clinical practice in hospitals. It is clear that the relevance of this approach can be questioned, but in a developing country it is a fact that X-ray services must be provided for the benefit of patients. The assessment results showed that all radiographs reported in this work were of the required quality for diagnosis and were therefore reported to the requesting physicians.

Data analysis

The collected data were analysed by descriptive statistics using Microsoft Office Excel Data Sheet (Windows 10). The statistics included the median, range, maximum/minimum ratio and 75th percentile of the median values of patient information, exposure parameters and dose data. The DRLs were set as the third quartile of the median ESAK values for all hospitals[3]. The statistics were useful to understand the characteristics of the data analysed and to allow appropriate interpretation. Relative combined uncertainty was also estimated from the relevant actual data following literature methodology[12]. The results were compared with published values for similar radiographic studies. The results of this study could be used to establish local or national DRL values.

Results

Median ESAK values

The summary of patient and exposure data in the hospitals studied is presented in Tables 3 and 4. In general, it can be seen that the patients in each hospital weighed differently. This was to be expected since the size of the patients usually varies in the clinical situation. It can also be seen that X-ray exposure parameters varied, with both high tube potentials and high tube loads being used. Some hospitals maintained a constant tube potential throughout the study (Table 1). Apparently, some hospitals cannot be excluded from using parameters similar to those previously used for screen-film systems. The results of the ESAK values for the DR system are shown in Table 5. It can be seen that the ranges of median values for chest PA, lumbar spine AP, lumbar spine LAT, abdomen AP and pelvis AP are 0.1–0.82 mGy, 1.38–5.32 mGy, 3.24–7.7 mGy, 0.87–5.11 mGy and 0.85–5.6 mGy, respectively. Thus, the corresponding differences between hospitals are a factor of 8.2 (chest PA), 3.9 (lumbar spine AP), 2.4 (lumbar spine LAT), 5.9 (abdomen AP) and 6.6 (pelvic AP). The results also show that in most cases (19 of 32), the mean ESAK varied by more than a factor of 2 between hospitals. Table 6 shows the ESAK results for CR systems, where the median for chest PA, lumbar AP, lumbar LAT, abdomen AP and pelvis AP were 0.44–0.57 mGy, 3.59–3.72 mGy, 6.16–6.35 mGy, 3.39–3.44 mGy and 2.92–3.47 mGy, respectively. Because of the mutual influence, it is not easy to exclude differences or similarities of the ESAK values of the DR and CR systems.

The 75th percentile of ESAK values

The results of the 75th percentile values of the distribution of medians of ESAK for DR systems in seven hospitals are shown in Table 7. It can be seen that the values are 0.31 mGy (chest PA), 4 mGy (lumbar spine AP), 5.4 mGy (lumbar spine LAT), 3.8 mGy (abdomen AP) and 2.4 mGy (pelvis AP). The corresponding values for the CR technology were not determined due to limited statistical power, as only two hospitals used this technology. Nevertheless, the previously presented results of the systems from CR may be useful for establishing baseline values in hospitals and for relative comparisons with results from other studies.

Estimated uncertainty

Table 8 summarises the sources of uncertainty in the ESAK estimate for the DR and CR systems. The relative expanded uncertainty is estimated to be 13.5% ($k = 2$). The uncertainty does not include the influence of variations in patient size that may result from a limited patient sample. Therefore, the estimated uncertainty may be useful to compare ESAK results from other studies that do not consider the influence of patient size.

Table 5. Entrance surface air kerma (ESAK) to adult patients in digital radiography.

Hospital	Examination/ FDS (cm)	Median value						Max/min
		Weight (kg)	Height (cm)	Tube potential (kV)	Tube load (mA.s)	Patient thickness (cm)	ESAK (mGy)	
Aga Khan	Chest PA/180	85	163	125	2.9	20	0.21	5.3
	LS AP/100	77	162	75	25.3	19	3.13	3.4
	LS LAT/100	80	162	81	27.9	24	4.3	3.5
	ABD AP/100	80	162	81	15.5	22	4.27	10.5
	Pelvis AP/100	73	164	75	15.1	18	3.01	7.5
Bugando	Chest PA/180	74	168	120	4	20	0.17	3.1
	ABD AP/100	73.5	167	80	53	19	3.27	2.4
	Pelvis AP/100	73.5	166	80	32	16	1.7	2.8
Muhimbili	Chest PA/150	70	152	125	1.63	25	0.2	2.4
	LS AP/100	65	152	77	14	24	1.38	3.2
	ABD AP/100	78	144	85	8.9	23	0.87	5.2
	Pelvis AP/100	82	150	80	11.7	24	0.85	3.9
Mbeya	Chest PA/150	70	167	110	1.7	23	0.82	1.7
	LS AP/100	63.5	166	80	16.4	22	5.31	2.7
	LS LAT/100	65	166	85	11	27	3.41	3.5
	ABD AP/100	73	166	80	12	24	2.09	3.4
	Pelvis AP/100	73.5	165	80	9.4	20	2.78	2.8
Ligula	Chest PA/150	67	162	105	0.6	23	0.1	8.6
	LS AP/100	75	157	72	23.5	22	4.27	1.7
	LS LAT/100	75	157	76	20	30	7.7	2.1
	ABD AP/100	70	154	77	16	23	5.11	1.6
	Pelvis AP/100	72	158	77	17.5	20	5.6	3.5
Mnazi	Chest PA/150	65	155	110	5	18	0.17	3.1
Mmoja	LS AP/100	61	164	77	58.5	21	2.45	2.9
	LS LAT/100	61	161	85	70	19	3.24	2.7
	ABD AP/100	60	160	80	25	21	1.07	8.6
	Pelvis AP/100	62	162	75	48	19	1.71	4.8
Mount	Chest PA/150	77	157	73	10	19	0.43	1.7
Meru	LS AP/100	78	157	80	23.5	20	3.1	3
	LS LAT/100	74	159	90	25	31	5.4	1.5
	ABD AP/100	75	154	76	22	22	3	3.1
	Pelvis AP/100	73.5	166	80	32	16	1.7	2.8

The ratio of maximum to minimum ESAK is shown as max/min. The examinations are indicated as chest PA, lumbar spine AP (LS AP), lumbar spine LAT (LS LAT), abdomen AP (ABD AP) and pelvis AP. Focus detector distance is indicated as FDS along with the examination.

Discussion

It is well known that in diagnostic radiology, patient dose and image quality surveys are performed in many parts of the world as an approach to optimisation[2, 3, 6]. Comparisons between studies conducted in one country and in other countries can help to assess the degree of optimisation in each country. With this in mind, the results of the present study were compared with other studies to determine the level of optimisation in Tanzania (Tables 9–11). It can be seen that the results of this study are higher than those reported elsewhere when the maximum values in the ESAK ranges are taken into account. Differences in patient size and the exposure parameters chosen offer a possible explanation. Regardless of the quantity used (ESAK or entrance surface dose (ESD)), ESAK values are reported in CR systems (Table 10). The results of this study are also generally higher than data reported in the literature, including a previous study conducted in Tanzania[7]. The differences with previous studies in this country can largely be attributed to the replacement of radiology staff due to the ageing of the workforce and the fact that new equipment requires prior training of new staff. Comparison of the 75th percentile of median ESAK values (in mGy) in this study with diagnostic reference values in other countries (Table 11) shows that the results of this study are higher than values reported in Greece, Japan, Oman and the UK for chest PA[15, 21, 22, 23], but roughly comparable with data from the EU and Sudan for chest radiographic projection[6, 24]. The results for the other X-ray projections follow a mixed trend.

Table 6. Entrance surface air kerma (ESAK) to adult patients in computed radiography.

Hospital	Examination/ FDS (cm)	Median value						Max/min
		Weight (kg)	Height (cm)	Tube potential (kV)	Tube load (mA.s)	Patient thickness (cm)	ESAK (mGy)	
Arusha	Chest PA/150	70	172	77	10	20	0.44	3
	LS AP/100	77	175	76	25	24	3.59	2.6
	LS LAT/100	73	174	78	42	31	6.35	2.8
	ABD AP/100	77	171	75	23	23	3.44	3.9
	Pelvis AP/100	74	174	75	25	28	3.47	3.2
TMJ	Chest PA/146	67	154	79	10	22	0.57	2.4
	LS AP/110	74	159	77	35	22	3.72	4.1
	LS LAT/110	77	163	85	42	28	6.16	2.6
	ABD AP/110	70	160	81	33.5	21	3.39	2.4
	Pelvis AP/110	71	158	79	33.3	23	2.92	2.8

The ratio of maximum to minimum ESAK is shown as max/min. The examinations are indicated as chest PA, lumbar spine AP (LS AP), lumbar spine LAT (LS LAT), abdomen AP (ABD AP) and pelvis AP. Focus detector distance is indicated as FDS along with the examination.

Table 7. The 75th percentile values of median entrance surface air kerma (ESAK) to adult patients in digital radiography.

Examination	Number of patients/ exposures	Median value						Third quartile of ESAK (mGy)
		Weight (kg)	Height (cm)	Tube potential (kV)	Tube load (mA.s)	Patient thickness (cm)	ESAK range (mGy)	
Chest PA	119	70	162	115	2.33	20	0.1–0.82	0.31
LS AP	118	69	160	79	18.4	21	1.38–5.31	4
LS LAT	99	72	160	83	25	25.5	3.24–7.7	5.4
ABD AP	139	72.5	162	80	16	21	0.87–5.11	3.8
Pelvis AP	135	71.5	160	77	17	19	0.85–5.59	2.4

The examinations are indicated as chest PA, lumbar spine AP (LS AP), lumbar spine LAT (LS LAT), abdomen AP (ABD AP) and pelvis AP.

Table 8. Estimation of uncertainty.

Source of uncertainty	Uncertainty ($k = 1$) %
Measurement scenario[12]	6.3[12]
Precision of reading	1
Uncertainty in X-ray tube output measurement position	0.5
Uncertainty in backscatter factors	2
Uncertainty in focus-skin distance measurement	0.5
Uncertainty in patient thickness measurement	0.5
Relative combined uncertainty ($k = 1$)	6.74
Relative expanded uncertainty ($k = 2$)	13.5

The frequency with which some X-ray examinations are performed with possible repetitions is the main problem in radiation protection. This may be the case when these examinations result in poor image quality or/and when there are significant dose differences between X-ray rooms or between patients. In this study, image quality was rated as adequate by experienced radiologists. This is not surprising for DR systems since digital detectors allow a much wider exposure range than screen-film systems[14]. This feature is made possible by the automatic image density adjustment function with which the systems are equipped. Despite this feature, radiographers should be aware of the differences in techniques used with digital systems to avoid unnecessary increases in patient dose and therefore optimise their procedures. Evidence suggests that such optimisation measures can reduce patient dose without compromising image quality[25, 26].

Inter-hospital ESAK variations were observed, with most cases (19 of 32) exceeding a factor of 2. In some

Table 9. Comparison of median ESAK values of this study with literature values in digital radiography.

X-Ray projection	Median ESAK (mGy)				
	This study (range)	Greece[15]	Greece[16]	India[13]	Peru[17]
Chest PA	0.1–0.82	0.12	0.08	0.11	0.15
Lumbar spine AP	1.38–5.32	3.41	2.64	1.52	0.25
Lumbar spine LAT	3.24–7.7	4.83	3.69	7.76	—
Abdomen AP	0.97–5.11	1.75	1.77	0.9	—
Pelvis AP	0.85–5.6	2.17	1.14	0.82	—

Dash (—) means data not available.

Table 10. Comparison of ESAK values of this study (in mGy) with literature values in computed radiography.

X-Ray projection	This study (median)	Tanzania[7] (mean)	Sudan[18]	Italy[19]	Canada[20]
Chest PA	0.44–0.57	0.16–0.37	0.1–0.9	0.11	1.02
Lumbar spine AP	3.59–3.72	—	0.9–4.2	2.57	—
Lumbar spine LAT	6.16–6.35	—	2.6–16.4	5.41	—
Abdomen AP	3.39–3.44	2–6	—	2.47	5.24
Pelvis AP	2.92–3.47	—	1.1–3	1.84	4.78

All ESAK values are in mGy units. Results in references[18–20] are entrance surface doses. Dash (—) means data not available.

Table 11. Comparison of 75th percentile of median ESAK values (in mGy) of this study with diagnostic reference levels in other countries.

X-Ray projection	Present study	India[13]	Greece[15, 16]	Japan[21]	EC[6]	Oman[22]	UK[23]	Sudan[24]
Chest PA	0.31	0.13	0.14 [0.11]	0.22	0.3	0.2	0.15	0.28
Lumbar spine AP	4	0.17	5.16 [3.73]	3.46	7.4	3.8	5.7	2.2
Abdomen AP	3.8	7.77	2.59 [1.86]	2.26	5.1	1.6	4	0.94
Pelvis AP	2.4	1.2	2.96 [2.28]	2.28	5.5	2.3	4	1.9

For Greece, data are presented for reference[15] with data of reference[16] presented in square brackets.

cases, inter-hospital variations reached a factor of 5 to 10, e.g. 8.2 for chest PA (Table 5). This is mainly attributed to variations in factors affecting patient dose, including beam energy, filtering, collimation, patient size and imaging, as discussed extensively in the literature[3–6, 11, 14, 27]. Selection of radiographic exposure parameters and variations in equipment performance in matching these factors are amongst the main causes of patient dose variations observed in similar studies[12,14–20], and this study is no exception. In addition, calibration and evaluation of the AEC is also a possible cause for variations of ESAK values found in the same hospital. The results obtained in this study for the CR systems show higher ESAK values compared with a previous study conducted nearly 9 years ago in the same hospitals (Table 10). Change in staff and imaging equipment is a possible explanation. Almost all hospitals (except Arusha at the time of this study) now use digital radiography systems, and radiology departments have recruited new radiographers to replace staff who were working at that time. Therefore, continued strengthening of training and retraining programs is essential. This should take into account an appropriate combination of factors affecting image quality and patient dose, as well as equipment performance maintained through a standard quality control program[11]. There is also a need to strengthen enforcement of medical exposure regulations regarding the need to implement quality control programs, including regular patient dose monitoring and the use of DRL values. Experience from other countries has shown that regular comparison of evaluated patient doses with DRL values has resulted in optimisation of reduction of patient dose without compromising image quality[3]. In this study, the 75th percentile values (Table 7) are proposed as preliminary DRL values for the systems of DR because

most hospitals in the country are likely to be equipped with such systems in the future. The proposed DRL values are 0.31 mGy (chest PA), 4 mGy (lumbar spine AP), 5.4 mGy (lumbar spine LAT), 3.8 mGy (abdomen AP) and 2.4 mGy (pelvis AP). These values can be used as preliminary national DRL values if approved by the competent authorities. However, there is a need for further studies/information on the implementation of digital systems in the participating hospitals and the status of the local optimisation process in each hospital.

The relative expanded uncertainty associated with ESAK measurements was also estimated to be 13.5% ($k = 2$). If necessary, uncertainty should be considered when comparing median ESAK results between different studies. As mentioned earlier, uncertainty does not include the influence of variations in patient size that may result from a limited patient sample. Sutton *et al.*[27] have performed extensive studies of uncertainty due to limited patient size, and their results can be adapted using the uncertainty of dosimetry equipment and the patient sample size used in this study. The uncertainty due to the limited sample size of 20 patients was estimated to be 30%, assuming a field instrument uncertainty of 7% ($k = 2$)[27]. In this study, the calibration uncertainty of the Raysafe x2 R/F estimated by the Unifors Ray Safe AB laboratory is 5% ($k = 2$). Considering the number of patients in this study, the uncertainty can be conservatively assumed to be 30% because of the limited patient sample size. This additional uncertainty contribution should be taken into account when comparing clinical patient dose values to DRL values especially for audit purposes. Taking into account the influence of patient size, the relative expanded uncertainty associated with ESAK measurements in patients in this study is estimated to be 33% ($k = 2$). This should not be surprising as the instrument of a measurement uncertainty of ±7% would need ~600 patients to achieve a total expanded uncertainty of ±15%[27].

The results showed that the median ESAK values of this study are higher than the literature values obtained in Greece, India and Peru (Table 9), considering the maximum values in the ESAK ranges (Table 6). Regardless of the size used (ESAK or entrance surface dose (ESD)), the 75th percentile values obtained in this study are roughly comparable to the DRL values reported in Greece, Japan, the European Commission (EC), Oman, Sudan and the UK (Table 11). It should be noted that screen-film systems were used in the studies in EC, Sudan and the UK. Despite the usefulness of this study, there are three major limitations. First, the number of facilities included is not truly national representative, and the number of patients in each facility was also limited. More representative results could have been obtained with a larger number of facilities and patients. The use of a subjective approach to assess image quality was the second weakness, as there is no guarantee that some of the reported images were not of the required quality, as the subjective assessment may hide this information. The third weakness is the possible suboptimal performance of the AEC devices during the study because detailed AEC performance tests were not performed before the study and periodically between patient data collections. Although some subjective verification occurred before the study, mishaps cannot be ruled out because of the lack of initial and regular quantitative testing.

Conclusion

ESAK values for adult patients in five common radiographic projections in digital imaging systems were determined. In most cases, intra-hospital variations exceeded a factor of 2, and in some cases, they exceeded a factor of 5 to 10. The observed variations call for optimisation of the clinical practice of digital X-ray examinations in hospitals. In addition to the causes of ESAK variations, calibration and evaluation of AEC are also part of the issue for variations found in the same hospital. Preliminary national DRL values have been proposed to help optimise protection. However, there is a need for further studies on the implementation of digital systems in participating hospitals and the local optimisation process in each hospital. Overall, the results of this study have provided experience on patient doses during common X-ray examinations using digital technology in Tanzania. It is expected that the information on patient doses will help to sensitise radiology staff on the optimisation and application of national DRL values, thus contributing to the improvement of patient protection programs. The study could familiarise staff with the proper use of exposure parameters in common X-ray examinations using digital technology in Tanzania during the current transition.

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