Session 2

Radiation protection of patients and staff in diagnostic radiography, fluoroscopy and CT

EVALUATION OF THE IMPLEMENTATION OF RADIOPROTECTION MEASURES FOR WORKERS IN RADIOLOGY SERVICES IN TOGO

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Abstract

Review the implementation of the practical radiation protection measures of the workers against harmful effects of ionizing radiations in radiology services of Togo. Sixty-two services of radiology were listed; 27.4 % of them had surfaces of rooms between 10-20 m ² and 87.6 % had full brick-built walls. Forty-two services (67.7 %) possessed wooden doors and 20 aluminum doors (32.3 %), 59 doors (95.2 %) were filled. The majority (64.5 %) defined a checked zone and 61.2 % of them indicated a public zone. More than half (56.4 %) services had a pictogram, 51.6 % had a bright signaling in the entrance of rooms and 09.7 % showed regulations of checked zone; 58.1 % of services had endowed their staff of a categorization and 33.9 % arranged dosimeters to their staff. Medical supervision of the staff was made in 08.1 % of the services and 3.2 % had an individual medical record to their staff. The majority of them 93.5 % possessed of hindered aprons. Insufficiency in the protection of the workers are connected to the absence of a process of authorization and inspection in the country. The creation of regulatory body is then a necessity.

1. INTRODUCTION

Medical applications of Ionizing Radiation (IR) have been an essential factor in the advancement of medicine over the past century. These medical applications are subdivided into diagnostic (radiodiagnostic and nuclear medicine) and therapeutic (radiotherapy) applications, and are dominated by radiodiagnosis, which is widely used in both developed and developing countries [1-3]. However, the benefits associated with the medical use of ionizing radiation should not obscure the potential risks of deleterious effects that can result from their uncontrolled uses. These risks, which are expressed by deterministic and stochastic induced radio-induced injuries, impose protective measures not only on workers and patients but also on the public [4]. All the measures taken to ensure the protection of humans and their environment against the harmful effects of ionizing radiation thus define radioprotection.

Implementation of radioprotection measures for workers requires compliance with the standards for the development of radiological installations and the medical management of staff working in services using IR [6].

The increasingly rampant installation of radiology services in our country Togo and the absence of an IR regulatory authority has motivated this work, whose overall objective was to evaluate the implementation of practical radiation protection measures of workers in radiology services in Togo.

2. METHODS

It is a descriptive cross-sectional study conducted from June 6th to September 20th, 2014. The data was collected in healthcare facilities throughout the six economic regions of the country which are Lome-Commune (Lome and its suburbs), Region Maritime, Region des Plateau, Region Centrale, Region de le Kara, and Region des Savanes. Togo is a small country located in West-Africa. The area of the country is 56,600 km^2. The population of the country is estimated to be six million. To be eligible for this study, the healthcare facility should have a service of radiodiagnostic. Healthcare facilities that have X-ray generator but are not using it for a diagnosis purpose are not included into the study.

The parameters analyzed were:

- General characteristics of services

- Standards for the development of radiological installations.

- Medical management of human resources in services.

These parameters were used to develop the survey form.

The data were analyzed and processed using the statistical software "Sphinx 5.3.1." The qualitative data was processed with Microsoft Word 2013 and the graphs were performed with Microsoft Excel 2013. The results were tested by the Chi-square test. Any difference less than 0.05 was consideredsignificant.

3. RESULTS

3.1. General characteristics of radiology services

Sixty-two radiology departments were counted throughout the country with more than half of them in the health region of Lomé Commune (Fig 1).

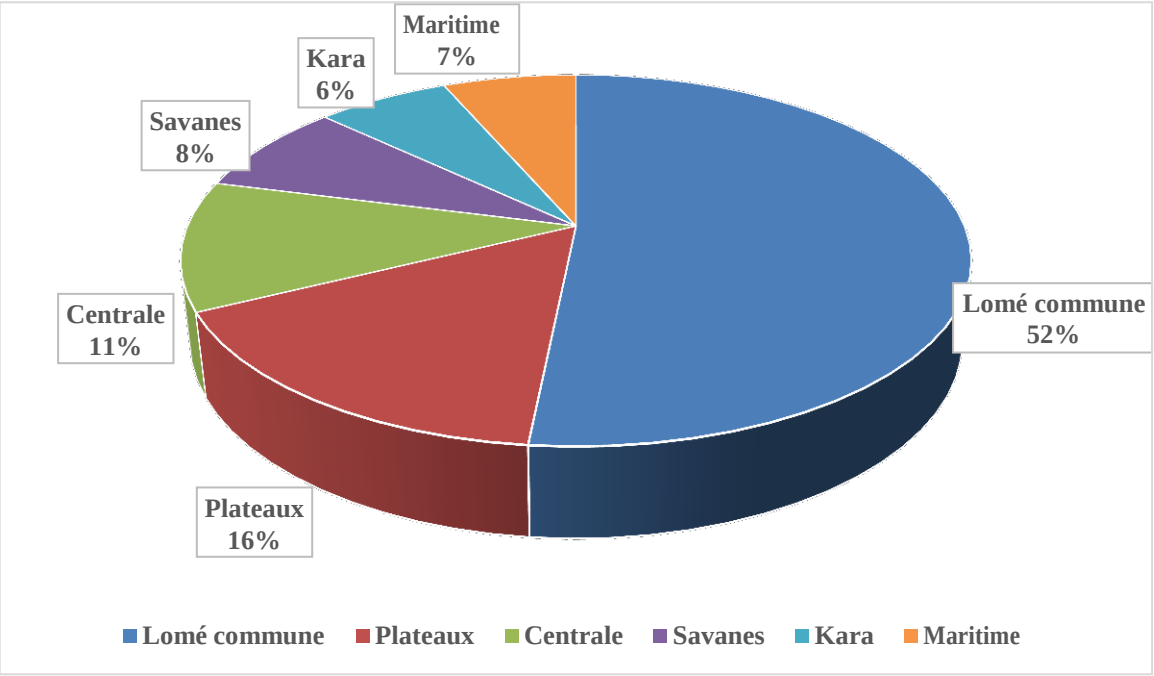

FIG 1: Distribution of radiology services according to health regions

Three radiology departments were in teaching hospital (4.8%), six were in regional hospitals (9.7%), fourteen were in prefectural hospitals (22.6%), and thirty-five in private healthcare facilities (61.7%).

Table I shows the distribution of services according to their seniority and health regions.

TABLE I: DISTRIBUTION OF RADIOLOGY SERVICES BY YEAR OF ESTABLISHMENT ACCORDING TO HEALTH REGIONS.

	Before 1980		1981-1990		1991-2000		2001-2010		After 2010	
	n	%	n	%	n	%	n	%	n	%
Savanes (n=5)	03	60.0	00	00.0	00	00.0	00	00.0	02	40.0
Kara (n=4)	02	50.0	00	00.0	01	25.0	01	25.0	00	00.0
Centrale (n=7)	02	28.6	02	28.6	01	14.3	02	28.6	00	00.0
Plateaux (n=10)	05	50.0	03	30.0	01	10.0	01	10.0	00	00.0
Maritime (n=4)	03	75.0	00	00.0	00	00.0	00	00.0	01	25.0
Lomé commune (n=32)	02	06.2	07	21.9	04	12.5	12	37.5	07	21.9
Total (n=62)	17	27.4	12	19.3	07	11.3	16	25.8	10	16.1

3.2. Development of radiological installations

Approximately 1/3 of the services had areas less than 20 m^2 (Table II).

TABLE II: DISTRIBUTION OF RADIOLOGY ROOM ROOMS ACCORDING TO HEALTH FACILITIES

	≤10 m^2		10-20 m^2		20-30 m^2		30-40 m^2		≥40 m^2	
	n	%	n	%	n	%	n	%	n	%
THs (n=3)	00	00.0	00	00.0	00	00.0	01	33.3	02	66.7
RH (n=6)	00	00.0	01	16.7	01	16.7	03	50.0	01	16.7
District hospitals (n=14)	00	00.0	03	21.4	02	14.2	04	28.6	05	35.7
Clinics (n=21)	01	04.8	05	23.8	08	38.1	03	14.3	04	19.0
Hospitals (n=6)	00	00.0	04	66.6	01	16.7	00	00.0	01	16.7
Cabinets (n=8)	02	25.0	03	37.5	02	25.0	01	12.5	00	00.0
Medical Social Centers (n=4)	00	00.0	01	25.0	01	25.0	00	00.0	02	50.0
Total (n=62)	03	04.8	17	27.4	15	24.2	12	19.3	15	24.2

The vast majority of services were constructed of solid bricks, including all regional hospitals (RHs) and 2/3 of the teaching hospitals (Table III)

TABLE III: DISTRIBUTION OF RADIOLOGY SERVICES ACCORDING TO THE WALLS BY HEALTH FACILITIES

	Full bricks		Hollow bricks	
	n	%	n	%
THs (n=3)	02	66.7	01	33.3
RHs (n=6)	06	100.0	00	0.00
District Hospitals (n=14)	12	85.7	02	14.2
Clinics (n=21)	17	80.9	04	19.1
Hospitals (n=6)	06	100.0	00	00.0
Cabinets (n=8)	08	100.0	00	00.0
Medical Social Centers (n=4)	03	75.0	01	25.0
Total (n=62)	54	87.1	08	12.9

Slightly more than half of the full brick walls had a thickness of between 200 and 300 mm (Table IV).

TABLE IV: DISTRIBUTION OF THE THICKNESSES OF THE FULL BRICK WALLS ACCORDING TO THE HEALTH FACILITIES

	≤100 mm		100-200 mm		2 200-300 mm		3 300-400mm	
	n	%	n	%	n	%	n	%
THs (n =3)	00	00.0	00	00.0	01	33.3	01	33.3
RHs (n=6)	00	00.0	02	33.3	04	66.7	00	00.0
District Hospitals (n=14)	00	00.0	00	00.0	10	71.4	02	14.3
Clinics (n=21)	00	00.0	03	14.3	06	28.6	08	38.1
Hospitals (n=6)	00	00.0	00	00.0	05	50.0	01	16.6
Cabinets (n=8)	01	12.5	03	37.5	04	50.0	00	00.0
Medical Social Centers (n=4)	00	00.0	01	25.0	02	50.0	00	00.0
Total (n=62)	01	01.6	09	14.5	32	51.6	12	19.3

The thickness of the hollow brick walls was 100mm for 3 services, between 100 and 200mm for 4 services and between 200-300mm for one service.

Approximately two-thirds of the doors were of wood, including all the doors of Région maritime (Table V). The doors were plumbed in 59 services, ie 95.2%.

TABLE V: DISTRIBUTION OF RADIOLOGY SERVICES BY GATE TYPE ACCORDING TO HEALTH REGION

	Wood doors		Aluminium doors	
	n	%	n	%
Savanes (n=5)	04	80.0	01	20.0
Kara (n=4)	03	75.0	01	25.0
Centrale (n=7)	04	57.1	03	42.9
Plateaux (n=10)	06	60.0	04	40.0
Maritime (n=4)	04	100.0	00	00.0
Lomé commune (n=32)	21	65.6	11	34.4
Total (n=62)	42	67.7	20	32.3

The delineation of the zones was not effective in all departments and only the radiology departments of the Teaching Hospitals (THs) had delineated the controlled, regulated and public areas (Table VI)

TABLE VI: DISTRIBUTION OF RADIOLOGY SERVICES WITH AN AREA DELIMITATION ACCORDING TO HEALTH FACILITIES.

	Controlled area		Monitored area		Public area	
	n	%	n	%	n	%
THs (n =3)	03	100.0	03	100.0	03	100.0
RHs (n=6)	06	100.0	01	16.7	06	100.0
District hospitals (n=14)	11	78.6	02	14.3	10	71.4
Clinics (n=21)	11	52.4	04	19.0	17	80.1
Hospitals (n=6)	04	66.7	03	50.0	06	100.0
Cabinets (n=8)	03	37.5	02	25.0	05	62.5
Medical Social Centers (n=4)	02	50.0	01	25.0	01	25.0
Total (n=62)	40	64.5	16	25.8	38	61.3

Pictograms and signaling were present in about half of the services, while ground marking and display of internal regulations were rarely effective (Table VII)

TABLE VII: DISTRIBUTION OF RADIOLOGY SERVICES WITH A ZONE DISPLAY ACCORDING TO HEALTH REGIONS

	Pictogram		Signal		Labelling		Regulation	
	n	%	n	%	n	%	n	%
THs (n =3)	03	100.0	03	100.0	00	00.0	01	33.3
RHs (n=6)	05	83.3	05	83.3	00	00.0	02	33.3
District hospitals (n=14)	07	50.0	10	71.4	00	00.0	00	00.0
Clinics (n=21)	13	61.9	09	42.8	02	09.5	02	09.5
Hospitals (n=6)	03	50.0	03	50.0	00	00.0	0I	16.7
Cabinets (n=8)	03	37.5	02	25.0	00	00.0	00	00.0
Medical Social Centers (n=4)	01	25.0	00	00.0	00	00.0	00	00.0
Total (n=62)	35	56.4	32	51.6	02	03.2	06	09.7

3.3. Management of medical personnel exposed to ionizing radiation

Only 21 services had a dosimeter, ie 33.9% with the vast majority in Lomé commune health region where the only active dosimeter was found (Table VIII).

TABLE VIII: DISTRIBUTION OF SERVICES WITH A STAFF DOSIMETER ACCORDING TO HEALTH REGIONS

	Passive dosimeter		Active dosimeter	
	n	%	n	%
Savanes (n=5)	00	00.0	00	00.0
Kara (n=4)	01	25.0	00	00.0
Centrale (n=7)	00	00.0	00	00.0
Plateaux (n=10)	03	30.0	00	00.0
Maritime (n=4)	00	00.0	00	00.0
Lomé commune (n=32)	16	50.0	01	03.1
Total (n=62)	20	32.2	01	01.6

Dosimeter reading was monthly in 2 services (3.2%), quarterly in 11 services (17.7%) and half-yearly in 7 services (11.2%).

Most services had a lead apron for staff, while lead gloves and lead glasses were only available in less than 10% of services (Table IX)

TABLE IX: DISTRIBUTION OF RADIOPROTECTION EQUIPMENTS ACCORDING TO HEALTH FACILITIES

	Lead apron		Lead glove		Gonad-guard		Lead glasses		Thyroid-guard	
	n	%	n	%	n	%	n	%	n	%
THs (n =3)	03	100.0	01	33.3	03	100.0	00	00.0	00	00.0
RHs (n=6)	06	100.0	00	00.0	03	50.0	00	00.0	01	16.7
District hospitals (n=14)	10	71.4	01	07.1	06	42.8	00	00.0	00	00.0
Clinics (n=21)	21	100.0	03	14.3	11	52.4	02	09.5	01	04.8
Hospitals (n=6)	06	100.0	00	00.0	02	33.3	00	00.0	00	00.0
Cabinets (n=8)	08	100.0	01	12.5	00	00.0	00	00.0	00	00.0
Medical Social Centers (n=4)	04	100.0	00	00.0	01	25.0	00	00.0	00	00.0
Total (n=62)	58	93.5	06	09.7	26	41.9	02	03.2	02	03.2

Thirty-six services (58.1%) had categorized their personnel.

Medical supervision of staff was not performed in 56 services (91.9%) and 60 services (96.8%) did not have individual medical records for staff.

As radioprotectionists the country had only one biophysicist and one RPO (Radiation Protection Officer)

4. DISCUSSION

Since Togo does not have a nuclear medicine or a radiotherapy service, the medical use of ionizing radiation is practically limited to radiodiagnosis in the country. Diagnostic services unequally distributed throughout the country were concentrated in Lomé (capital of Togo) and its suburbs represented by the Lomé Commune health region, which housed more than half of the services.

The design of any radiological installation must meet essential standards for better protection of workers [6]. These standards relate to room sizing, electrical safety and radiological safety. As regards the dimensioning of radiology services rooms, a minimal surface area of $20m^2$ for computed tomography rooms and conventional public radiology is recommended, and $12m^2$ for private radiology out-of-state clinics [7] . Unfortunately, our study shows that 5% of private practices in Togo had less than 10 m^2. Similarly, 16.7% of the radiology rooms of RHs and 21.4% of those of District Hospitals have a surface area of less than $20m^2$.

Radiological safety of workers requires that the walls of the premises be constructed with the thicknesses required to ensure the protection of workers and the public at the lowest possible level with reference to the dose limits of 20 mSv and 1 mSv respectively. It depends on the delimitation of the controlled and monitored zones in relation to the contiguous zones. The thickness of the walls is usually encrypted in "mm equivalent of Pb". One mm of lead is equivalent to 6 mm Fe, 70 mm concrete, 20 mm barium concrete, 30 mm barium plaster, 100 mm full bricks, 200 mm hollow breeze block or 300 mm hollow brick [7]. It is therefore understandable that the walls constructed with full bricks with a thickness of less than 100 mm and those of hollow bricks with a thickness of less than 300 mm in our study do not comply with the standards for the layout of the premises and cannot therefore provide protection to workers and the public at the lowest possible level.

In addition to the walls, doors and windows particularly must be protected if the electrical voltage of the installation is greater than 50kV. The doors were made of wood in 67.7% of the services in our study. Made of

wood or of other materials, these doors must be plumbed. It is therefore encouraging to note that 95.2% of the radiology services doors in Togo are plumbed.

The delimitation of areas is important for the radioprotection of workers. In France, the regulations provide, in the articles. R. 4451-18 to 4451-28 of the Labor Code, the delimitation of monitored, controlled, specially regulated or prohibited work areas. The decree of 15 May 2006, known as "arrêté zonage", lays down the conditions for the delimitation and marking of these areas, taking account of exposure to ionizing radiation and the rules of hygiene, safety and maintenance are affixed to it [8].

The purpose of this provision is to adequately inform the worker on the occupied workplace and to prevent any fortuitous intrusion. It is a risk assessment that must take into account the reality of the radiological activity and should never be over or underestimated.

Employers in services where areas are not delimited (over one-third of the services) in our country must therefore make arrangements to ensure that the monitored areas and the controlled areas are always properly delimited. This delimitation must be continuous, visible and permanent, and a specific road sign must be displayed on all accesses to rooms and within the area, ionizing radiation sources must be indicated.

Our study shows that the pictogram and light signals were only effective in half the services and that ground markings were scarce. This situation is unfortunate and efforts must be made to ensure that the zones are signaled at each access by means of a pictogram in accordance with the NFM60-101 standard, which defines the characteristics of the pictograms, also known as trefoils [7]. Ionizing radiation sources must be reported and dual signaling must be mandatory.

The management of medical personnel in the radiology services was not reassuring. Thus, more than 2/3 of the services did not have a dosimeter for their medical staff, which was not only not categorized in about 40% of the services but also did not receive medical follow-up in 92% of the services. This mediocre medical management of medical personnel was also reported in Nepal by Adhikari et al where 65% of workers did not have dosimetric follow-up [9].

The above deficiencies in the implementation of radiation protection measures are partly due to the shortage of radioprotectionists in the radiology services of Togo, especially Radiation Protection Officer (RPO). Provision must therefore be made for the designation and training of RPOs to ensure better compliance with radioprotection measures for workers exposed to IRs in the Togolese medical community.

Furthermore, the absence of a regulatory authority not only to authorize but also to inspect the radiology services in Togo favors the non-conformity of radiological installations with the required standards and the unsatisfactory medical management of workers exposed to ionizing radiation in Togo. The Togolese health authorities should therefore take advantage from Togo's accession to the IAEA in 2012 to accelerate the establishment of a strong and independent regulatory authority to ensure a rigorous implementation of the radiation protection measures in the country.

4. CONCLUSION

Radioprotection measures in radiology services in Togo do not always meet the required standards.

The establishment of a regulatory authority to manage the licensing and inspection processes of radiology services is desirable for better protection not only for workers but also for patients and the public.

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ESTIMATION OF PATIENT ORGAN DOSE FROM CT EXAMINATIONS USING THE IMPACT CT PATIENT DOSIMETRY CALCULATOR

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Abstract

The study was aimed at implementing the ImPACT Computed Tomography (CT) Patient Dosimetry Calculator software to determine the magnitude of radiation doses received by selected organs of patients undergoing CT examinations and to compare them with international studies. Patient organ doses from 3 common CT examinations were obtained from 2 diagnostic centres in Lagos, Nigeria. A large variation of mean organ doses between both centres was observed for similar CT examinations. These variations largely originated from the different scanning protocols used in both centres and scanner types. The mean organ doses in this study for stomach, bladder, liver, lung, breast, thyroid, heart, brain and eye lens for CT Abdomen-Pelvis, Chest and Brain examinations were: 23.1 mGy, 24.7 mGy, 20.4 mGy, 33.4 mGy, 28.3 mGy, 43.4 mGy, 32.1 mGy, 23.4 mGy, and 28.5 mGy respectively. These values were mostly comparable to the values of organ doses reported from the literature for the United Kingdom, Japan, Germany, the Netherlands and Malaysia. The values reported in the study were lower than that of Tanzania. It was concluded that the ImPACT CT Patient Dosimetry Calculator is suitable for estimating patient organ doses especially for large scale epidemiological studies. However, it contributes significant uncertainties to estimated organ doses because the scanning range does not correspond to that of patient data collected, does not consider the use of contrast materials which affect dose distribution, and the datasets are based on old scanner models, which are no longer in use today.

1. INTRODUCTION

Computed tomography is one of the most modern diagnostic imaging modalities used in medicine today. The modern CT scanner was made possible with the invention of the computer and it probes the inner depths of the body slice by slice. Advances in acquisition geometry, detector arrays and X-ray tube design have led to scan times as low as fractions of a second. Modern CT scanners deliver higher computational power that allows the reconstruction of CT images in real time. When compared to other X-ray diagnostic procedures, the CT scan provides excellent spatial resolution, good anatomical orientation, good reproducibility and better contrast resolution.

However, the ionizing radiation used in CT is multiple folds bigger than that of conventional X-ray examination which results in a significant amount of radiation to the patient which is not always considered during the clinical process. The deposition of radiation dose in CT is due to the following.

Firstly, a single CT image is acquired in a highly collimated manner which implies that the volume of irradiated tissue is much smaller when compared with conventional radiography.

Secondly, the volume of tissue irradiated in CT is irradiated from all angles which evenly distribute the radiation dose to all the tissues within the beam.

Finally, CT acquisition requires high signal-to-noise ratio to achieve high contrast resolution. This results in higher radiation dose to the slice due to the use of higher scanning parameters compared to other X-ray diagnostics modalities. As a result of the frequent use of CT in diagnostic procedures in medicine, concerns have been raised that the large radiation dose from CT procedures can in a small but significant way pose cancer risk to the general public. Incidents of radiation over exposure have led to interest in evaluating doses delivered in CT examinations.

In evaluating radiation doses several CT specific dose descriptors have been developed which include, Multi-Scan Average Dose (MSAD), Computed Tomography Dose Index (CTDI) and its variations ($CTDI_{vol}$, $CTDI_{w}$, $CTDI_{100}$) and the Dose Length Product (DLP).

Organ doses in clinical CT procedures can be measured experimentally by direct measurement using phantoms and detectors. The evaluation of organ doses is done directly by dose measurements on the patient or on a humanoid phantom using radiation dose measuring devices such as ion chambers, TLD, OSLD, and photodiode. These detectors are placed on the phantom and their positions correspond to the position of the organ to be measured

[1]. Another method to assess organ dose is through measurement of CT dose indexes (CTDI) and published conventional factors obtained from Monte Carlo simulation and mathematical phantoms. These simulations account for various scanners and technique factors, including scanner geometry, bowtie filtration, beam collimation, tube potential, and current as well as the CT dose index (CTDI) and the scan length for a given CT examination.

It also requires tissue weighting factors for the estimation of organ doses and effective dose. Many organ dose calculation software are presently available some of which include, CT-Expo, CT DOSE, ImPACTDose, VirtualDose, CTDosimetry among others. These programs are based on Monte Carlo transport code and a dataset generated from CT data surveys.

There are two major CT dose databases that are most widely cited and used for current software-based programs. One database was introduced in 1991 by the National Radiation Protection Board (NRPB) of the United Kingdom, and the other was introduced in 1991 by the National Research Centre for Environment and Health (GSF) of Germany [2].

The NRPB database was computed using an adult hermaphrodite mathematical stylized phantom that was an amalgamation of Cristy's 1980-revision stylized adult phantom, Kramer's 1982-revision neck model, and a breast model of 50% fat and 50% water composition [3]. The database is composed of dose results from 208 5-mm axial beam slices from the head to the thigh of the phantom for 27 scanner models and 23 sets of exposure conditions (i.e. kVp, beam filtration, and source-to-isocentre distance) based upon a 1989 CT survey conducted by the NRPB within the UK.

The ImPACT CT patient Dosimetry calculator employs the NPRB database, it computes organ doses based on patient data extracted from the CT scanner. Patient data required from the scanner include, scanner type and manufacturer, KV and mA used, pitch, rotation time and collimator or beam width. It calculates the organ doses, the effective dose, $CTDI_{vol}$, $CTDI_{w}$ and DLP. The aim of this study was to estimate patient organ doses from CT examinations in 2 diagnostic centres in Lagos Metropolis using the ImPACT CT Patient Dosimetry calculator and to compare the organ doses from the centres to those of international studies.

2. METHODOLOGY

The data used in this study were collected from two diagnostic centres in Lagos that have CT scanners. For the purpose of this study, the centres will be denoted as A and B. The CT scanner in Centre A is a General Electric (GE) Bright Speed Edge Select, 8-slice and it can function in helical and axial modes. The scanner in centre B is a GE Optima 64-slice CT scanner and can also function in helical and axial modes.

The patient data collected from both centres include patient-related parameters such as demographic information (age & sex), diagnostic purpose of the examination and body region, dose data displayed (dose index parameters) such as volumetric computed tomography dose index ($CTDI_{vol}$) and the dose length product (DLP), and exposure related parameters such as kilo-voltage (kV), tube current (mA), rotation time, beam width (collimation), slice thickness, pitch (table increment) and scanning range.

The data collected from both centres were for CT Abdomen-pelvis, CT Brain and CT Chest protocols. A total number of 180 patient data were collected from both centres. The data were collected for Abdomen-Pelvis, Chest and Brain CT examinations. In both centres, 35, 35 and 20 patient data were collected for Abdomen-Pelvis, Chest and Brain respectively making a total of 90 patients' data for each centre.

The estimation of patient organ doses from CT examinations using Monte Carlo technique requires measurement of CTDI and conversion coefficient packages. CTDI, which is a measure of the dose from a single-slice irradiation, is defined as the integral along a line parallel to the axis of rotation of the dose profile divided by the nominal slice thickness. Unfortunately, $CTDI_{100}$, air for both scanners in this study were not determined due to the unavailability of necessary equipment hence, required organ doses in this study were estimated using normalized CTDI values published by the ImPACT group.

The dose to a given organ or region from a series of scans is then given by the product of the total normalized organ dose for the scanned volume, the packing factor and the CTDI for the exposure as shown in equation (1) .

$$\Sigma \qquad 1$$

The packing factor, p is given as

$$\frac{}{2}$$

where L is the total length of scan, n is the number of slices and w is the nominal width of scan.

The ImPACT CT Patient Dosimetry Calculator was used to implement equation (1). The software consist of an hermaphrodite phantom and does not take into account the patient size, that is, the software does not discriminate between tall and short patients or male or female, it was necessary to adjust the scan region indicated on the human skeleton from each patient survey form in NRPB's mathematical phantom for each individual examination. This was done by manually adjusting the start and end positions on the virtual phantom as shown in Fig. 1 to correspond to the appropriate scanning protocol.

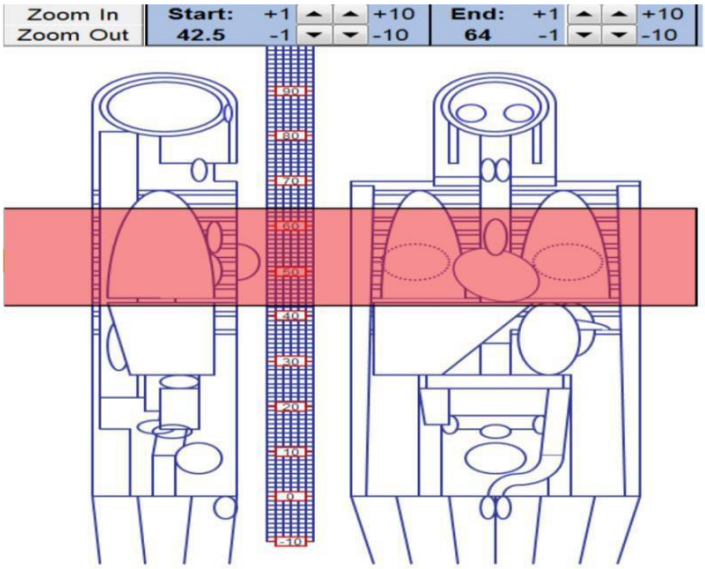

FIG. 1. Hermaphrodite phantom for the ImPACT CT patient dosimetry calculator

This information was used in the selection of the part of the phantom irradiated in order to improve the correspondence between the organs irradiated in the patient and the phantom. Since the scanners used in this study were not in use at the time of the NRPB survey, the estimation of organ dose has to rely on the attributes of the new model compared to that of older designs.

This was done using scanner-matching data published by the ImPACT Group, and may lead to uncertainty of not more than 15% of organ dose measurement. In order to evaluate how well both centres performed in terms of minimization of organ doses associated with CT imaging, it was useful to compare mean organ doses and effective dose per examination for both centres.

This was done by finding the mean organ dose from the typical patient organ dose weighted by the number of scans performed per given examination for each centre. On the other hand, the mean value of the typical patient organ doses weighted by the number of scans per given examination, based on both centres, and was taken as the country mean organ dose. The country mean organ doses were determined in order to compare with other studies.

A summary of organ doses was estimated from about 200 examinations using the CTDosimetry software. The specific organs selected include Abdomen-pelvis (stomach, bladder and liver), Chest (lung, breast, thyroid and heart), Brain (brain, eye lens) for each centre. The summary consisted of scanning parameters such as kV, mA, and collimation. For this summary, the total organ dose for selected organs for each examination was calculated by the summation guided by its respective scan sequences. By using the Microsoft Excel statistical application, the mean organ doses and related statistics were determined.

3. RESULTS AND DISCUSSION

The total mean organ doses of selected organs were determined for different examinations including Abdomen-pelvis, Chest and Brain using exposure parameters specific to the hospitals and the scanners used. It was evident from the Table 1 that a significant variation in organ doses exists between the centres. The variation of organ doses observed in Fig. 2, Fig. 3 and Fig. 4 for all examinations in abdomen-pelvis, chest and brain respectively was an indication that different scanning parameters (i.e kV, mA, and scan length) used in both centres have a significant influence on organ dose determinations.

TABLE 1: SUMMARY OF THE MEAN ORGAN DOSES FOR SELECTED ORGANS IN BOTH CENTRES

Selected Organ	Mean Doses Per Centre(mGy)	
	Centre A	Centre B
(a) ABDOMEN-PELVIS		
Stomach	27.8±6.6	18.5±8.0
Bladder	29.8±7.1	19.6±8.2
Liver	26.1±6.2	17.3±7.3
(b) CHEST		
Lung	30.1±10.1	36.4±10.2
Breast	25.3±8.3	31.3±8.7
Thyroid	39.8±14.6	47.4±10.8
Heart	29.3±10.1	34.9±9.7
(c) BRAIN		
Brain	15.0±1.5	31.8±10.9
Eye lens	17.6±2.0	39.5±12.8

It was observed that for Abdomen-Pelvis (stomach, bladder and liver) organ doses (27.8 mGy, 29.8 mGy and 26.1 mGy respectively) were higher in Centre A. However, for Chest (36.4 mGy for lung, 31.3 mGy for breast, 47.4 mGy for thyroid and 34.9 mGy for heart) and Brain examinations (31.8 mGy for brain and 39.5 mGy for eye lens), the doses in centre B were significantly higher than in Centre A. At both centres, the highest dose recorded was for thyroid 39.8±14.6 mGy and 47.4±10.8 mGy for centres A and B respectively.

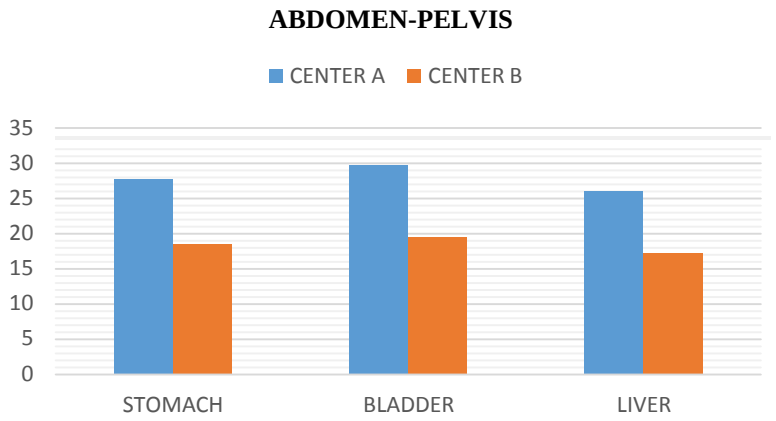

FIG. 2. Histogram comparing organ doses in both centres for abdomen-pelvis CT examination

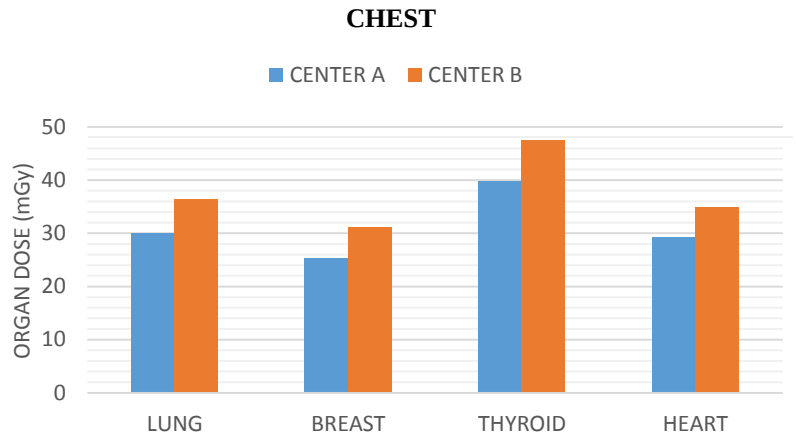

FIG. 3. Histogram comparing organ doses in both centres for chest CT examination

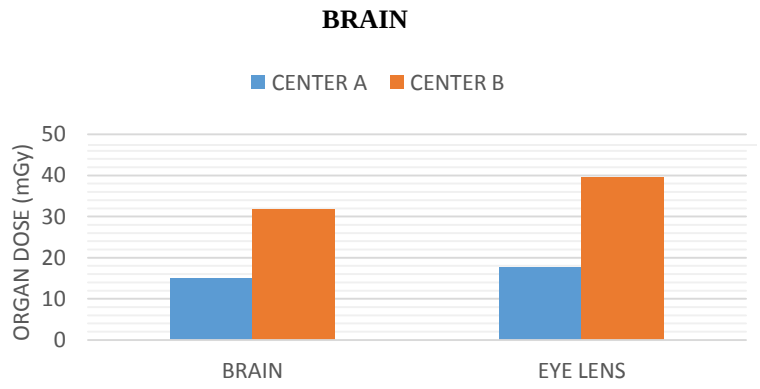

FIG. 4. Histogram comparing organ doses in both centres for brain CT examination

To facilitate the comparisons of the mean organ doses of selected organs in this study to that reported in literatures from the United Kingdom, Germany, the Netherlands, Japan and Tanzania, the mean organ doses for the selected organs were presented in Table 2. The values of this study were taken to be the mean organ doses for both centres. It was clear from Table 2 that the mean organ doses were mostly comparable with those from other studies. In this study organ doses were estimated from patient data from more modern multi-slice CT scanners using NRPB conversion factors.

TABLE 2. COMPARISON OF CALCULATED MEAN ORGAN DOSES TO INTERNATIONAL STUDIES

CT Examination	Selected Organ	This Study D (mGy)	UK D(mGy)	Germany D(mGy)	Netherlands D(mGy)	Tanzania D(mGy)
Abdomen-Pelvis	Stomach	23.1	22.2	15.4	38.5	35.6
	Bladder	24.7	23.2	16.1	-	28.8
	Liver	20.4	20.4	15.0	35.5	34.1
Chest	Lung	33.4	22.4	20.5	37	31.5
	Breast	28.3	21.4	22.6	32	26.1
	Thyroid	43.4	2.3	-	7	12.3
	Heart	32.1	-	-	-	-
Brain	Brain	23.4	-	-	-	-
	Eye lens	28.5	-	24.8	-	63.9

The mean organ doses in the literatures from the UK, Germany, the Netherlands and Tanzania were also estimated using NRPB conversion factors. The differences in organ doses between this study and those reported in the UK, Germany, the Netherlands, and Tanzania [4] [5] [6] [7] were mainly attributed to CT scanning protocols (i.e. kV, mA, slice thickness, etc.) and type of scanners used.

It was also observed from the table that mean organ doses from this study for most organs is comparable with the exception of thyroid which is reported to be 43.3 mGy. It was evident that the organ doses for CT chest (33.4, 28.3 and 43.4 mGy for lung, breast and thyroid respectively) was significantly higher than other studies, this can be attributed to the number of slices used in both centres. However, dose to the eye lens was considered moderate for this study (28.5 mGy) compared to values from Germany and Tanzania which are 24.8 mGy, and 63.9 mGy respectively.

The ImPACT CT Patient Dosimetry Calculator provides an easy platform for estimating patient organ doses from CT examinations with the following limitations:

(1) the software employs a hermaphrodite mathematical stylized phantom, which does not account for patient gender, size, shape and children.
(2) it does not take into account the use of contrast materials, which influence dose distribution inpatients.
(3) the scanning length on the phantom does not correspond to that collected from the CT scanners which requires that the scanning range must be set manually on the Excel spreadsheet.
(4) the software whose most recent update was 2001 does not account for more modern CT scanners, which introduces significant uncertainties in estimated values.

4. CONCLUSION

In this study, the patient organ doses from selected CT examinations (CT Abdomen-Pelvis, CT Chest, CT Brain) at 2 diagnostic centres in Lagos, Nigeria were investigated using the ImPACT CT Patient Dosimetry Calculator. Large variations of radiation dose were observed between the two centres. Different scanning protocols used in both centres and variation in equipment design among manufacturers and models were responsible for these variations.

The mean organ doses in this study were mostly comparable to reported values in the UK, Germany and the Netherlands. However, they were lower than values reported from Tanzania. The software proves to be an easy way to estimate patient organ doses and it is useful to conduct epidemiological studies on a large scale. However, it does not give accurate values of organ doses when compared to experimental measurements due to its limitations.

ACKNOWLEDGEMENTS

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ASSESSMENT OF RADIATION DOSE TO THE LENS OF EYES AND THYROID OF PATIENTS UNDERGOING HEAD AND NECK COMPUTED TOMOGRAPHY AT FIVE HOSPITALS IN MASHHAD-IRAN

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Abstract

In recent years, the number of CT scans prescribed has been increased significantly. CT scan is a high dose technique, thus it is the largest component of ionizing radiation from man-made sources. Head and neck CT examinations are more frequently performed. Thyroid, particularly in children has always been considered a sensitive organ. In recent years radiobiologists and health physicist have been more concerned to the safety of lenses of the eyes too, as cataract is no longer considered a deterministic effect. In the present study incurred dose to thyroid and lens of the eyes of 140 patients who were subject to head and neck CT, in five hospitals in Mashhad-Iran were measured by TLD-100 (LiF:Mg,Ti). All patients were divided into two age groups (pediatrics and adult). TLDs were calibrated by standard method recommended by the producer. TLD chips were placed on patient's skin surface. For each patient scan parameters, sex and age were recorded. Exposed TLDs were read by manual TLD reader Harshaw model 3500. Average absorbed dose of thyroid, lens of left and right eyes were: 6.92 ±1.13 mGy, 18.34±1.22 mGy and 21.64 ± 1.28 mGy respectively, individual patient's organs dose were influenced by scanned region, scan protocol, and patient's age.

INTRODUCTION

Medical applications of ionizing radiation play a significant role in diagnosis and treatment of patients worldwide, without which lives of many patients may be endangered. Nowadays CT scan, a high dose technique, has been recognized as the largest component of man-made sources of ionizing radiation(1).

In spite of the well stablished detrimental effects following to exposure to ionizing radiation, ever increasing use of ionizing radiation is inevitable (2).

CT scan provides very high quality images which is reproduced transverse cross sections of the body, at the same time (3, 4). CT examinations represent just over 44% of the global collective dose equivalent from medical radiation exposures (5, 6).

Depending on the prescribed CT scan one or a few of sensitive organs may be exposed to primary or scattered X-rays, e.g. ovaries in CT scan of pelvic, thyroid and lens of the eyes in CT scan of head and neck region.

A rational approach to this "double edge sword "phenomenon is to fully implement ICRP principles: Justification, optimization and limitation. In a country, region, city or even a big hospital with several radiological facilities, established DRLs, would help individual facilities to keep in line with limits and ALARA principle. Thus, undoubtedly monitoring of patient's dose in CT scan centres is particularly important. In this context sensitive organs deserve extra considerations to reduce various somatic and genetic radiation induced risks. (5,7-9)

1. MATERIALS AND METHODS

The radiation dose to the lens of eyes and thyroid of 140 Patients who under-went common head and neck CT examinations in five hospitals in Mashhad-Iran were measured. Four CT machines: Siemens-16 slice, Siemens-2 slice, Philips- 16 slice and Toshiba-16 slice were included in this work.

The protocols performed in the study were Brain (sequential & spiral), Sinus (sequential & spiral), Neck (spiral) and Neck -brain (spiral). The scanning parameters of the protocols such as the CT dose index (CTDI), Dose length product (DLP), for peak kilovoltage, tube current-time product (milliamperes), pitch factor and sex and age for each patient were recorded.

Out of 140 patients examined, 39% were male and 61% were female. All Patients were divided into two age groups: 1.5 to15 years for the paediatric and > 15years for adult patients.

Thermoluminescent dosimeters (TLD-100, LiF:Mg,Ti) were placed on patient skin at three different locations to measure absorbed dose by thyroid and lens of eyes (two TLD chips on each eye lid and two TLDs on thyroid surface). The TLDs used were (3.2*3.2*0.9 mm^3) in dimensions. TLDs were annealed by standard protocols recommended by the producer at 400^oC for 1 h, then cooled at room temperature, again heated at100^oC for 2 h. To calibrate TLDs, standard protocols established in our dosimetry laboratory (based on approved protocols in literature) were employed. TLDs were irradiated by ^{137}Cs irradiator 2210 manufactured by Thermo Electron Cooperation. Irradiated TLDs, (on patient's body) were read after 24 hours, as recommended, by a manual TLD reader (Harshaw 3500).

2. RESULTS:

The employed parameters for different CT protocols for pediatric and adult patients are shown in table 1.
The average value of all scan parameters for various protocols and both age groups were determined.
Average dose of thyroid and the lens of eyes resulted from head and neck CT scan of both age groups are presented in Table 2.
Mean measured organ dose of adults and paediatrics subjected to different head and neck CT protocols at the studied centres are showed in Figure 1 and Figure 2.

TABLE 1. DETAILS OF PHYSICAL FACTORS ADAPTED TO SIX CT SCAN PROTOCOLS STUDIED IN THIS WORK.

parameters	Brain (sequential)		Brain (spiral)		Neck -brain (spiral)		Neck (spiral)		Sinus (sequential)		Sinus (spiral)	
Age groups	pediatric	adult	pediatric	adult	pediatric	adult	pediatric	adult	pediatric	adult	pediatric	adult
kV	139	127	125	146	-	166	120	120	-	113	130	97
mAs	151	223	180	191	-	109	130	156	-	137	225	94
Pitch	1	1	0.87	1.24	-	1.67	1.01	0.8	-	1	0.9	2.63
CTDI (mGy)	24.90	39.46	27.36	38.41	-	16.20	22.35	16.67	-	26.09	44.07	26.67
DLP (mGy.cm)	309.62	497.14	?	755.49	-	1735.16	406.75	198.77	-	142.77	451.71	101.83

TABLE 2. AVERAGE DOSE TO THE LENS OF EYES AND THYROID FROM HEAD AND NECK CT EXAMINATIONS FOR BOTH AGE GROUPS

	Number of patients	Thyroid (mGy±SE)	Left eye (mGy±SE)	Right eye (mGy±SE)
Paediatrics(1.5:15 y)	15*	5.89±1.74	15.84±2.81	16.25±2.57
Adults (≥ 50 y)	95*	5.00±1.17	17.64±1.69	24.41±1.89

* On 30 forms, patient`s age were not clearly recorded, thus they were omitted.

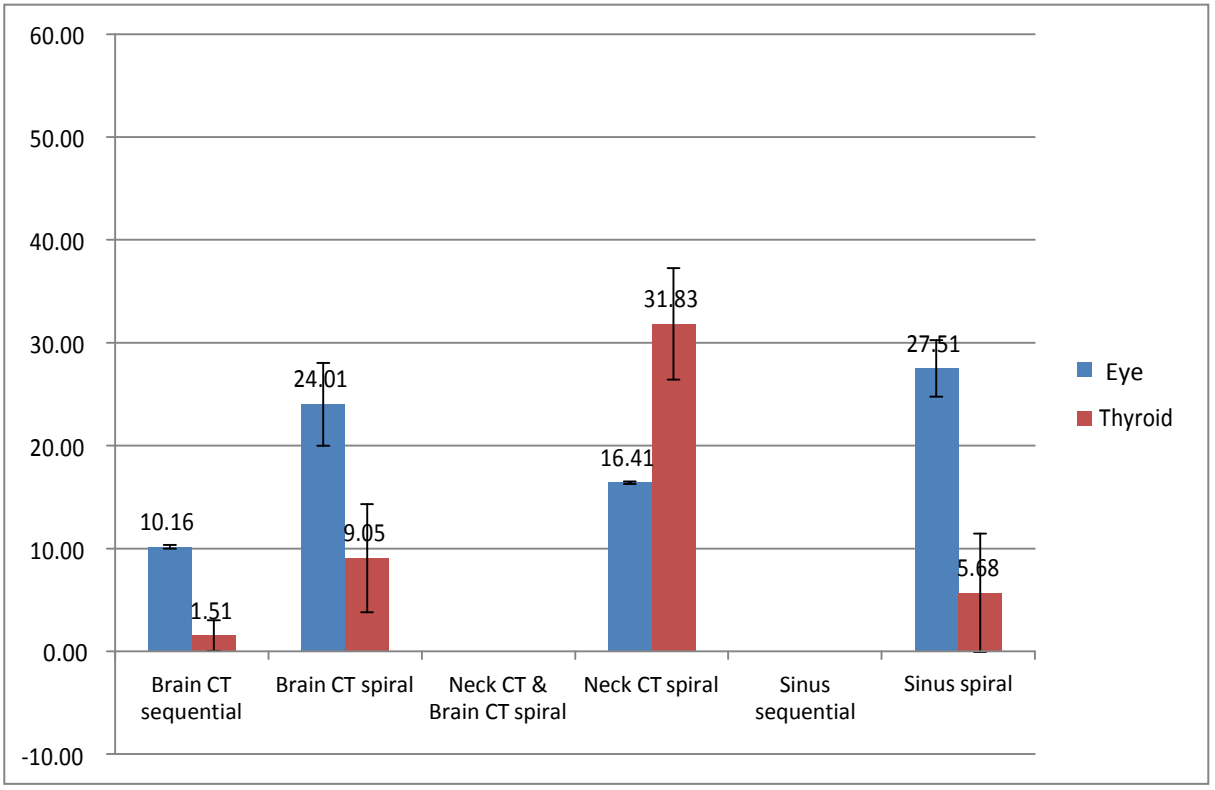

FIG. 1. Thyroid and total doses of both eyes of pediatric patients following performance of the six CT scan protocols.

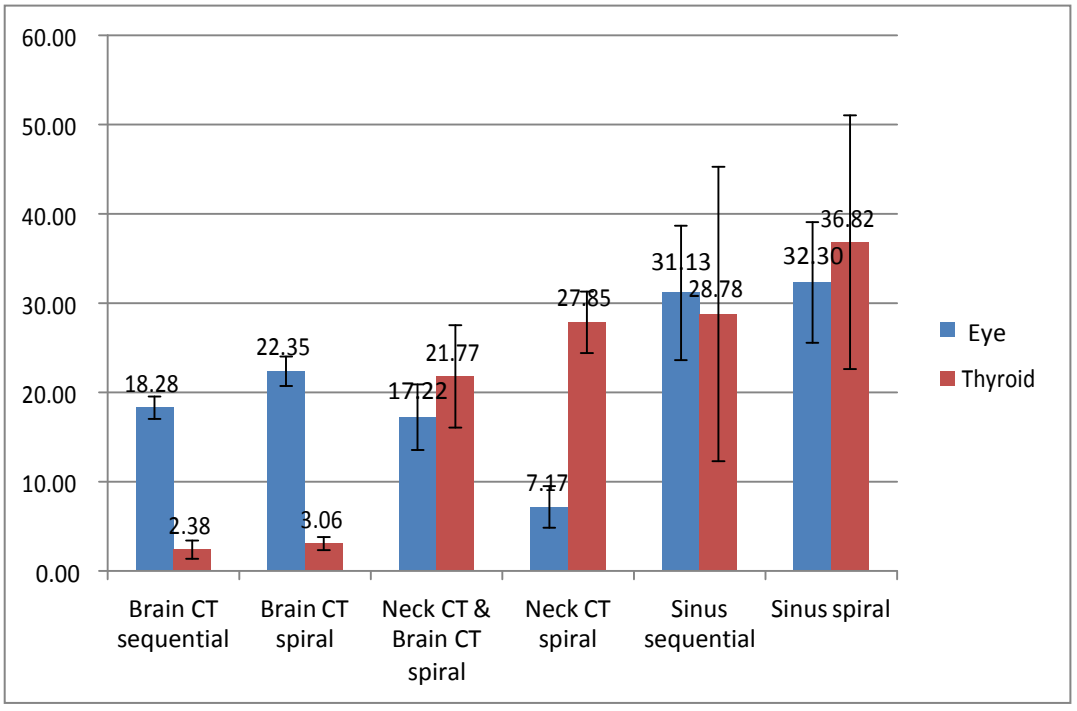

FIG. 2. Thyroid and total doses of both eyes of adult patients following performance of the six CT scan protocols.

3. DISSCUSSION

In the present study, we estimated the eyes and thyroid absorbed dose received by pediatric and adult patients undergoing six different head and neck CT protocols. Average doses to the lens of eyes and thyroid from head and neck CT examinations showed in table 2 are evident that for two age groups lens of both eyes received much higher doses. Compared to thyroid on the other hand absorbed thyroid and lens of eyes incurred doses for patients of the two age groups are not very different. However thyroid dose from brain spiral CT is substantially smaller than doses delivered to lens of both eyes (by a factor of 7 for adults and a factor 2.5 for pediatric), on the contrary thyroid dose from neck spiral CT is higher from similar values for lens of both eyes (by a factor of 4 for adults and a factor 2 for paediatrics). This is due to nearness of thyroid to the radiation field in CT scan procedures.

Figures 1 and 2 shows that in brain and sinus protocols performed in spiral mode, lens of eye and thyroid doses are higher than sequential mode. The dose difference between spiral and sequential acquisition is largely due to the difference in the kVp and mAs used for spiral and sequential protocols. Also, the lens of eyes and thyroid dose of paediatrics in brain spiral CT is higher than adult patients. It is a cause for concern, because paediatrichave longer life expectancy after radiation exposure than adults and the lifetime radiation risks are higher for them.

The results revealed that the mean eye dose from different head and neck CT examinations varied from 10.16 mGy to 42.25 mGy depending on protocol type, the patient's age and the acquisition mode used. Results of epidemiological studies of populations with low-dose radiation have recommended that the lens of eyes is more sensitive to ionizing radiation and that the cataract caused by ionizing radiation may even be stochastic without a threshold dose. Therefore, the International Commission on Radiological Protection (ICRP) has reassessed the equivalent dose limit of the lens of eyes by decreasing the suggested dose threshold for cataract and opacity effects of lens from 2–8 Gy to 0.50 Gy. (ajr.14.12763, ICRP_118). In the present study the mean eye dose is much lower than the 500 mGy threshold recommended by ICRP for lens of eye damage and thus appears to be clinically safe.

4. CONCLUSION

While CT scan remains a crucial tool especially for pediatrics, further dose reduction can be achieved through controlling different factors affecting patient doses. Some of these parameters are user dependent (e.g. kVp, mAs and pitch). Optimizing the parameters of CT examinations is one of important factors to radiation dose reduction. Therefore, the Radiologists should be trained to reduce exposure as low as reasonably achievable (ALARA).

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RADIATION RISK AND ORGAN DOSE ASSESSMENT DURING CONE BEAM CT PROCEDURES IN IMAGE GUIDED RADIATION THERAPY

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Abstract

Cone-Beam CT (CBCT) provides 3D images of tumor anatomy, size and location for cancer treatment by Image-Guided Radiotherapy. Despite its benefits, imaging doses from CBCT scans are a clinical concern due to additional exposure to healthy tissues surrounding the exposed target-organs. This study aims at quantifying concomitant organ doses involved in CBCT procedures and at estimating the corresponding risk of cancer incidence, in order to provide justification of CBCT exposures. In this work, a computational model of a CBCT scanner (Edge^{TM}, Varian Medical Systems), previously simulated using MCNPX2.7.0 and validated against $CTDI_{100}$ measurements, was used. To calculate organ doses during CBCT, male and female voxel phantoms were implemented. The risk of cancer incidence, from typical CBCT scanning protocols, was determined. The results reveal that the benefits of a single CBCT outweigh the resulting cancer risk to the patients. However, multiple CBCT procedures may lead to considerable lifetime risk. The adequacy of the CBCT model to estimate concomitant risks is discussed, with the objective of keeping imaging doses as low as reasonably achievable and to improve the balance between benefit and radiation risk.

1. INTRODUCTION

Cone-Beam CT (CBCT) is used for pre-treatment verification and patient setup in Image-Guided Radiation Therapy (IGRT). This technique provides 3D images of tumour anatomy, size and location, in a single axial rotation, using X-ray beam widths, along the z-axis, wide enough to cover a significant anatomical length [1,2]. CBCT imaging is employed daily and several times per patient, resulting in high cumulative imaging doses to healthy tissues surrounding the exposed target-organs. For this reason, CBCT has the potential to become a non-negligible source of radiation dose to the patients´ healthy tissues. The issue of CBCT imaging dose is addressed by the AAPM Task Group 75 report [3] that made recommendations to reduce and to estimate the dose to the patient. Previous studies were developed by *A. Amer et al* [4] and *L. J. Sawyer et al* [5] to assess the additional CBCT imaging dose to patient organs. Both authors found high doses when compared with some other imaging techniques, such as CT, and highlighted the need to optimize the radiation protection and to minimize the risks of adverse health effects due to CBCT exposures.

Therefore, the aim of this study is to quantify the concomitant organ doses involved in CBCT procedures frequently used in clinical environment during IGRT treatments and to estimate the corresponding risk of cancer incidence, in order to provide justification of CBCT exposures.

The effective dose is an essential radiological protection tool to manage exposures prospectively and to assess risks for generic populations retrospectively [6]. However, a limitation of this methodology is that the risk is averaged in gender and age for adults. As an alternative to effective dose, a direct conversion of mean organ dose to cancer risk should be used. Since the BEIR VII Phase II report [7] introduced risk estimates of radiation induced cancer incidence and mortality including age and gender dependence, in this study, the BEIR VII organ-specific cancer risk coefficients were used to perform a risk assessment for CBCT procedures.

2. MATERALS AND METHODS

A Monte Carlo (MC) model of a CBCT scanner was previously developed, using the MC radiation transport program MCNPX 2.7.0 [8], and validated against CTDI measurements with physical phantoms [9].

The simulated CBCT equipment corresponds to the On-Board Imager (OBI) mounted on Varian Edge™ (Varian Medical Systems, Palo Alto, CA) LINAC at Champalimaud Center for the Unknown (Lisbon, Portugal).

2.1. CBCT system and scanning protocols

The CBCT system is mounted on the gantry of the LINAC at 90° to the therapeutic beam. A 3D image is reconstructed from several projections that are acquired through the rotation of the kV source around the patient.

Two CBCT scanning protocols, Thorax and Pelvis, were studied and their acquisition parameters are listed in Table 1. The Half-Fan acquisition mode was selected to allow larger fields-of-view (FOVs) by scanning target regions asymmetrically. Four collimator blades work independently: the X pair (X1 and X2) sets the diameter of the scan while the Y pair (Y1 and Y2) controls the beam width (W) along the rotation axis (z-axis).

TABLE 1. ACQUISITION PARAMETERS OF THE CBCT SCANNING PROTOCOLS

Parameters		Thorax Scan Protocol	Pelvis Scan protocol
Tube Voltage (kVp)		125	
Tube current time product (mAs)		270	1080
Gantry Rotation (º)		360	
Acquisition mode		Half-fan	
Beam width (mm)		214	
Collimator Blades	X1 and X2 (cm)	-24.7 and +3.4	
	Y1 and Y2 (cm)	-10.7 and +10.7	

2.2. MCNPX calculations

The MCNPX 2.7.0 program was used to mimic the CBCT acquisition process and to perform dosimetric calculations. A detailed description of the implemented CBCT scanner geometry and the results for the validation of the developed MC tool can be found in *Baptista et al.* [9]. For the organ dose assessment, MC simulations, including male and female voxel phantoms, were used. The selected tissues were the target organ, the organs at risk (surrounding the target organ) and exclusive female and male organs. The MCNPX F8 tally (energy deposition in a defined volume) was chosen to calculate the doses received by specific organs. $2x10^8$ particle histories were run, corresponding to a statistical uncertainty up to 30% for the smaller organs.

2.2.1. Voxel phantoms for organ dose assessment

To calculate the organ doses during the CBCT scans, MC simulations, including a male (Golem) and a female (Laura) computational voxel phantoms, were carried out [11]. Laura, is based on a CT of an adult woman in supine position with 167 cm height and 59 kg weight (ICRP reference values: 163 cm and 60 kg). The voxel resolution is 1.875x1.875x5.00 mm^3. Laura was used to study the organ doses during a typical thorax CBCT scan which is routinely performed for patient positioning in breast cancer treatment with IGRT. The isocentre of the CBCT system was set at the left breast of the phantom.

Golem is based on a CT of an adult male with 176 cm height and 68.9 kg weight (ICRP reference values: 176 cm and 73 kg), having a voxel resolution of 2.08x2.08x 8.00 mm^3. Golem was selected to calculate the organ doses: i) for a thorax CBCT scan, used for patient positioning during lung cancer treatment, with the isocentre of the CBCT scanner set at the left lung; ii) for a pelvic CBCT scan, used for patient positioning during prostate cancer treatment, with the isocentre of the CBCT system was set at the prostate.

2.3. Radiation risk assessment

The Effective Risk (ER) concept, proposed by Brenner [10] is calculated using the following equation:

$$\Sigma$$

where H_T is the organ dose for tissue T and r_T is the gender, age and tissue-specific risk coefficient for lifetime attributable risk (LAR) of radiation induced cancer incidence from BEIR VII – Phase II Report [7]. The LAR coefficients are provided for discrete ages and the values for intermediate ages were obtained by interpolation of

the data presented in Table 12D-1 of the report [7]. The lifetime risk for each organ assessed was calculated taking into account the organ doses obtained through the MCNPX simulations.

3. RESULTS

3.1. Organ doses calculation

Table 2 shows the radiation doses received by the specific organs from a CBCT scan, taking into account the selected clinical protocols. For each protocol, the CBCT dose per session was calculated. During a complete course of a radiotherapy treatment many CBCT scans may be performed, thus the total CBCT imaging dose was also determined, assuming that at least one CBCT scan was performed per session for a complete course of treatment for lung, prostate and breast cancer.

TABLE 2. ORGAN DOSES FOR CBCT SCANNING PROTOCOLS

Organ	Thorax protocol for lung			Pelvis protocol for prostate			Thorax protocol for breast		
	Dose per session (mGy)	MCNPX statistical uncertainty (%)	24 sessions for lung cancer treatment (mGy)	Dose per session (mGy)	MCNPX statistical uncertainty (%)	28 sessions for prostate cancer treatment (mGy)	Dose per session (mGy)	MCNPX statistical uncertainty (%)	15 sessions for breast cancer treatment (mGy)
Left Lung	3.32	2.38	79.78	0.03	0.61	0.77	2.00	2.19	29.98
Righ Lung	2.12	1.56	50.83	0.03	0.54	0.70	1.81	2.71	27.10
Stomach	3.16	4.33	75.88	0.08	1.76	2.09	------	------	------
Colon	0.56	1.53	13.42	0.61	9.82	17.05	------	------	------
Liver	1.22	0.71	29.21	0.04	0.79	1.19	1.53	1.49	22.92
Thyroid	2.73	12.36	65.44	0.03	2.83	0.95	3.14	20.30	47.03
Bladder Wall	0.02	0.46	0.55	2.69	28.70	75.29	------	------	------
Prostate	0.03	0.85	0.73	17.41	31.10	487.59	------	------	------
Breast - glandular tissue	------	------	------	------	------	------	1.64	3.84	24.64
Breast - adipose tissue	------	------	------	------	------	------	5.14	5.97	77.11
Uterus	------	------	------	------	------	------	0.06	1.59	0.91
Ovary	------	------	------	------	------	------	0.38	26.75	5.64

A typical lung cancer patient may receive 3.32 mGy per session to the left lung (target organ) per CBCT scan and at least 79.78 mGy at the end of the 24 sessions of radiotherapy. The surrounding organs (right lung, stomach and liver) receive also considerable CBCT imaging doses (50.83, 75.88 and 29.21 mGy, respectively) when a course of IGRT is completed. For a prostate cancer patient, the prostate, as target tissue, may receive 17.41 mGy per CBCT scan and up to 487.59 mGy at the end of the fractioned treatment. The organs at risk, such as colon and bladder, may receive 75.29 mGy and 17.05 mGy, respectively. For a breast cancer female patient, the dose to the breast (considering both glandular and adipose parts) is of about 6.78 mGy per session but may reach at least 101.75 mGy end of the 15 sessions of radiotherapy. The lungs are the surrounding tissues that may receive higher values of additional CBCT imaging dose.

3.2. Effective risk estimation

The CBCT scanning protocols evaluated in this work are only applicable for adult patients, whereby the lifetime organ risk was determined for ages between 18-80 years. Fig.1 shows the results for each protocol, per session and for a complete course of IGRT treatment, taking into account the three target organs: lung, prostate and breast. The lifetime risk is also presented for surrounding organs that received higher CBCT doses.

Concerning the CBCT scans studied for the male phantom (thorax CBCT for lung cancer and pelvis CBCT for prostate cancer), the target organ is the tissue that registered a higher cancer incidence. This trend was not verified for the thorax CBCT scan for breast cancer, where the female voxel phantom was used. In this case, the breast remains the organ with higher cancer incidence if the CBCT exposure occurs up to 45 years approximately. After that age, the lung is the organ at risk that presented a higher cancer incidence. This was also the CBCT exposure scenario that registered the highest cancer incidence per CBCT scan.

Moreover, for both cancer sites analysed for the thorax CBCT scan, the thyroid, which receives relatively high imaging doses after a complete course of radiotherapy treatment, presented a steep decrease in cancer incidence when the age at exposure increases.

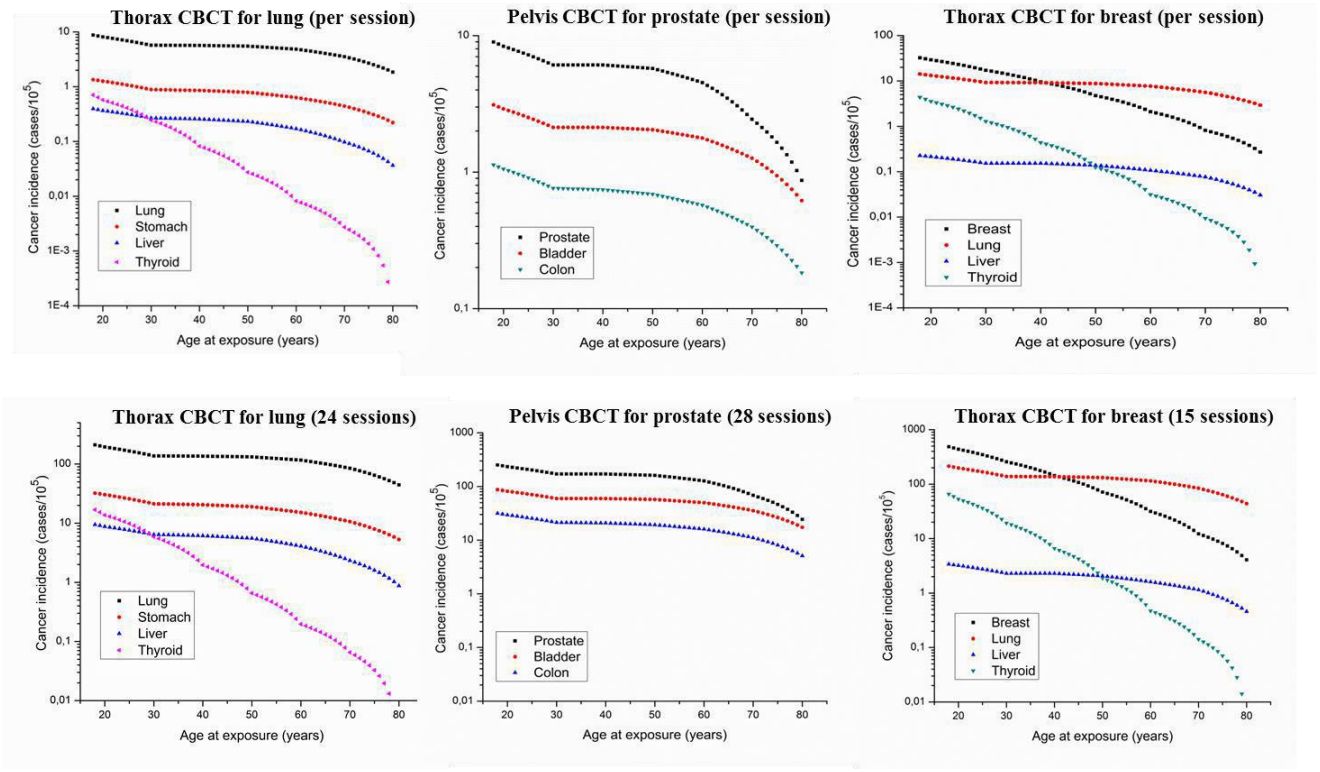

FIG. 1. Lifetime risk for each protocol, per session and for a complete course of IGRT treatment, taking into account the three target organs (lung, prostate and breast) and the organs at risk.

4. DISCUSSION AND CONCLUSION

The knowledge about organ doses in CBCT procedures is still limited, whereby the achieved results highlight the need to improve the awareness concerning the doses received in typical CBCT scans and from repeated exposures, helping clinicians planning treatments and the adequate use of CBCT.

This work has some limitations due to the use of voxel phantoms and the LAR coefficients of the BEIR VII Report. Concerning the voxel phantoms, the limitations are related with their lack of flexibility to represent the anatomic individual variability associated with organ size, shape and location, since these phantoms are based on CT images of a single patient [12]. Also, it is difficult to quantitatively estimate the bias introduced by the cardiac and respiratory motion and the daily variation of the geometric position of the patient organs, which is a critical aspect during the course of radiotherapy treatments. Regarding the risk estimation study, this is limited by the cancer incidence risk models proposed in BEIR VII Report, mainly due to inherent limitations in epidemiological data, which is largely based on the life-span studies of atomic bomb survivors [7].

In conclusion, this study shows the need to better assess the radiological risk associated with CBCT procedures for organs with high radio-sensitivity, such as lungs, prostate and breast. Similar remarks were made in studies involving CT diagnostic examinations [13], whereby CBCT procedures require the same attention in terms of risk assessment due to uncertainties in the latency time for the detrimental biological effects induced by ionizing radiation, both for the target organ and for the surrounding tissues.

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ORGANIZATION OF DATA COLLECTION AND ESTABLISHMENT OF DIAGNOSTIC REFERENCE LEVELS IN BOSNIA AND HERZEGOVINA

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Abstract

Regulations in Bosnia and Herzegovina (BiH) have defined diagnostic reference levels (DRL) based on international data and recommendations. However, national DRLs have never been established. In order to define the DRLs, BiH has proposed a national technical cooperation project with the International Atomic Energy Agency (IAEA) on establishment of DRL for the 2016-2017 cycle. The implementation of this project is ongoing, as well as the dose harvesting among diagnostic radiology departments around the country. Working group of medical physicists for implementation of this project has been formed by the counterparts. This paper discusses the methodology of data collection in the country, role of the project counterparts, Inspectorate of State regulatory agency for radiation and nuclear safety, working group of medical physicists, and IAEA. In addition, the paper gives an overview of the content and amount of data being collected, as well as a way forward for the establishment of national DRLs in BiH.

1. INTRODUCTION

Regulations in Bosnia and Herzegovina (BiH) have defined diagnostic reference levels (DRL) based on international data and recommendations. Regulation on the ionizing radiation protection in medical exposure published in 2011 by the State regulatory Agency for Radiation and Nuclear Safety (SRARNS) set up the

diagnostic reference levels, for all common diagnostic procedures, both in diagnostic radiology and nuclear medicine [1].

Establishment of national DRLs, based on national data, was not an easy task. Shortage of personnel with necessary knowledge and skills to perform this job was one of the problems. However, over the past two decades continuous support from the International Atomic Energy Agency (IAEA), as well as dedicated work of several medical physics professionals, made Bosnia and Herzegovina one of the leaders in the field.

2. METHODS

Bosnia and Herzegovina is a small country, with 3.5 million inhabitants. It is divided into one district and two regions (entities), and one of them into 10 cantons. The government responsibilities in healthcare are complex and divided between many ministries of health, none of them on national level. On the other hand, all responsibilities in radiation protection and nuclear safety are on national level. SRARNS, amongst other things, does licensing and inspection of all radiological facilities in the country. Problems may arise when SRARNS needs to implement or enforce a regulation in medicine, especially when they rely on activities in ministries of health or health insurance funds.

Regulation on the ionizing radiation protection in medical exposure is a transposition of European Council Directive 97/43. It forces all licence/registration holders in medicine to be covered by medical physics service. In case a hospital has a radiotherapy or nuclear medicine department, a fully employed medical physics specialist is mandatory. All large hospitals that have diagnostic radiology, nuclear medicine, and radiotherapy, are required to have an independent department of medical physics. This provided the base for medical physics to develop.

However, the real boost was given by the IAEA. Strategically planned national technical cooperation (TC) IAEA projects, with realistic objectives and valuable outcomes, have provided the local physicists knowledge and equipment to take part in broader activities, such as radiation protection and medical physics in nuclear medicine and diagnostic radiology.

Projects titled “Establishing a Medical Radiation Physics Centre” from 2009, “Strengthening Radiotherapy Physics Units to Meet the Requirements of International Standards” from 2012, and “Strengthening Radiation Protection in Medicine” from 2014 paved the way for the most complex and high demanding project yet: “Establishing National Diagnostic Reference Levels in Diagnostic Radiology” in 2016.

This project required not only the equipment and knowledge provided by the Agency over the years, but also a commitment of several professionals who were either employed in recent years or transitioned from physicists specialized in one field only to those who can perform tasks in diagnostic radiology too.

3. RESULTS AND DISCUSSION

Before the project started the group planned to complete the task was diverse. Some of them already had the experience in patient dosimetry, other were newly recruited medical physicists or physicists who worked in other fields.

The first step was to meet with an expert. At the meeting members of steering committee selected members of working group that will do most of the work related to data collection. The steering committee, together with the IAEA expert, selected the procedures for DRLs. This included basic radiography and computed tomography (CT) examinations. While in CT the common quantities are used (volume computed tomography air kerma index C_{vol} and air kerma length product $P_{KL,\mathrm{CT}}$), the steering committee decided to go with air kerma area product P_{KA} in case of radiography. For this purpose, we utilized the equipment provided by the IAEA through the project or SRARNS, as well as equipment already available in hospitals.

Members of the working group were assigned to create measurement and intercomparison procedure, and adapt the data collection tables from those provided by the IAEA project technical officer (Fig. 1).

Next important step was to collect test data and present it at the national training course. This gave some insights on how data collection will look like. During this period less experienced working group members had an opportunity to learn from their mistakes and have a hands-on experience on how the real data collection would look like.

Following the training course IAEA organized fellowships and scientific visits for several steering committee and working group members. During this period, they learned how patient doses are measured, collected, analysed, interpreted, and in the end how the DRLs are set-up and published.

Meanwhile, SRARNS sent out the letter to 5 large hospitals and 30 small diagnostic centres (public and private) with information on patient dose data collection.

After the training was completed data collection followed. A working group member together with SRARNS inspector would visit the site, set up the KAP meter (if necessary) and provide the technologists with data collection form. They introduce the responsible person to quantities that must be recorded (P_{KA} or C_{vol} and $P_{KL,\mathrm{CT}}$, tube voltage etc.), as well as others that are not mandatory (patient height, body mass, etc.). The proposed minimum number of recorded procedures is 50, but this was proven to be a challenge, especially in small radiological centres.

In October 2017 (before this paper was written) a national training course was organized where all centres presented their data to each other and to the experts. By the end of the year some data collection will continue, after which we expect the State Regulatory Agency for Radiation Protection and Nuclear Safety to change the Regulation to include new DRLs.

				Podaci o pacijentu				Radiografska tehnika			Veličina detektora		Parametri ekspozicije			Doza		
Broj pacijenta	Datum pregleda (Godina-Mjesec-Dan)	Dijagnostička pretraga	Projekcija	Spol	Starost (godina)	Visina (cm)	Tjelesna masa (kg)	Udaljenost fokus-film (cm)	Da li se koristi rešetka?	Veličina fokusa (veliki/mali)	Širina (cm)	Dužina (cm)	Anodni napon (kV)	Proizvod anodne struje i vremena (mAs)	Vrijeme ekspozicije (ms)	Proizvod kerme i površine (P_{KA})	Jedinica proizvoda kerme i površine	Ocjena kvaliteta slike
1																		
2																		
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Figure 1. Data collection form for radiography. Dark grey titled columns mark mandatory fields: procedure name, projection, tube voltage, air kerma area product and unit used. Light grey column titles are optional fields, such as patient sex, age, height, body mass, focus-film distance, anti-scatter grid used, focus size, cassette size, tube current exposure time product, and exposure time. The last column is reserved for image quality score.

4. DISCUSSIONS

It is necessary to note that some countries find the national diagnostic reference levels to be insufficient. They are being phased out and priority is given to the local DRLs, at hospital level, where single numbers are sometimes replaced with reference curves that take into account patient body mass or some other quantity. This, of course, means that one should strive to achieve the optimal patient dose, a dose that will be small, but still provide all the necessary diagnostic information, no matter on how high the doses are in other institutions or on national level. DRLs are, in this case, just a tool for optimization [2].

However, when the skills and knowledge on optimization of diagnostic procedures is limited, such use of DRLs would be an impossible mission. Setting up a trained human resource base is important, especially in a less developed countries with limited funds.

Optimization also depends on availability of large amounts of data. None of the large hospitals in the country have patient dose collection software. Collecting data manually is a formidable task. Institutions

included in the project have one (or rarely two) medical physicists working in diagnostic radiology. Most likely their job includes radiation protection too. It is difficult to expect this job to be done on a regular basis.

However, the necessity of optimization, as one of the three fundamental principles in radiation protection, cannot be neglected. The same group of institutions will continue their work in the next project cycle (2018-2019) with the project titled "Strengthening Infrastructure for Radiation protection of patients in medical exposure," whose main objective is to improve justification and optimisation of radiological examinations in the country. For the first time the project will have a team approach (medical physicist, radiologist, and technologist). This method has been proven as very effective.

5. CONCLUSIONS

Establishment of national diagnostic reference levels in a small country cannot be done without a good base of skilled professionals in medical physics. IAEA TC projects could provide all necessary help to achieve this goal. Experienced medical physicists will be able to tackle bigger problems, such as optimization of examinations in diagnostic radiology which will most likely lead to reduction of patient doses and doses to population from medical sources in general.

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COMPUTED TOMOGRAPHY CHALLENGES IN THE UNITED STATES

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Abstract

Computed Tomography (CT) imaging is a common diagnostic imaging study in the United States, offered in a wide variety of medical facilities. Use of this technology improves patient care, yet challenges regulators who oversee the safe use of radiation devices. Following several CT perfusion incidents in 2009, the Conference of Radiation Control Program Directors issued a safety warning and developed inspector training and requirements for radiation protocol committees (RPC), uniting physicists, radiologists and technologists to review and optimize CT protocols to lower patient dose while maintaining image quality. The Joint Commission, which accredits healthcare organizations in the US, recently expanded its requirements for CT by incorporating RPC concepts. The US Food and Drug Administration's dose reference card and the Image Wisely campaign promote awareness of radiation dose and education of patients and medical staff. The American College of Radiology developed criteria using evidence-based guidelines to assist physicians in choosing appropriate imaging studies for their patients. Since progress in CT technology outpaces the regulatory process, safe and appropriate patient care is most often achieved with best practices. Collaborative efforts between regulators, manufactures, and professionals to develop best practices is keyto improving radiation safety.

1. INTRODUCTION

X-ray imaging using computed tomography (CT) is a very common diagnostic test in the United States (US) and while it was originally only available in larger hospitals, it is now found in facilities of all sizes. This is wonderful from the aspect of access to better care, yet it poses challenges to regulators who are tasked with overseeing the safe use of radiation devices. In addition, the creation of cone beam CT opened the door for these units to be found in independent dental and medical offices. This poses new challenges as the operators in these smaller facilities often have less experience in radiation safety and quality control.

2. DISCUSSION

The Conference of Radiation Control Program Directors (CRCPD) is a national non-governmental non-profit organization dedicated to radiation protection. The CRCPD membership consists of directors and staff of state and local radiation control programs plus others who are interested in radiation protection issues. CRCPD's mission is "to promote consistency in addressing and resolving radiation protection issues, to encourage high standards of quality in radiation protection program directors, and to provide leadership in radiation safety and education." Since the use of x-ray machines in the United States is regulated primarily at the state level, CRCPD's model regulations and guidance for state and local radiation control programs are useful in achieving consistency nationwide in the regulation of thesedevices.

In 2009, over 200 patients at an individual facility received radiation doses that were approximately eight times the projected level during CT brain perfusion scans intended to aid in the diagnosis and treatment of stroke. Some patients reported erythema and hair loss, which was attributed to the overexposures. The ensuing investigation by the U.S. Food and Drug Administration (FDA) identified the overexposures were due to inappropriate adjustments that were made to a CT protocol [1]. This raised concerns that a widespread problem with CT quality assurance mayexist.

Following the CT head perfusion incidents, CRCPD issued a position statement urging facilities with CT units to review their CT protocols [2]. The goal was to ensure the current protocols were appropriate to provide the best possible study while assuring they were keeping patient exposures as low as reasonably achievable. Specifically, the statement urged all facilities with CT units to review their CT default protocols to ensure they

were the correct and intended protocol. Prior to the perfusion incidents, very few facilities had ever asked this question. As urged, facilities began to password protect their protocols and review them on a regular basis. CT technologists began talking to their service engineers to learn how the automatic exposure control functions on their scanners worked. Facilities began to monitor the dose indices for each patient and they established thresholds to investigate any procedures resulting in a radiation dose above the established levels.

This new awareness paved the way for medical facilities to form radiation protocol committees (RPC), bringing together qualified medical physicists, interpreting radiologists and CT technologists to review CT protocols and work to optimize them to lower patient dose while still ensuring image quality remained high. RPC's were intended to enhance and not replace traditional Radiation Safety Committees that have long been a standard in US radiation safety programs. CT manufacturers also took notice and began to incorporate safety checks to assist technologists in the safe operation of the CT units. The CT perfusion incidents also identified a problem with CT imaging naming conventions among the various manufacturers of CT scanners. The Medical Imaging and Technology Alliance (MITA), an organization of medical imaging equipment and radiopharmaceutical manufacturers and product developers, worked directly with CT manufacturers to facilitate common naming of CT studies [3]. MITA continues to work with industry leaders and regulatory agencies to improve patient safety relating to the use of x-ray equipment.

State regulators began to realize their inspection staff may not have the sufficient background to adequately inspect facilities with CT units. Since many states have limited resources, the states collaborate, with the help of the CRCPD, to develop suggested state regulations, guidance, and training that can be used as templates for the requirements in each state. In response to the need for inspector training for CT units, the CRCPD H-32 Committee on CT worked with the American Association of Physicists in Medicine to provide 2-days of education and hands-on training to enhance the state inspectors' knowledge base and skill set. An additional response resulted in the H-32 Committee developing a checklist for state inspectors to use when inspecting CT units [4].

The individual states often struggle to keep their regulations current with advancing technology. Several state regulatory programs implemented regulations which require all CT facilities in their state to develop and maintain an active CT RPC [5]. One of the charges that CRPCD maintains is to provide suggested state regulations. This is done to facilitate rule development that can be used by individual states who may not have the staff to update their regulations in a timely manner. The CRCPD Suggested State Regulations Part F – Medical Diagnostic & Interventional X-ray & Imaging Systems were updated to include RPC's for CT units in 2015 [6]. In a survey conducted by CRCPD to inquire if states are updating regulations to specifically address RPC's for CT facilities, several states indicated that they had made these updates and others indicated they will do so the next time their regulations are opened for changes. CRCPD has also provided guidance to state regulators on approving low dose lung CT screening programs for early lung cancer detection after the US Medicare program approved reimbursement for the procedure.

The CRCPD Suggested State Regulations Part F specifically address the following items for CT Radiation Protocol Committees:

- Membership.
  - Lead CT Radiologist;
  - Lead CT technologist;
  - Qualified Medical Physicist or Qualified Expert; and
  - Other individuals as deemed necessary.
- Provisions for establishing a system-wide RPC or forming a cooperative with multiple facilities.
- Responsibilities of the RPC.
  - Review existing CT protocols and then modify them as needed to improve image quality and/or lower patient dose;
  - Review the CT scanner capabilities to ensure optimumperformance;
  - Identify frequently used protocols and work to optimize image quality while lowering radiation dose. This should include a review at least annually of the protocolsfor:
    - Pediatric Head;
    - Pediatric Abdomen;
    - Adult Head;
    - Adult Abdomen;

- Adult Chest; and
- Brain Perfusion.

— Maintaining records.

- Record of all RPC meetings to include attendees, minutes and any actions taken;
- Maintain RPC policies and procedures;
- Record of radiation output information to include:
  - Patient identification;
  - Date and type of CT study;
  - Identification of the CT system used; and
  - Dose values provided on the CT system.

The Joint Commission recently expanded its requirements for CT units located in accredited facilities to include the same concepts that were established for RPC's [7]. Collaborative efforts to address patient concerns resulted in the Image Wisely campaign and the FDA's development of a patient medical imaging record [8]. The Image Gently campaign promotes awareness of the radiation dose received from imaging studies and provides education for patients, technologists, radiologists and referring physicians [9]. The American College of Radiology worked collaboratively with other professional societies to develop evidence-based guidelines which can be used to assist referring physicians in choosing the appropriate imaging study based on the indicated clinical conditions [10]. The ACR updates the appropriateness criteria guidelines annually to ensure they keep pace with current technology and treatments.

Cone beam computed tomography (CBCT) created additional regulatory and inspection concerns. CBCT first entered the imaging world in the US at dental and medical offices. The radiation output of early CBCT imaging systems was recognized as being much lower than traditional CT imaging systems and some states made the decision to regulate them in the same way dental or radiographic x-ray systems. As the technology and imaging capabilities with CBCT systems has improved, making them more commonplace. CBCT has also found in radiation therapy facilities as on-board imaging systems used to aid in identifying patient anatomy for positioning accuracy prior to treatments.

At this time, most states do not hold CBCT units to their RPC standards. In response to dichotomy in regulatory requirement, CRCPD created the H-44 Task Force on Cone Beam CT to study the issue and make recommendations [11]. One issue of concern that the Task Force is examining relates to facilities electing to not purchase a phantom from the manufacturer to perform digital imaging QA/QC. To address this and other issues, H-44 is currently developing a white paper on CBCT. Once it is finalized, the paper can be used as a training document for inspectors. The H-44 Task Force is also developing a CBCT inspection checklist to provide guidance to state inspectors.

3. CONCLUSION

The progress in CT technology will always outpace the regulatory process. Safe and appropriate patient care can only be achieved by working together to develop best practices and safety guidelines. Collaborative efforts between regulators, manufacturers, health care professionals and professional societies to develop best practices is key to improving radiation safety.

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U.S. TRACKS DIAGNOSTIC X-RAY DOSES AND PRACTICES THROUGH SURVEYS OF FACILITIES NATIONWIDE

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Abstract

The Conference of Radiation Control Program Directors (CRCPD), an organization representing the state and territorial radiation control programs in the United States, has long partnered with the U.S. Food and Drug Administration to conduct the Nationwide Evaluation of X-Ray Trends (NEXT) program in the United States. The NEXT program looks at particular x-ray studies in depth providing an objective analysis of technique, dose, operator requirements and training, and workload. NEXT is a randomized study conducted across the United States. Over forty plus years, the program has looked at exams including dental, mammography, computed tomography (CT), chest, abdomen, pediatric chest and cardiac catherization. These studies are published by CRCPD and have been a valuable resource for both states and facilities. Over the years, the results of the NEXT studies have led to improvements in dose and lowering of technique in many instances. The studies provide a way for states to compare facilities at inspection to a national average and for facilities to self-evaluate. As imaging has changed, the NEXT program has also adapted; however, it continues to be a valuable source of information on imaging in the United States.

1. INTRODUCTION

The Conference of Radiation Control Program Directors (CRCPD), an organization representing the state and territorial radiation control programs in the United States (US), has long partnered with the U.S. Food and Drug Administration (FDA) to conduct the Nationwide Evaluation of X-ray Trends (NEXT). The NEXT program looks at particular x-ray studies in depth providing an objective analysis of technique, dose, operator requirements and training and facility workload. Over the last forty plus years, the program has looked at exams including dental, mammography, computed tomography (CT), adult and pediatric chest, abdomen and cardiac catherization. The information gathered during the NEXT studies has led to improvements made by lowering techniques and reducing radiation dose across the country [1].

2. DISCUSSION

The Conference of Radiation Control Program Directors (CRCPD) is a national non-profit non-governmental organization dedicated to radiation protection. The CRCPD membership consists of directors and staff of state and local radiation control programs plus others who are involved in radiation protection matters. CRCPD's mission is "to promote consistency in addressing and resolving radiation protection issues, to encourage high standards of quality in radiation protection program directors, and to provide leadership in radiation safety and education."

The U.S. Food and Drug Administration (FDA) Center for Devices and Radiological Health (CDRH) works collaboratively with the CRCPD Nationwide Evaluation of X-ray Trends (NEXT) Committee through a unique state and federal partnership to survey the radiation doses patients receive and document diagnostic radiology practices across the country [2]. The partnership was formed in 1971 with the first survey being conducted the following year, in 1972. This study focused on collecting data for 12 commonly performed x-ray procedures. It included documentation of exposure technique factors, radiation dose exposure to the patient and

facility workloads for these procedures. The 12 x-ray studies included three dental procedures, lower extremities (foot) and anterior posterior (AP) views of the cervical, thoracic, and lumbar spine, abdomen (to include kidneys, ureters and the bladder) and chest.

As the popularity of automatic exposure control (AEC) for x-ray imaging grew, the committee recognized the need to capture AEC date in the surveys. The studies done in the early 1980's incorporated attenuation phantoms used to simulate an average adult patient in the anterior-posterior lumbar spine and abdominal surveys. To begin capturing data on high-contrast spatial resolution and low contrast image performance, a test tool was developed to document the x-ray facility's clinical imaging conditions under normal viewing circumstances.

In 1984 the surveys changed to begin focusing on one specific imaging procedure at a time. This started with the AP chest study in 1984, which was repeated again in 1986. The AP lumbar spine and AP abdomen studies were done in 1987 and 1989. By changing the survey focus to one radiology procedure, greater comprehensive data has been collected to capture a better understanding of the elements that influence x-ray image quality and the radiation exposure received bypatients.

As x-ray imaging equipment technology improved and clinical practices evolved, the data collected during NEXT surveys documents positive changes over time through quality indicators. The test methods used to collect data during the 1985, 1988 and 1992 NEXT mammography surveys were closely modelled to inspections under the US federal Mammography Quality Standards Act in the early 1990's. The National Council on Radiation Protection and Measurements used NEXT data to develop a number of recommendations for radiation diagnostic reference levels [3].

Computed tomography (CT) studies have also been addressed by the NEXT program with surveys completed in 1990, 2000 and 2006 [4]. The surveys documented the advances in CT technology to include improved scanning speed, the transition from single slice to helical and multislice technology, and tube current modulation which is used to adjust the tube current to account for varying attenuation in the scan field due to changes in body habitus. Survey data captured significant growth of the use of CT imaging between each study.

In the US, there are federal performance regulations for diagnostic x-ray systems [5]. The federal standards do not address radiation dose or the safe use of x-ray equipment and is up to the individual states to establish these regulations. The data collected during NEXT surveys has been adopted by several state to establish maximum limits on entrance skin exposures for the 12 commonly performed x-ray procedures that were surveyed in the early years of NEXT [6] [7]. These limits have been instrumental in ensuring lower patient radiation exposures and establishing consistency across thenation.

The training provided to NEXT survey participants enhances the skill set of individual state inspectors as it exposes them to new test methods. Many of the test methods developed by NEXT have been incorporated by individual states into their standardized methods used to test x-ray equipment. The NEXT committee also produces information in simplified trifold format that state inspectors can share with the facilities they inspect [8]. The information allows the facility to see how their current clinical standards compare with other facilities across the country, allowing them to identify and address areas where improvements in their radiation safety program can be made.

3. CONCLUSION

The NEXT program has served the United States well as the CRCPD and individual state programs have been able to use the collected information to make positive changes in patient dose and radiation safety. NEXT continues to evolve by looking at x-ray studies which have not been previously surveyed, such as chiropractic x-ray exams. The committee has also improved accessibility to their training methods using webinars to reach a larger audience than face-to-face training sessions allow. NEXT has shared information with the International Atomic Energy Agency (IAEA), the American Association of Physicists in Medicine and the U.S. National Council on Radiation Protection and Measurements (NCRP) in an effort spread these positive changes even further. Collaboratively, efforts such as these will continue to have a positive impact on patient health and the radiation community.

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ACR DIAGNOSTIC REFERENCE LEVELS AND ACHIEVABLE DOSES FOR MEDICAL IMAGING IN THE US

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Abstract

A diagnostic reference level (DRL) is an investigational level used to identify unusually high radiation doses for common diagnostic medical X-ray imaging procedures. DRLs are suggested action levels above which a facility should review its methods and determine if acceptable image quality can be achieved at lower doses. They are not regulatory dose limits. The American College of Radiology (ACR) has published reference levels for the US in their Practice Parameters and Technical Standards since 2002. These levels are based on published literature, data from the ACR Accreditation Program, and, more recently, the ACR Dose Index Registry data. The newest Practice Parameter for Diagnostic Reference Levels and Achievable Doses in Medical X-ray Imaging is currently under development by ACR, AAPM, and SPR and will be reviewed and, hopefully approved, by these sponsoring organizations in May 2018. The purpose of this work is to discuss the data that is being used to develop these DRLs along with the proposed DRL recommendations. The presentation will focus on the development and use of benchmarks provided from the ACR Dose Index Registry's analysis of 1.3 million examinations from the top 10 adult CT examinations performed at 583 facilities in 2014.

1. INTRODUCTION

A diagnostic reference level (DRL) is an investigational level used to identify unusually high radiation doses for common diagnostic medical X-ray imaging procedures. DRLs are suggested action levels above which a facility should review its methods and determine if acceptable image quality can be achieved at lower doses. The International Commission on Radiological Protection (ICRP) emphasizes that DRLs "are not for regulatory or commercial purposes, not a dose restraint and not linked to limits or constraints" [1-3].

DRLs are based on standard phantom or patient measurements under specific conditions at a large number of representative clinical facilities. DRLs have been set at approximately the 75th percentile of measured patient or phantom data. This means that procedures performed at 75% of the institutions surveyed have exposure levels at or below the DRL. The ICRP also emphasizes that DRLs should not be applied to individual patients [9]. To make meaningful comparisons, aggregate facility data collected in the same manner that the benchmark DRLs were developed should be compared against the DRL.

The National Council on Radiation Protection and Measurements (NCRP) Report 172 explains that achievable dose (AD) can be used with DRLs to assist in optimizing image quality and dose. ADs are set at approximately the median (50th percentile) of the study dose distribution, i.e., half of the facilities are producing images at lower doses and half are using higher doses [3].

DRLs and ADs are part of the optimization process. It is essential to assure that image quality appropriate for the diagnostic purpose is achieved when changing patient doses. Optimization must balance image quality and patient dose, i.e., image quality must be maintained at an appropriate level as radiation doses are decreased.

2. HISTORY OF DOSE COLLECTIONS AND GUIDANCE IN THE US

The United States has a long history of federal, state and professional organization programs that collect national exposure and dose information from common imaging examinations. Until recently, most of the exposure and dose information collected was based on the use of phantoms representing the attenuation of standard size body structures. The ACR Dose Index Registry, launched in 2011, was the first program that collected dose information that was obtained during examinations of actual patients. (See Table 1.)

TABLE 1. EXAMPLES OF DOSE DATA COLLECTION IN US

Study	Year
US Public Health Service X-Ray Exposure Studies (XES)	1964, 1970
US Food and Drug Administration (FDA) Dental Exposure Normalization Technique (DENT)	1972
Conference of Radiation Control Program Directors (CRCPD) - FDA Nationwide Evaluation of X-ray Trends (NEXT)	1973
FDA Breast Exposures Nationwide Trends (BENT)	1977
American College of Radiology (ACR) Accreditation Programs	1987
ACR Dose Index Registry (DIR)	2011

As a result of the dose information collected, US agencies and organizations started publishing dose guidance for facilities specifying maximum dose levels for standard size patients for various examinations. Although most of the information published by the agencies and organizations in Table 2 was true guidance, some were not. The Mammography Quality Standards Act provided a regulatory dose limit for a phantom representing a standard size and density breast in mammography; the ACR accreditation programs likewise specified dose limits for a phantom representing a standard size body part.

TABLE 2. EXAMPLES OF MAXIMUM DOSE GUIDANCE

Organization	Year
US Environmental Protection Agency (Federal Guidance Report No. 9)	1976
ACR Accreditation Programs	1987
Mammography Quality Standards Act (MQSA)	1994
ACR (Standards; Practice Guidelines)	2002, 2008, 2013
CRCPD (Patient Exposure and Dose Guide)	2003
American Association of Physicists in Medicine (AAPM)	2005
National Council of Radiation Protection and Measurements	2012

3. ACR DOSE INDEX REGISTRY

The National Radiology Data Registry (NRDR™) is a data warehouse for diagnostic imaging registries run by the ACR to collect examination data and results. The primary purpose of NRDR is to provide national and regional data to aid facilities in improving patient care. The CT Dose Index Registry (DIR) continuously collects, de-identifies and transmits dose indices and patient size information to the NRDR for storage and analysis [4] enabling the development of benchmarks.

Using data from the ACR's Dose Index Registry, the world's largest registry of dose information, Kanal et al [5] have established U.S. national dose levels based on patient size. Data from the 10 most common CT examinations on adult patients (aged 19 years and older) performed between January and December 2014 at 583

US facilities were analysed. For head examinations, the lateral thickness was used as an indicator of patient size; for neck and body examinations, water equivalent diameter [6] was used. Data from over 1.3 million examinations provided median values as well as mean, 25th and 75th (DRL) percentiles for $CTDI_{vol}$, dose-length product (DLP) and size-specific dose estimate (SSDE) [7] to enable the development of ADs and DRLs. (See Table 3.)

TABLE 3. DIAGNOSTIC REFERENCE LEVELS AND ACHIEVABLE DOSES OF MEDIAN SIZE PATIENTS FOR THE 10 MOST COMMON ADULT CT EXAMINATIONS IN THE ACR DOSE INDEX REGISTRY

Examination	Median Patient Size (cm)	$CTDI_{vol}$ (mGy)		SSDE (mGy)		DLP (mGy-cm)	
		DRL	AD	DRL	AD	DRL	AD
Head and brain without contrast	14-16	56	49			962	811
Neck with contrast	18-22	19	15			563	429
Cervical spine without contrast	18-22	28	20			562	421
Chest without contrast	29-33	12	9	15	11	443	334
Chest with contrast	29-33	13	10	15	11	469	353
Chest pulmonary arteries with contrast	29-33	14	11	17	13	445	357
Abdomen and pelvis without contrast	29-33	16	13	19	15	781	639
Abdomen and pelvis with contrast	29-33	15	12	18	15	755	608
Abdomen, pelvis and kidney without contrast	29-33	15	12	19	14	705	576
Chest, abdomen and pelvis with contrast material	29-33	15	12	18	14	947	779

Figures 1 and 2 provide examples of how DRLs vary with patient size. "All" represents the average DRL for the examination. Note that SSDE is not defined for the head and is thus not presented in the figure. For abdomen-pelvis examinations, note that the SSDE DRLs are much higher than the $CTDI_{vol}$ DRLs for the smallest categories of patients; conversely, the $CTDI_{vol}$ DRL is higher than the SSDE for the largest category of patients. This is to be expected since $CTDI_{vol}$ is based on a 32-cm PMMA cylinder phantom and does not provide an estimate of the dose received by the patient on the scan table. For the head examination, both $CTDI_{vol}$ and DLP DRLs vary slightly with patient size. For body examinations, as illustrated by the abdomen-pelvis figures, there is a stronger relationship of $CTDI_{vol}$, SSDE and DLP DRLs with patient size.

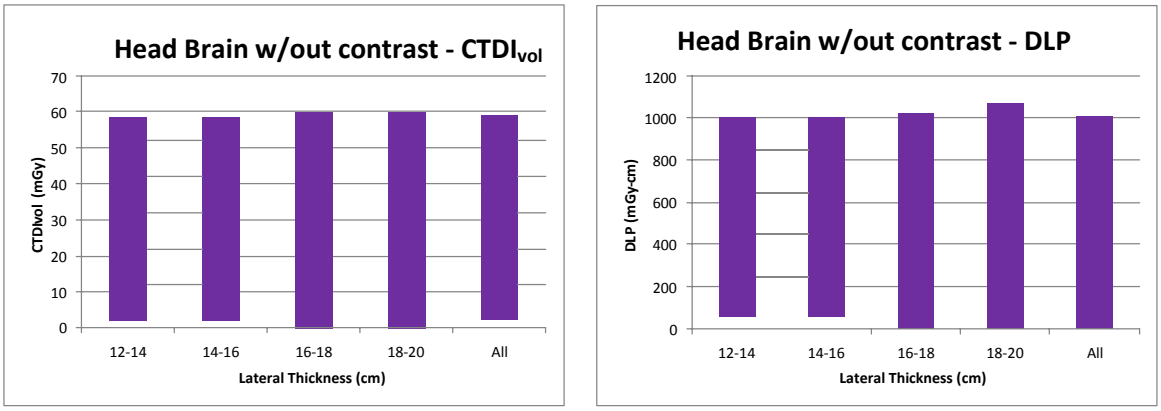
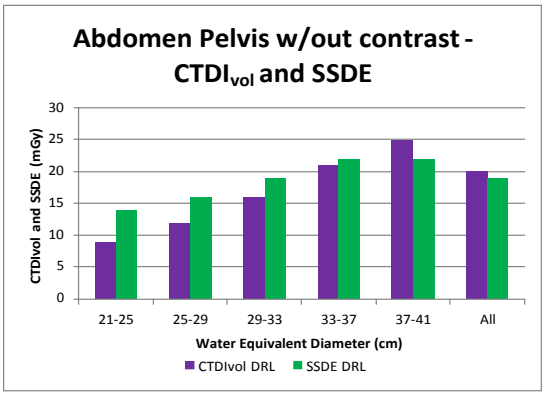


FIG 1. Patient size-based $CTDI_{vol}$ and DLP DRLs for head CT examinations.



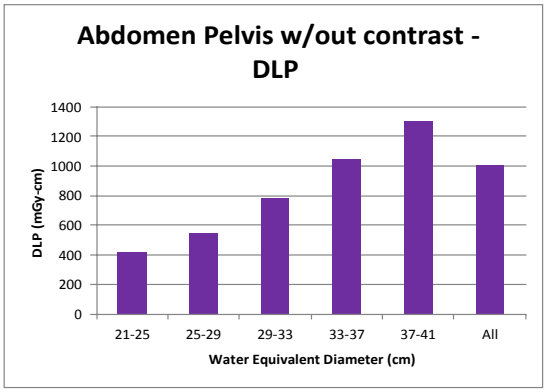


FIG 2. Patient size-based $CTDI_{vol}$, SSDE and DLP DRLs for abdomen-pelvis CT examinations.

4. ACR–AAPM PRACTICE PARAMETER FOR DIAGNOSTIC REFERENCE LEVELS AND ACHIEVABLE DOSES IN MEDICAL X-RAY IMAGING

The ACR, in collaboration with the AAPM and the Society of Pediatric Radiology (SPR), publishes practice parameters with diagnostic reference levels for commonly performed imaging examinations and updates them, based on current published literature, every five years. The current practice parameters [8] were published in 2013 and are primarily based on data from NEXT surveys, data from ACR accreditation and NCRP Report 172. The practice parameter is publicly available on the ACR website.

The 2018 ACR–AAPM Practice Parameter for Diagnostic Reference Levels and Achievable Doses in Medical X-Ray Imaging has been drafted and expands the previous version with the addition of size-based adult CT DRLs from Kanal's Dose Index Registry work and size-based paediatric CT DRLs from Strauss's [9] and Goske's [10] studies. The draft is currently undergoing review by ACR, SPR and AAPM members and will subsequently be reviewed and approved after the ACR's May 2018 annual meeting. The final document will contain DRLs and ADs for commonly performed adult and paediatric x-ray examinations (mGy), fluoroscopic procedures (mGy min^{-1} and mGy), and CT (mGy and mGy-cm).

5. DISCUSSIONS

Developing and maintaining current national DRLs and ADs are a challenge due to changing technology, evolving practice, variation in patient size and the time and personnel expertise necessary to acquire the data. The ACR Dose Index Registry has streamlined some of the process to enable the collection of large numbers of examinations.

Setting DRLs and ADs are not the final step in the process. Radiologists, other physicians and technologists in the US frequently are not aware of the doses that they and their equipment administer to their patients. Most don't even know what diagnostic reference levels or achievable dose are or that dose benchmarks are available. Raising awareness is key. Programs such as Image Wisely [11] and Image Gently [12], as well as professional organizations in the US continue to work towards raising this awareness and providing educational material to help facilities optimize their doses. The growing participation of US imaging facilities in the ACR Dose Index Registry and the popularity of commercial dose monitoring software will help facilities in this effort as they establish solid and relevant benchmarks going forward.

6. CONCLUSIONS

Healthcare facilities can use DRL and AD information to effectively compare their patient doses to national benchmarks, optimize their exam protocols so that dose is commensurate with the size of the patient, and help avoid unnecessary radiation exposure.

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A Monte Carlo method to generate energy spectra and filtration for multi-detector computed tomography

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Abstract:

Multidetector computed tomography (MDCT) scanners have largely replaced single-slice CT scanners in radiation oncology, offering shorter scan times and higher resolution. While the MDCT simulator has gained wide use in radiation oncology, the characteristics of MDCT X-ray beams have not been thoroughly investigated. The aim of this work is to investigate the application of the Monte Carlo method to determine the characteristics of the X-ray beams generated by an MDCT scanner. The code used was BEAMnrc, a general-purpose Monte Carlo transport package. An MDCT machine was simulated in the MC system. The X-ray tube geometries and materials were based on the specifications provided by the manufacturer. Two physical characteristics of the MDCT beams, i.e., the derived X-ray spectrum and the half value layer (HVL), were benchmarked in order to validate the MC model used in this work. We developed Monte Carlo X-ray tube models to characterize the X-ray beams of the commercial MDCT. The model was validated by comparing the simulation results with manufacturer's data or with existing experiments. Overall, the model was shown to reproduce the X-ray output ofthe MDCT system.

1. INTRODUCTION

The use of multidetector row CT (MDCT) imaging is escalating, resulting in a considerable increase in the contribution from CT scans to the estimated collective radiation dose from medical procedures [1-3]. To understand and quantify the risk associated with MDCT examinations, efforts have been made to more accurately determine the radiation doses of individual radiosensitive organs, which are important quantities used to calculate metrics such as effective dose and cancer risk [4-8].

The Monte Carlo method (MC) is a powerful tool for investigating the characteristics of X-ray beams in diagnostic radiology. Although many studies have investigated the dosimetric effects of MDCT in MC simulations, most of them used precalculated or manufacturer-provided X-ray spectra as an initial X-ray source in their simulations. While using the spectrum data as an X-ray source can reduce the simulation time for bremsstrahlung generation, it ignores the off-axis variation and beam hardening effects. These effects are more important in MDCT than in single-slice CT since MDCT uses wider beams. Therefore, to achieve a more realistic simulation of X-ray generation, a full MC simulation of bremsstrahlung generation within an X-ray tube is necessary.

An accurate MDCT MC simulation typically requires a detailed description of the scanner under investigation, including specifications of the photon energy spectrum, the bowtie and inherent filtration design, and the geometry of the scanner (the focal spot to isocenter distance, fan angle, etc.).

In this study, we performed full MC simulations of an MDCT machine. The X-ray tube geometries and materials were based on the specifications provided by the manufacturer. We implemented the MDCT X-ray tube models using a BEAMnrc/EGSnrc MC code system. The MDCT beam outputs were simulated in order to characterize the MDCT beams. The simulation produces a phase space (PHSP) file, which contains particle information (energy, position, direction, weight, and interaction history) for each particle as it crosses a plane perpendicular to the radiation source. The PHSP file is used for beam characterization.

2. METHODS

The code used was BEAMnrc, a general-purpose Monte Carlo transport package. The features in BEAMnrc include the use of component modules (CMs), information about particles' stored phase space, the track of the history of each particle, and various variance reduction techniques, and it provides files and structures for parallel processing, together with a user friendly interface. The component modules are actually a variety of elementary geometric entities and can be used to represent the components of an accelerator. Each CM deals with a specific class of geometric shape and is contained between two planes, which are perpendicular to the beam axis. No overlap between CMs is allowed. Each CM operates completely independent of the other CMs. A CM is defined with a variety of parameters that are explicit values related to the geometric shape and material type. The parameter values are specified in an input file given by the user to model a specific accelerator component when performing a simulation.

We employed BEAMnrc to characterize the MDCT beam. The X-ray tube geometries and materials were based on the specifications provided by the manufactures. The MDCT simulation was composed of several CMs: a tungsten target (XTUBE CM), a tube housing (FLATFILT CM), an inherent filter (SLAB CM), a bowtie filter (JAWS CM), and a collimator (JAWS CM).

The phase space file was scored below the collimator and was used to analyze the X-ray spectrum and half-value layer (HVL).

A variance reduction technique called the directional bremsstrahlung splitting (DBS) method was used, with a splitting number of 10000 to reduce the computational time. DBS uses a combination of bremsstrahlung splitting and the Russian roulette technique. All other low energy particle transport options were turned on in the simulations: electron impact ionization, bound Compton scattering, photon electron angular sampling, Rayleigh scattering, atomic relaxation and simple bremsstrahlung angular sampling. For the bremsstrahlung cross sections, NIST data were used for all simulations, and XCOM data were used for photoabsorption and Rayleigh scattering cross sections. Electron and photon cutoff energies were set to 512 and 1 keV, respectively, and all material data were reproduced using PEGS4 user code.

We simulated two physical characteristics (the X-ray spectrum and HVL) of the MDCT beam in order to validate the MC model used in this work. We derived the X-ray spectrum of the MDCT system from the phase space file and compared it to the manufacturer's data. A peak kilovoltage of 120 kVp was chosen. The X-ray spectrum was extracted in a region of 1x1 cm^2 at the central axis using the BEAM Data Processor (BEAMDP), and we estimated the HVL for an MDCT system by varying the thickness of aluminum filters in the narrow beam geometry. The cavity code was used for thesesimulations.

3. RESULTS

The X-ray spectra of our MC models were benchmarked against the manufacturer's data. The MC results were normalized to the manufacturer's data. As shown in figure 1, the MC generated X-ray spectra were in good agreement with the manufacturer's data over the entire energy range. We needed to adjust the bowtie filter to match the MC spectra with the spectra provided by the manufacturer.

Table I gives the measured and simulated first HVL for the MDCT system for 120 kVp.

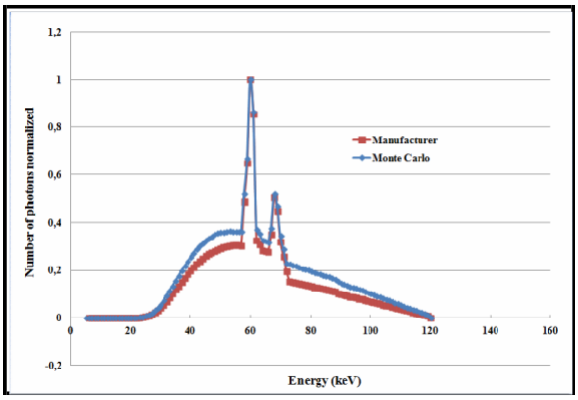

Figure 1: Comparison of X-ray spectra between MC results and manufacturer's data.

Table I: Measured and simulated first HVL for the MDCT system for 120 kVp.

Energy (kVp)	Measurements (mm Al)	Simulations (mm Al)	Percent Difference (%)
120 (PHSP)	8.58	7.5	11
120 (manufacturer)	8.59	8.0	7

The measured and simulated first HVL agree within for all beam energies. The agreement of the first HVL demonstrates the adequate modeling of the added and inherent filtration and the correct incident electron energy. The statistical uncertainties of the simulations are within 0.5%.

4. CONCLUSIONS

We have developed full MC models for a commercial MDCT scanner and benchmarked them against measurements and manufacturer data. The characteristics of the MDCT beams were analyzed with regard to X-ray spectra and the HVL.

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A Monte Carlo method to generate energy spectra and filtration for a Multi-Detector Computed Tomography

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Abstract: Multidetector computed tomography (MDCT) scanners have largely replaced single slice CT scanners in radiation oncology offering shorter scan time and higher resolution. While the MDCT simulator has gained wide use in radiation oncology, the characteristics of MDCT x-ray beams have not been thoroughly investigated. The aim of this work is to investigate the application of the Monte Carlo method to determine the characteristics of x-ray beams generated by a MDCT scanner. The code used was BEAMnrc, a general-purpose Monte Carlo transport package. A MDCT machine was simulated in the MC system. The x-ray tube geometries and materials were based on the specifications provided by manufacturer. Two physical characteristics of the MDCT beams were benchmarked in order to validate the MC model used in this work. The derived x-ray spectrum and the half value layer (HVL). We developed Monte Carlo x-ray tube models to characterize the x-ray beams of the commercial MDCT. The model was validated by comparing the simulation results with manufacturer's data or experiments. Overall, the model was shown to reproduce the x-ray output of MDCT system.

1. Introduction:

The use of multidetector row CT (MDCT) imaging is escalating, resulting in a considerable increase in the contribution from CT scans to estimated collective radiation dose from medical procedures [1-3]. In order to understand and quantify the risk associated with MDCT examinations, efforts have been made to more accurately determine the radiation dose to individual radiosensitive organs, which are important quantities used to calculate metrics such as effective dose and cancer risk [4-8].

The Monte Carlo method (MC) is a powerful tool for investigating the characteristics of x-ray beams in diagnostic radiology. Although many studies have investigated the dosimetric effects of the MDCT in MC simulations, most of them used precalculated or manufacturer-provided x-ray spectra as an initial x-ray source in their simulations. While using the spectrum data as an x-ray source can reduce the simulation time for

bremsstrahlung generation, it ignores the off-axis variation and beam hardening effects. These effects are more important in MDCT than in single slice CT since MDCT use wider beams. Therefore, to achieve a more realistic simulation of x-ray generation, full MC simulation of bremsstrahlung generation within x-ray tube is necessary.

An accurate MDCT MC simulation typically requires a detailed description of the scanner under investigation, including specifications of the photon energy spectrum, the bowtie and inherent filtration design, and the geometry of the scanner (focal spot to isocenter distance, fan angle).

In this study, we're performed full MC simulations of a MDCT machine. The x-ray tube geometries and materials were based on the specifications provided by manufacturer. We're implemented the MDCT x-ray tube models using BEAMnrc/EGSnrc MC code system. MDCT beam outputs were simulated in order to characterize the MDCT beams. The simulation produces a phase space (PHSP) file, which contains particle information (energy, position, direction, weight, interaction history) for each particle as it crosses a plane to the radiation source. The PHSP file is used for beam characterization.

2. Material andMethods

The code used was BEAMnrc, a general-purpose Monte Carlo transport package. The features in the BEAMnrc includes the use of the component modules (CMs), information about particles storage phase space, track of the history of each particle, application of various variance reduction techniques, they provide files/structure for parallel processing, which are developed in a user friendly interface. Component modules are actually a variety of elementary geometric entities and can be used to represent the components of an accelerator. Each CM dealt with a specific class of geometric shape and is contained between two planes, which are perpendicular to the beam axis. No overlapping between CMs is allowed. Each CM operates completely independent of the other CMs. A CM is defined with a variety of parameters that are explicit values related to the geometric shape and material type. The parameter values are specified in an input file given by the user to model a specific accelerator component when performing a simulation.

We're employed the BEAMnrc to characterize the MDCT beam. The x-ray tube geometries and materials were based on the specifications provided by manufactures.

The MDCT simulation was composed by several CMs: tungsten target (XTUBE CM), tube housing (FLATFILT CM), inherent filter (SLAB CM), bowtie filter (JAWS CM), and collimator (JAWS CM).

The phase space file was scored below the collimator and was used to analyze the x-ray spectrum and half-value layer (HVL).

A variance reduction technique called directional bremsstrahlung splitting (DBS) method was used, with a splitting number of 10000 to reduce the computational time. DBS uses a combination of bremsstrahlung splitting and Russian roulette technique. All other low energy particle transport options were turned on in the simulations: electron impact ionization, bound Compton scattering, photon electron angular sampling, rayleigh scattering, atomic relaxation and simple bremsstrahlung angular sampling. For the bremsstrahlung cross sections, the NIST data were used for all simulation and XCOM data were used for photo-absorption and Rayleigh scattering cross sections. Electron and photon cutoff energies were set to 512 and 1 keV, respectively and all material data were reproduced using PEGS4 user code.

We're benchmarked two physical characteristics (x-ray spectrum and HVL) of the MDCT beam in order to validate the MC model used in this work. We derived the x-ray spectrum of the MDCT system from the phase space file and compare it to a manufacture's data. The peak kilovoltage of 120 kVp was chosen. The x-ray spectrum was extracted in a region of 1x1 cm^2 at central axis using BEAM Data processor (BEAMDP) and we estimated the HVL for a MDCT system varying the thickness of aluminum filters in the narrow beam geometry. The cavity code was used for these simulations.

3. Results

The x-ray spectra of our MC models were benchmarked against the manufacturer's data. The MC results were normalized to the manufacturer's data. As shown in figure 1, MC generated x-ray spectra were in good agreement with the manufacturer's data over the entire energy range. We need adjusted the bowtie filter to match the MC spectra with the manufacture's.

Table I gives the measured and simulated first HVL for the MDCT system for the 120 kVp.

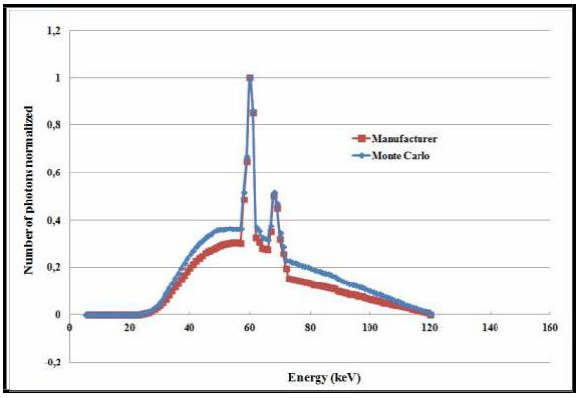

Figure 1: Comparison of x-ray spectra between MC and manufacture's data.

Table I: Measured and simulated first HVL for the MDCT system for the 120 kVp.

Energy (kVp)	Measurements (mmAl)	Simulations (mmAl)	Percent Difference (%)
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The measured and simulated first HVL agree within for all beam energies. The agreement of the first HVL demonstrates the adequate modelling of the added and inherent filtration and correct incident electron energy. The statistical uncertainties on the simulations are within 0.5%

4. Conclusions

We have developed full MC models for the commercial MDCT scanner and benchmarked them against measurements and manufacturer data. The characteristics of MDCT beams were analyzed with regard to x-ray spectra and HVL.

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POTENTIAL FOR THE ESTABLISHMENT OF NATIONAL CT DIAGNOSTIC REFERENCE LEVELS IN THE RUSSIAN FEDERATION

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Abstract

Computed tomography (CT) is a widespread diagnostic modality that is commonly associated with relatively high patient doses. Hence, optimization of radiation protection of the patients from CT examinations is extremely important. An integrant part of radiation protection in medicine is a system of diagnostic reference levels (DRLs). The aim of the study was to evaluate the possibility of establishing DRLs for typical CT examinations on national level in the Russian Federation. The study is based on the dose surveys performed in different regions of Russia in 2009-2017. Data was collected on the most common native and multiphase CT examinations as well as whole body CT as a part of positron emission tomography combined with computed tomography (PET/CT) examinations. Establishment of DRLs on the region level in Russia is complicated due to the high number of regions and limited availability of dose data. Comparison between typical dose distributions indicated no significant regional differences, hence allowing establishing DRLs on the national level. The 75% percentiles of both DLP and effective dose distributions were proposed as the preliminary values of national DRLs. It was proposed to establish DRLs for whole native CT examinations or for one phase of multiphase CT examination.

1. INTRODUCTION

Computed tomography (CT) is a widespread diagnostic modality that is used either as an independent diagnostic method or as an addition in nuclear medicine. In Russia, the number of CT examinations is rapidly increasing (by a factor of 5 during the last decade, corresponding to 8 mln examinations in 2015). CT contributes up to 45% to the collective dose to the Russian population from medical exposure [1]. Moreover, CT examinations can be associated with high patient dose (up to 50-100 mSv per examination) [2]. That indicates the importance of focusing the radiation protection on this diagnostic modality.

Radiation protection of the patients from medical exposure in developed countries is based on the system of diagnostic reference levels (DRLs) [3]. DRLs are defined as a specific (usually 75%) percentile of a selected dose quantity distribution for a certain examination. A common approach to the establishment of CT DRLs is to use dose-length product (DLP, mGy·cm) or computer tomography dose index (CTDI, mGy). However, according to Russian legislation, each patient should be informed about the dose and the possible consequences (radiation detriment) from medical exposure [4]. The effective dose is used for rough risk assessment in Russia [5].

Establishing DRLs on a regional level allows considering the variations in local radiological practice. However, it is complicated due to the high number of regions in Russia (82 as on 2015). Not all CT examinations (i.e. whole-body CT-examinations) are widespread in each region. Hence, the aim of the study was to combine results from CT dose surveys in Russia and to evaluate the possibility of establishing DRLs for most common CT examinations on national level.

2. MATERIALS AND METHODS

Dose surveys were performed in two representative regions of Russia: St. Petersburg and Belgorod region [2] in 2014; previously collected data was complemented in 2015. Data was collected on typical native CT examinations of head, chest, abdomen, pelvis and multiphase CT examinations with contrast injection (computed tomography angiography - CTA) of head, chest and abdomen. Additionally, data on whole body CT examinations as a part of whole body positron emission tomography combined with computed tomography (PET/CT) examinations was collected in 2012-2017. The following information was collected: patient data (sex, weight, age); protocol parameters (kV, total mAs, collimation, pitch, time per tube rotation), and patient dose parameters (CT dose index – CTDI and dose length product – DLP). Data was collected for at least 10 standard patients for each type of CT examinations for each CT unit. Typical patient doses were estimated as an average for the standard patient sample for each CT unit. Typical patient doses from current survey were combined with the published data on patient doses from CT examinations in Russia [7,8]. Overall data on the hospital/CT unit sample and the selected examinations is presented in Table 1.

TABLE 1. OVERALL DATA ON DOSE SURVEYS AND THE SELECTED EXAMINATIONS

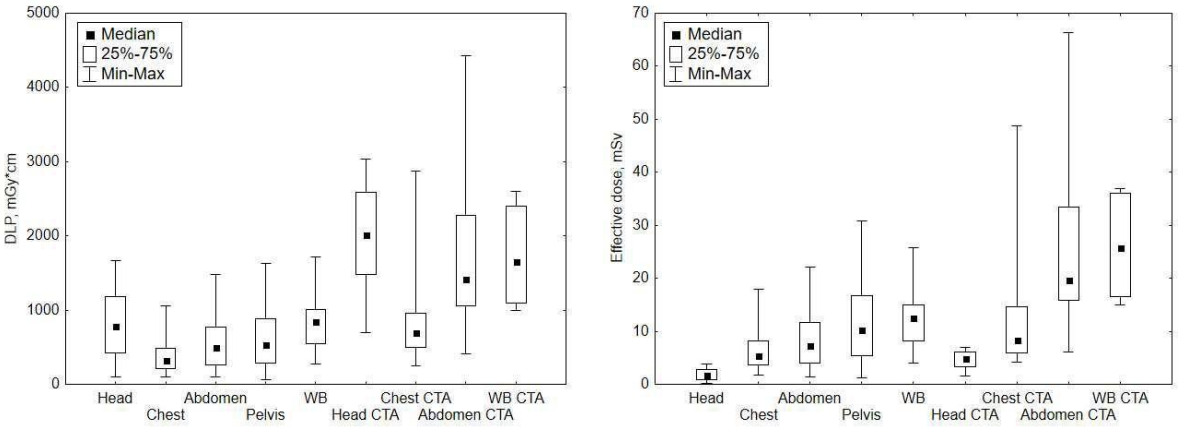
CT examination type	Native CT examinations			Computer tomography angiography (CTA)	Positron-emission tomography combined with CT (PET/CT)
Data source	Current survey	Bratilova et al. 2014 [7]	Matkevich et al. 2016 [8]	Current survey	Current survey
Typical examinations	Head, chest, abdomen, pelvis	Head, chest, abdomen, pelvis	Head, chest	Head, chest, abdomen	Whole body native and CTA
Surveyed regions	St-Petersburg/ Belgorod region	St-Petersburg/ Leningrad region	Moscow	St-Petersburg/ Belgorod region	12***
Total № of hospitals	5/7*	12/3**	1	5/7	17
Total № of CT units	8/14*	14/3**	4	8/14	20
Year of survey	2014-2015	2009-2012	2012-2014	2014-2015	2012-2017

* St-Petersburg/Belgorod region
** St-Petersburg/Leningrad region
*** St-Petersburg, Moscow, Belgorod region, Kazan region, Primorsky krai, Bashkortostan, Tumen region, Tambov region, Kursk region, Lipetsk region, Orel region, Sverdlovsk region

The effective dose was calculated using CT-EXPO software [9] based on the tissue weighting coefficients from ICRP Publication 60 [10]. Median, 25-75%-percentiles of typical dose distributions were estimated for each examination for both DLP and effective dose. Due to specificity of radiation protection of medicine in Russia, two dose quantities were considered as a potential quantities for DRLs in Russia: DLP and effective dose. Preliminary national DRLs were estimated as 75%-percentiles of typical patient dose distributions for a pooled sample.

3. RESULTS AND DISCUSSIONS

The typical patient dose distributions in DLP and effective dose for the pooled sample are presented on Fig. 1.



a b

FIG.1. Distribution of typical doses for different CT examinations for the pooled sample: a- for DLP (mGy·cm); b – for effective dose (mSv).

Comparison between typical dose distributions indicated no significant regional differences, hence allowing establishing DRLs on the national level. Analysis of distributions indicated that variation in typical doses was smaller for standardized examinations (up to a factor of 10 for native CT examinations of head or chest). Variation in typical doses was significant (up to a factor of 25) for multiphase CT examinations or examinations where scan length was influenced by the physician preferences or the objective of the examination.

The 75% percentiles of dose distribution of pooled samples were used as the preliminary values of national DRLs (table 2). Preliminary DRLs were determined for native CT examinations or for one phase of multiphase CT examination and compared with the DRLs from other countries (see Table 2). No significant differences with most common values of European DRLs were found.

TABLE 2. PROPOSED CT DRLs IN RUSSIAN FEDERATION IN COMPARISON WITH DRLs FROM OTHER CONTRIES

Anatomical region	DLP, mGy·cm	
	Russian Federation*	European DRLs [11]
Head	1190 (3)	1000
Chest	500 (8)	400
Abdomen	780 (12)	800
Pelvis	880 (17)	550
Whole body**	1000 (15)	-

*DLP, mGy·cm (effective dose, mSv)
** Dose from whole body CT scan of PET/CT examination

4. CONCLUSION

DRL establishment on a regional level for all regions of Russia is complicated due to the limited patient dose data available and the complexity of performing dedicated dose surveys. Hence, it is practicable to establish DRLs on a national level, providing all practitioners with initial values of DRLs for most common CT examinations. More data should be used to establish national DRLs; however, preliminary DRLs were proposed based on the available data. Preliminary national DRLs in DLP are comparable with the European DRLs.

ACKNOWLEDGEMENTS

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AN OVERVIEW OF EURADOS WORKING GROUP 12 ACTIVITIESON PATIENT DOSIMETRY IN MEDICAL IMAGING

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Abstract

Working group 12 (WG12) of EURADOS is dealing with various aspects of dosimetry in medical imaging. The workof WG12 is focused on harmonization, evaluation and development of dosimetry methods, intercomparisons, literature reviews and measurement campaigns to assess occupational and patient dose. In line with most recent developments in radiation protection in medicine, a lot of effort has been made in the area of patient dosimetry in medical imaging,in particular in the area of dosimetry for interventional procedures in cardiology and radiology as well as dosimetry for dental cone beam CT imaging.

1. INTRODUCTION

Medical procedures using ionising radiation constitute by far the largest contribution to the public's exposure by man-made sources of radiation [1]. Although the benefit for the patients will normally outweigh the radiation-associated risk, there is concern that patients may undergo radiological examinations that will not have any benefit on their healthcare, or that unnecessary high doses could be delivered with regard to the diagnostic outcome. This implies that it is essential to implement the basic radiation protection principles in medical exposures, in particular justification and optimisation [2,3].The European Radiation Dosimetry Group (EURADOS) is a self-sustainable network of more than 60 European institutions and 300 scientists active in the field of radiation dosimetry. The aim of the network is to promote research and development and European cooperation in the field of dosimetry of ionizing radiation [4]. The main scientific work is done in working groups, whichpromote technical developments and theirimplementation in routine work, and contribute to harmonizationwithin Europe and conformance with international practices. With an aim to identify the future research needs in radiation dosimetry, EURADOS has developed a Strategic Research Agenda (SRA) that is used as a guideline for the activities of the working groups [4].Working group 12 (WG12) is dealing with various aspects of dosimetry in medical imaging. The aim of the WG12 is focused ondosimetry harmonization, evaluation and development of dosimetry methods, intercomparisons, literaturereviews and measurementcampaigns to assess occupational and patient exposure[5-10]. In line with most recent developments in radiation protection in medicine, a lot of effort has been made in the area of patient dosimetry in medical imaging [7-10]. Through WG12, EURADOS can position itself as the expert organisation on dosimetric aspects both for patients and staff in medical applications.Following vision 4 of EURADOS's SRA: "*Towards integrated personalized dosimetry in medical applications*", WG12 is currently focusing on the development and evaluation of dosimetricbasis for organ dose and risk estimation in different imaging modalities, in particular in interventional radiology and cone beamCT examinations [4]. These activities are to a large extent in line with the aims of the Bonn Call-for-Action initiative, in particular those focused on "strengthening the radiation protection of patients and health workers overall, attaining the highest benefit with the least possible risk to all patients by the safe and appropriate use of ionizing radiation in medicine, aiding the full integration of radiation protection into health care systems, helping to improve the benefit/risk-dialogue with patients and the public, and enhancing the safety and quality of radiological procedures in medicine [11].

This paper presentsWG12 activities in the area of dosimetry for interventional procedures in cardiology and radiology as well as on the dosimetry for dental cone beam CT imaging.

2. ESTABLISHMENT OF DOSE REFERENCE LEVELS IN INTERVENTIONAL CARDIOLOGY

The importance of Dose Reference Levels (DRLs) is emphasized in the recent revision of the Basic Safety Standards in European Directive 2013/59/EURATOM [12] and other international standards and guidelines [11-13]. DRL establishment and application have a key role in optimization of both patient and staff protection – the latter is connected with the DRLs via improved radiation hygiene. In particular, patients who undergo interventional cardiology (IC) procedures may receive radiation doses that are high enough to be of concern regarding an increase in the incidence of cancer, while in some cases, skin doses or dose to heart vessels may be high enough to cause minor or major tissue reactions.At the moment, not too many countries in Europe (or even worldwide) have set DRLs for interventional cardiology.

Variations in dose levels between different hospitals and countries are expected to be large and there is a general need to analyse how locally (or how globally) reference levels can and should be set. To draw any conclusions, reliable data covering the widest range of practices are needed.Therefore, a European consortium has been established in the framework of EURADOS to fulfil this demand. This project will increase the awareness of the importance of DRLs in cardiology, and help different centres to assess their own dose levels and to support them to set up DRLs also for new high-dose procedures such as TAVI (transcatheter aortic valve implantation) or CTO (Chronic Total Occlusion). Ideally, the results will be used to identify parameters for pre-procedure evaluation of the radiation risk. Eleven European countries participated in the data collection. In total, approximately 2600 data entries were obtained for CA procedures, 5600 for PCI, 700 for TAVI, 1300 for electrophysiological procedures and 1500 for pacemaker installations. In data collection protocol, special

emphasis was put to acquire complete data on acquisition parameters and patients. The preliminary results from the data analysis will be available in late 2017.

3. VALIDATION OF SKIN DOSE CALCULATING SOFTWARE IN INTERVENTIONAL CARDIOLOGY AND HARMONISATION OF RADIATION DOSE STRUCTUREDREPORT

As the number and complexity of IC procedures have been steadily growing, it becomes crucial toprovide patient-specific, skin dose estimate during IC procedures. In fact, EURADOS, EURAMED and ICRP Committee 3 have identified patient-specific dose calculation in IC as a top-priority topic [4,14].To tackle this issue, online or offline software havebeen developed to estimate the maximum skin dose (MSD) to the patient during or after IC procedures. However, the capabilities and accuracy of such skin dose calculation (SDC) software to estimate MSDs and 2D skin dose distributions markedly differ among vendors.In addition, those systems are usually validated by the very same people who developed them, and there is currently no acceptance testing performed at the installation of SDC software. Furthermore quality control protocols (QC)which allow medical physiciststo routinely assess the software performance do notexist.

Preliminary measurementson two commercial SDC software, using combinations of up to three simplebeam projections and two beam qualities, were performed within WG12 activities. The results showed some disagreement between measured and calculated MSD values, highlighting the need for further tests. Also, the reporting of the MSD estimate and the related accuracy in the Radiation Dose Structured Report (RDSR) was neither systematic nor harmonised, preventing accurate dosimetry of patients who underwent multiple procedures.From this preliminary exercise, it was also evidentthat not all exposure information required to compute MSDsmanually was available in the RDSRs; the information could also be displayed differently among the SDCsoftware. This lack of harmonisation makes the follow-up of patients undergoing multiple procedures on systems from different manufacturers very difficult;a crucial issue when procedures are repeated in a short period oftime.

The aim of this research is to foster the harmonisation of RDSRs and to validate SDC software in IC, which will help to develop patient-specific dosimetry and optimise radiation protection.Acceptance testing and QC protocols of SDC systems will also be developed and tested.In addition to the current WG12 research on this topic, a project proposal was prepared to answer the 2017 transnational call of the CONCERT programme.

4. DOSIMETRY FOR DENTAL CONE BEAM CT

While WG12 is considering patient dosimetry associated with the various Cone beam CT (CBCT) technologies, i.e. dental, flat detector (FD) and On-Board Imaging (OBI) systems, the focus of this paper is on dental techniques. CBCT devices were introduced in dental and maxillofacial radiology in the late 1990s. Dentists quickly became aware of the potential for CBCT imaging and today this radiology technique isused for diagnostic purposes, pre-operative planning, postoperative evaluation and image-guidance during navigated surgery in this region. While patient doses in dental radiology are deemed to be low for standard imaging examinations i.e. Intra-oral, Panoramic and Cephalometric, CBCT devices can deliver considerably higher patient doses than these techniques.

A literature review focusing on dosimetry in dental CBCT imaging was undertaken by members of WG12 during February 2017. The review showed that although limited information was available for patient studies, numerous experimental studies have been undertaken using phantoms of various types in conjunction with a range of radiation detectors. While effective dose was by far the dominant dosimetry quantity in the literature, a range of other dose metrics was quoted in the published articles. These included Dose Area Product (DAP), Kerma Air Product (KAP), Dose Length Product (DLP), Dose Height Product (DHP), $CTDI_w$, $CTDI_{vol}$, amongst others. It is evident from the published literature that the most appropriate dose metric for dental CBCT imaging has yet to be agreed upon.A large range in effective dose measurements was quoted in the literature with one author citing a 20 fold difference between CBCT devices. The countless imaging parameters available to operators of dental CBCT equipment has, without doubt, contributed to this extensive variation in effective dose. It is clear that there is a need for manufacturers of CBCT systems to implement technical solutions to ensure patient doses are as low as reasonably achievable to meet the clinical objective. DRLs are a practical tool

which can be used to promote optimisation. While numerous studies have estimated effective doses, there is a noticeable lack of published data on the existence of DRLs for CBCT examinations in dental radiology.This project aims to increase awareness amongst the dental profession of the importance of protocol optimisation in dental CBCT imaging by establishing DRLs for specific examinations. It also focuses on the importance of the role of the medical physicist in terms of the optimisation process.

5. CONCLUSION

WG12 of EURADOS is dealing with various aspects of patient dosimetry in medical imaging, in particular in the area of interventional procedures in cardiology and radiology as well as in dental cone beam CT imaging, with an aim to improve dosimetry methods, to increase awareness amongst the medical professionals and to foster the implementation of the optimization principle by establishing DRLs for specific examinations.

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ASSESSMENT OF WORKER RADIATION DOSES AT CT-SCAN DIAGNOSTIC FACILITIES: A Case Study of Radiation Dose of Workers at Hospital A, B, C, and D in Indonesia

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Abstract

The purpose of this study is to investigate and determine whether the workers' radiation dose in hospital A, B, C, and D are still within safe limits according to regulations. The results showed that the distribution of annual dose of radiation workers in hospital A is most alarming, namely more than 993.06 milliSievert/yr (at a height of ± 2.2 m from floor on the upper wall, between operator room and CT-Scan room), followed by Hospital D and Hospital C. While Hospital B is most secure, namely, 0.191 milliSievert/year, although it still needs to be optimized. Workers' radiation dose analysis can be approached by the optimization of radiation protection at design stage of CT-Scan facility, work scheduling, work execution in accordance with the procedures and dose evaluation. BAPETEN Inspectors are to verify dose according to the working conditions at the location of the CT-Scan utilization, and the principle of radiation protection standards. An increase in worker doses greater than usual for CT-Scan facilities, due to inadequate in design stage of facilities. So as to achieve the right level of optimization, corrective actions need to be implemented in the design stage of the CT-Scan facility.

Keywords: *BAPETEN, occupational dose, CT-Scan, optimisation*

1. INTRODUCTION

1.1. Background

Utilization of CT Scan for diagnostic purposes is the scope of Indonesia Nuclear Energy Regulatory Agency, i.e. BAPETEN's regulatory function in medical sector. Computed Tomography or computed axial tomography (CAT scan) or X-ray computed tomography is a medical imaging tool, using an X-ray processing computer that produces a tomographic image (according to the Encarta Encyclopedia, tomography is a technique using X-ray to get the image focused on a certain depth in the body, with the other depth blurry) or "slice" of the body parts of living things, especially humans. The cross-sectional image is used to diagnose and treat in various medical fields. Digital geometry processing is used to generate a three-dimensional image on the inside of an object compiled from a number of X-ray imagery generated from rotation of one rotation axis [1,2].

The authors' experience when conducting inspections at the CT Scan facility shows that there are radiation workers' concerns at the facility regarding the radiation dose they exposed to. The results of radiation exposure measurements in the inspection report show that there is an increase in radiation dose rates at workplaces in certain hospitals in some areas which have CT Scan facilities. Therefore, in this paper, the authors will describe the study of doses of radiation workers at the diagnostic CT Scan facility by conducting case studies of increasing radiation dose of workers in 4 hospitals, namely hospital A, B, C, and D in order to optimize radiation protection.

1.2. Objectives

The objectives are to know and to make sure whether the dose of radiation workers in hospitals A, B, C, and D are still within safe limits and sound in accordance with applicable regulations.

1.3. Scope

The scope of this paper includes an analysis of the dose of radiation workers at the Diagnostic CT Scan facility for protection and radiation safety in the medical sector.

2. METHODS

The study was conducted at CT-Scan facilities in 2012 in various locations with random sampling method. Data collected based on radiation safety inspection reports. The data analysed are listed in Table 1.

3. RESULTS AND DISCUSSION

3.1. Radiation Protection Concept in the Regulatory Framework and Licensing

BAPETEN requires all license applicants to create and submit the Radiation Protection and Safety Program document as one of the technical requirements for a diagnostic CT Scan facility. In the document, should be clearly stated the commitment of the license applicant to implement the principles of radiation protection i.e. justification, dose limitation and optimization, the principle of As Low As Reasonably Achievable (ALARA) and the concept of dose constraint [3, 4, 5, 6].

3.2. Data Analysis

The authors have taken and analyzed the measurement data of the radiation exposure at the CT Scan for diagnostic and / or therapy support facilities at 4 (four) hospitals, namely hospital A, B, C, and D from the 2012 inspection report as listed in Table 1. In Table 1 it was found that there was an increase in a fairly high radiation dose rate on the upper wall of the barrier between the CT Scan exposure chamber and the operator room, i.e. more than 50 milliSievert / h (surveymeter OVERLOAD) at a distance of ± 2.2 m from the floor) in Hospital A; and, 90 microSievert / h (at a distance ± 2.5 m from the floor, near the ceiling) in Hospital C. It was suspected that the upper wall in position above 2 meters does not work properly as the attenuator or radiation shield for the operator. Based on the results of interviews with the responsible facility, the wall material at an altitude of 2 meters up is not made of concrete or wall in accordance with applicable regulations. However, the wall material

Table 1: Results of Radiation Dose Rate Measurements at the Diagnostic CT Scan Facility

NAME AND LOCATION HOSPITAL / **DOSE RATE MEASUREMENT**	Hospital A, in Jakarta Selatan, DKI Jakarta	Hospital B, in Tangerang, Banten	Hospital C, in Balikpapan, Kalimantan Timur	Hospital D, in Denpasar, Bali
X-Ray Mechine Data (each of it, has a valid license)	Brand: Philips CT Scan 256 Slice, Type: 9806 058 00103, Serial No.al No: SN001267	Brand: Siemens Somatom Definition, Type: Straton MX, Serial No.al No: 13F415	Brand: Philips CT Scan; Type: 9806 058 00103; Serial No.al No: 300529	Brand: Siemens Somatom Emotion; Type: DURA 422-MV; Serial No.al No: 721 240 894
Exposure conditions	Scan Head: 120 kV; 500 mA; 11 s	**Scan: unknown;** 450 kV; 120 mA; 12 s	Scan Abdomen: 120 kV; 30 mA; 11 s	Scan Head : 130 kV; 38 mA; 2 minutes
Radiation dose rate in operator room (1 meter from Pb glass shielding), where operator sits.	29 microSievert/h (1 meter from Pb glass)	1.31 microSievert/h	35 microSievert/h	49 mocroSievert/h
Radiation dose rate at Pb glass shielding	18 microSievert/h	–––	22 microSievert/h	26.3 microSievert/h
Radiation dose rate at operator room door	---	8.8 microSievert/h	35 microSievert/h	23.7 microSievert/h
Radiation dose rate at the upper wall, the boundary between the operator room and the CT Scan room	**more than 50 milliSievert/h** (surveymeter OVERLOAD indication) at a height of ± 2.2 meters from the floor	–––	**90 microSievert/h** (at a height of ± 2.5 meters from the floor)	---
Radiation dose rate at the entrance of the examination room	4 microSievert/h	3.2 microSievert/h	---	3.5 microSievert/h
Radiation dose rate at the patient's waiting room	9 microSievert/h	–––	---	---
Radiation dose rate at wall surface between the operator room and the CT Scan room at less than 2 meters height	3.8 microSievert/h	same as background radiation dose rate	22 microSievert/h	2.14 microSievert/h

at these altitudes is apparently made of gypsum or ordinary partition. The highest radiation dose rate condition was in Hospital A. While lower dose rate was in Hospital C. For Hospital B and Hospital D, there were no measurement at that positions.

The data shows that, in fact that radiation safety requirements did not fulfill at the design stage of the CT-Scan facilities. Increased dose rates in these positions indicate that radiation protection for radiation workers at CT Scan facilities is not optimal at the facility design stage.

For the position of the operator, it can be seen on the table that Hospital D has the highest dose rate of 49 microSievert / h and the lowest is 1.31 microSievert / h in Hospital B. This is probably caused by non-homogeneous wall material at the wall position at over 2 meters, so that radiation scatter from the CT Scan room is still passing through it and read by the surveymeter in the operator room at the operator position.

3.3. Dose Reconstruction

To reveal the facts more deeply, the authors perform dose reconstruction based on the data in Table 1. Reconstruction doses are performed based on the following assumption methods:

- Exposure or radiation dose rate at the operator room, for example 35 microSievert / h
- Duration of scan, for example 11 seconds
- Number of patients / day administered by 1 (one) CT Scan operator: 25 patients
- Working time 5 days / week, 52 weeks / year = 260 days / year

Examples of dose reconstruction calculations are as follow:

$$dosis\ pekerja\ harian\ (rata2) = 35\frac{\mu Sv}{jam} x\ \frac{1}{3600}\frac{jam}{detik} x\ 11\frac{detik}{pasien} x\ 25\frac{pasien}{hari} = 2{,}67\frac{\mu Sv}{hari}$$

$$dosis\ pekerja\ tahunan\ (rata2) = 2{,}67\frac{\mu Sv}{hari} x\ 260\frac{hari}{tahun} = 695\ \frac{\mu Sv}{tahun} \sim 0{,}7\ \frac{mSv}{tahun}$$

So, as it can be seen from above calculation that the annual radiation dose is close to 0.7 milliSievert/year. Furthermore, the results of dose calculations are also performed in other positions. Thus, the distribution of radiation doses at the points of measurement in each of Hospital A, B, C, and D are listed in Table 2. The results of dose reconstruction are very surprising. Table 2 shows that the highest annual radiation dose was achieved at the position in the operator room where the operator sits, which is 10.62 milliSievert / year in Hospital D. The lowest radiation dose at the same position is 0.0284 milliSievert / year in Hospital B.

Table 2: Reconstruction of Radiation Dose Distribution at Workplace in Diagnostic CT Scan Facility

NAME AND LOCATION HOSPITAL / **DOSE RECONSTRUCTION**	Hospital A, in Jakarta Selatan, DKI Jakarta	Hospital B, in Tangerang, Banten	Hospital C, in Balikpapan, Kalimantan Timur	Hospital D, in Denpasar, Bali
X-Ray Mechine Data (each of it, has a valid license)	Brand: Philips CT Scan 256 Slice, Type: 9806 058 00103, Serial No: SN001267	Brand: Siemens Somatom Definition, Type: Straton MX, Serial No: 13F415	Brand: Philips CT Scan; Type: 9806 058 00103; Serial No: 300529	Brand: Siemens Somatom Emotion; Type: DURA 422-MV; Serial No.: 721 240 894
Exposure conditions	Scan Head: 120 kV; 500 mA; 11 s	**Scan: unknown;** 450 kV; 120 mA; 12 s	Scan Abdomen: 120 kV; 30 mA; 11 s	Scan Head : 130 kV; 38 mA; 2 minutes
Radiation dose in operator room (1 meter from Pb glass shielding), where operator sits	0,576 milliSievert/year	0,0284 milliSievert/year	0,7 milliSievert/year	**10,62 milliSievert/year**
Radiation dose at Pb glass shielding	0,358 milliSievert/year	——	0,437 milliSievert/year	5,698 milliSievert/year
Radiation dose at operator room door	---	0,191 milliSievert/year	0,7 milliSievert/year	5,134 milliSievert/year
Radiation dose at the upper wall, the boundary between the operator room and the CT Scan room	**more than 993,06 milliSievert/year** (surveymeter OVERLOAD indication) at a height of ± 2.2 meters from the floor.	——	**1,788 milliSievert/year** (at a height of ± 2.5 meters from the floor)	---
Radiation dose at the entrance of the examination room	0,0794 milliSievert/year	0,0693 milliSievert/year	---	0,758 milliSievert/year
Radiation dose at the patient's waiting room	0,179 milliSievert/year	——	---	---
Radiation dose at wall surface between the operator room and the CT Scan room at less than 2 meters height	0,0755 milliSievert/year	same as background radiation	0,437 milliSievert/year	0,464 milliSievert/year

However, when examined in more detail, it compared to the distribution of radiation dose of the four hospitals, the highest radiation dose found in Hospital A, namely the radiation dose of more than 993,06 milliSievert / year was found in the upper wall, the boundary between the operator room and the CT Scan room at a height of ± 2.2 meters from the floor. This is almost 50 times greater than the annual dose (yearly Threshold Limit Value) of radiation workers, that is 20 milliSievert / year. High doses of radiation at a distance of 2.2 - 2.5 m from the floor are the findings that BAPETEN must pay attention to, environmental hazards due to the possibility of serial scattering, and harmful to the general public. For radiation workers in the operator room of less than 2.2 m height, will be exposed to indirect reflections (possibly from the ceiling). Because it is very

dangerous for radiation workers and the general public, the CT Scan facility in Hospital A must be suspended its operation, until the management of Hospital A performs corrective actions.

3.4. Radiation Overdose Incidence

The incidence of overdose of radiation workers at CT Scan facilities has never been occurred in Indonesia, even so in international level. Nevertheless, the utilization of CT Scan facilities should still be subject to reasonable regulatory enforcement by BAPETEN.

At the licensing stage, not only ionizing radiation sources are subjected to surveillance, but also work facilities, including radiation exposure room, radiation protection equipment and its supporting facilities. The authors argue that verifying compliance to license requirements is very important, especially at the design stage of the facility. But, it is not enough just to get there. Futhermore, regulatory inspection activities should be targeted to detect early warnings of safety level reductions, such as an increase in dose rates greater than ALARA, as it has been being occured in Hospital A, B, C and D.

3.5. Optimisation of Radiation Protection in Diagnostic CT Scan

For CT-Scan facilities, in ALARA's plan and its implementation [6], the things that need to be considered in order to optimize work exposure are:

- Consideration the design of CT Scan facilities and operational planning should be conditioned on the situation of lower dose rates.
- Factors associated with all CT Scan operations.
- The choice of protection should be optimal including the cost for all types of dose reduction especially starting from the design phase of the CT Scan facility.
- Effectiveness for each type of dose reduction.

While the elements that should be considered to reduce occupational exposure are: planning and scheduling work; guidance to workers; awareness and involvement of workers; communication; the design of facilities and equipment; decreased length of time in the radiation area; decrease in the number of workers required; decrease in dose rate; and training.

4. CONCLUSION

Asessment of worker radiation worker dose can be approached with optimization of radiation protection at the planning / design phase of CT Scan facility, work plan / scheduling, work implementation arrangement in accordance with procedures / SOP, and dose evaluation.

The annual distribution of radiation doses of radiation workers at Hospital A is most worrying, that is, the highest is more than 993,06 milliSievert/year, followed by Hospital D and Hospital C. While Hospital B is the safest, that is 0.191 milliSievert/year although it still needs to be optimized.

Do not panic too much if you meet the results of larger dose measurements than usual. Inspector may perform dose measurement and calculations with assumptions in accordance with working conditions at CT-Scan utilization location, and radiation protection principles. To achieve the proper level of optimization, it is necessary to take corrective action on the design stage of the CT-Scan facility.

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ELABORATION OF NEW NDRLS AS PART OF THIRD NATIONAL PATIENT DOSE SURVEY IN DIAGNOSTIC RADIOLOGY IN BULGARIA– PRELIMINARY RESULTS

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Abstract

The aim of Third National Patient Dose Survey in Diagnostic Radiology is to elaborate an update of the National Diagnostic Reference Levels (NDRLs) in Bulgaria. Collection of patient dose data was performed via distribution of special forms and methodology instructions to hospitals in the country. An MS Access National patient dose database was elaborated for data storing, processing and analysis. Over 10000 patient dose records on 187 X-ray systems from over 91 health establishments have been collected and analyzed. Preliminary DRLs for: Chest-PA, Pelvis-AP, LS-AP, LS-Lat, IVU, Ba-meal, Ba-enema, Skull-AP - in terms of KAP; for Computed Tomography (CT) of Head, Abdomen and Lumbar Spine - in terms of CTDIw and DLP; for Mammography – in terms of ESAK and AGD, were elaborated. Most of preliminary DRL values are expected to remain unchanged until finalization of the survey at beginning of 2018 and to become official national values. Preliminary NDRLs derived are comparable with other European National DRLs with a few exceptions mainly due to difference in the level of optimization in radiologypractice.

1. INTRODUCTION

Bulgarian Ordinance 30 of Ministry of Health (MoH) requires repetition of nationwide patent dose surveys and NDRLs update once at every 5 years [1]. Two National Surveys (NS) of patient doses in DR have been performed earlier:

- First National Survey was carried out as part of European Commission (EC) Phare Programme Twinning Project Bulgaria-Germany (2002-2004), Twinning reference number: BG/2000/IB/EN01-05 [2]. The project was funded by EC and co-financed by Bulgarian government to a total budget of 2 650 000 EUR. The First NS included: 81 radiography X-ray units with 513 patient dose records totally. The measured quantity was Entrance Surface Air Kerma (ESK) = Ke, mGy. Measuring method was: in vivo with Thermoluminescence Dosimeters (TLDs) [3]. 21 mammo X-ray systems were comprised in the survey, as the measured quantity was Entrance Surface Air Kerma (ESAK) without backscatter for a standard 45 mm polymethyl methacrylate (PMMA) breast phantom [3].

- Second National Survey (SNS) was carried out as part of EC Phare Programme Twinning Project Bulgaria-Finland (2008-2009), Twinning reference number: BG 2006/IB/SO/01, funded jointly by EC and the Bulgarian government to a budget of over 4 750 000 EUR. The Second NS included 46 X-ray units with totally 1600 patient dose records. Measured quantities were: ESK, mGy measured in vivo with TLD; and Dose Area Product (DAP), $cGy.cm^2$. The second national survey included also32 mammo systems, as the measured quantity remain ESAK for a standard 45 mm PMMA breast phantom [3].

The Third National Patient Dose Survey (TNS) in Diagnostic Radiology (DR) in Bulgaria started in June 2016. Its goal is to update existing National Diagnostic Reference Levels (NDRLs) and to establish Diagnostic

Reference Levels (DRL) for projections and examinations not included in the list of NDRLs, so far. The survey received non-financial support from Ministry of Health and Departments of Radiation Hygiene (DRH) to the Regional Health Inspectorates (RHI), based in 5 of the main bigger cities in Bulgaria.

2. METHODS

Laboratory of Radiation Protection at Medical Exposure (LRPME) at National Centre of Radiobiology and Radiation Protection (NCRRP) developed web-based platform and standard paper forms for collection of data [4]. The methods of patient dose data collection and analysis in frame of TNS are based on earlier prepared recommendations "National protocol for measurement methods of patient doses in X-ray Diagnostics" and "Recommendations and Guidance for use of Diagnostic Reference Levels in Radiology" [5, 6]. Different foreign protocols for measurement of Patient doses and NDRLs estimation were also considered [7-10]. 20 X-ray systems were required as a minimum for each examination or projection according to the method deployed. A sample of at least 20 standard sized patients was needed for each standard projection on an X-ray system. Exception of this rule was allowed for rare examinations only with a minimum of 10 patients as a must, as well as for paediatric examinations. Patient weight considered was lying in 50 to 90 kg range with an average of 70±3 kg. The Typical Patient Dose (TPD) for each standard X-ray examination was calculated as a mean of respective dosimetric quantity for patient's sample. Both Bulgarian and foreign protocols recommend a rounded third quartile value of distribution of the typical doses as NDRL for each projection. For children slightly different approach was employed in accordance with recent European guide [11].

2.1. Organization and data collection methods of Third National Survey.

Four methods of data collection have been employed:

A. Via direct submission at special web based system at web page: www.drl-bg.org[12];
B. Via electronic tables sent by e-mail to the electronic address of the survey: rzmo@ncrrp.org;
C. Via paper hard copy submitted by post mail;
D. Via submission of information for local typical doses derived in Health Institutions.

All information including terms and conditions for data collection and submission was made available on web page of NCRRP [13]. On the web page of the TNS following information is available for download on both MS Excel and Adobe Acrobat format files: a Short and a Full Instruction for data collection (on Adobe Acrobat format only); all necessary forms for registering of X-ray systems properties; patient dose registration forms for all types of Diagnostic Radiology Examinations. These forms include data for age, sex, personal weight of patients as well as main technical and radiation exposure parameters like: kV; mAs; ms; focus type and size; detector type and size; focus to skin distance (FSD); total filtration of X-ray tube; automatic or manual exposure mode; automatic exposure control (AEC) chamber selection; measured Kerma Area Product (KAP); displayed dose index in case of Computed Tomography (CT): $CTDI_w$, $CTDI_{vol}$, DLP, etc. The contact details of the Laboratory of Radiation Protection at Medical Exposure are also displayed. The web page has also a link to the system for registering of typical doses at X-ray examinations and procedures for those sites, which prefer to use corresponding method of data submission to NCRRP [12]. Calls to the Health Institutions to participate in TRS were published on on the web page as Circular Letters of the Director of NCRRP and the Minister of Healthcare [13].

For mammography the reported parameters are, tube potential (kVp); target/filter combination; exposure tube current and time product (mAs); half value layer (HVL); tube output (μGy/mAs); optical density (OD for film-screen systems); source to breast support distance (mm) and patient data. The mammography study analysed data coming from patient exposure as well as regular technical quality control (QC) reports of the mammography systems. The mammo QC testing is performed by NCRRP and some private QC companies and is based on the European guidelines for QC in the diagnostic imaging. In the tests was also implemented the measurements of incident air kerma (IAK). Incident air kerma is the air kerma from the incident beam on the central x-ray beam axis at the focal-spot-to surface distance at the skin entrance plane. Only primary radiation incident on the patient or phantom is measured. Backscattered radiation is not included. The AGD can be determined by first getting the IAK measurements on the standardized 45mm PPMA phantom and standard breast. Patient exposure parameters are recorded on paper and sent to the NCRRP by either of A to C methods mentioned above. Reported patient dose parameters and data coming from QC measurements were used to propose a diagnostic reference level in terms of IAK and AGD. At this preliminary phase of the survey the analysis of individual patient dose data is not included. Almost all dose estimations were done for Mo/Mo target-filter combination. AGD is the average absorbed dose in the glandular tissue in a uniformly compressed

breast. As direct measurement of the AGD is not possible, it is often estimated from product of measured IAK and related conversion factors. In TNS AGD is calculated according to the method recommended by the EUREF European guidelines for quality assurance in mammography screening [14].

AGD is derived by calculation using the following formula:

AGD = IAK.g.c.s (1)

This formula applies the Dance's conversion coefficients [15-17]. The formula is applied in all European protocols and IAEA TRS 457 Code of Practice [18].

3. RESULTS

A total number of 10203 patient dose records were collected at NCRRP, as corresponding numbers per modality were as follows: 5631; 1793; 960; 1115; 704, for: Radiography; Computed Tomography (CT); Mammography; Interventional Cardiology and Fluoroscopy respectively. Those data comprised 187 X-ray systems distributed as follows: 81% in Hospitals and 19% in Ambulances and smaller Medical Centres. 53 of the X-ray units were situated in the Capital – Sofia, 39 in bigger cities and 95 in middle and small size cities. About 67% of patient dose data were submitted via e-mail and about 22% by post mail on paper – via above mentioned methods B and C respectively. Submission of data via direct input in the web based system available at web page: www.drl-bg.org (Method A) appeared to be not a popular choice for the Health establishments included in TNS and contributed to about 13% of TNS collected data only. Submission of information for local typical doses derived in Health Institutions (Method D) appeared to be not a preferred choice for most of Health Establishments also. Such data were collected mainly for mammography units with an assistance and input from an external medical physics group providing quality control (QC) service to most of mammography sites participated in TNS.

Preliminary NDRLs from TNS: "BG, 2017" and NDRLs from SNS: "BG 2013" and some foreign National surveys for Radiography projections and Fluoroscopy Barium Contrast studies are shown in Table 1 [10, 19] .

TABLE 1. PRELIMINARY NDRLs VALUES FROMTNS AND DIFFERENT NRDLs, GIVEN IN [$\mu Gy \cdot m^2$] FOR RADIOGRAPHY PROJECTIONS AND FLUOROSCOPY CONTRAST EXAMINATIONS

	Chest (PA)	Abdomen (AP)	LS (AP)	LS (Lat)	Pelvis (AP)	TS (AP)	TS (Lat)	Skull (Lat)	Skull (AP)	Ba Enema	Ba meal
BG, 2013	40	-	300	400	400	-	-	-		4000	1800
BG, 2017	**35**	**340**	**240**	**350**	**220**	**95**	**145**	**90**	**75**	**1840**	**1570**
UK, 2000	12	300	160	300	300	340	1040	160	280	3130	1300
UK, 2010	10	250	150	250	220	100-	150	110	180-	2100	1180
DE, 2010	16	300	230	420	300	130	170	60	65	3700	-
IE, 2010	16	232	162	268	264	97	203	-	65	-	-
LU, 2010	16	300	260	-	310	130	170	60	-	4000	-
NO, 2010	12	550	320	800	150	-	300	-	-		
PL, 2010	50	550	-	-	500	220	320	100	-		
SE, 2010	-	200	150	275	-	-	-	-	-	5000	-

Preliminary values of NDRLs for CT from TNS: "BG, 2017", SNS: "BG 2013" and some foreign National surveys are shown in Table 2 [10, 19].

TABLE 2. PRELIMINARY NDRLs VALUES FROMTNS AND DIFFERENT NDLRLs FOR CT

	Head		**Chest**		**Abdomen**		**Lumbar spine**	
	DLP [mGy·cm]	$CTDI_{vol}$ [mGy]	DLP [mGy·cm]	$CTDI_{vol}$ [mGy]	DLP [mGy·cm]	$CTDI_{vol}$ [mGy]	DLP [mGy·cm]	$CTDI_{vol}$ [mGy]
BG, 2010	1000	25	550	60	600	30		
BG, 2017	**1040**	**9**	**450**	**47**	**480**	**16**	**520**	**15**
AT, 2010	1300		550		1200			
BE, 2010	1020		400		830		870	
CH, 2010	1000	10	400	65	650	15	850	30
DE, 2010	950		400		900			
FI, 2010	1000	30	500	65	600	15	500	50
FR, 2010	1050	30	500	65			700	45
IE, 2010	950		460		640			
IT, 2010	1050	30	650	60	800	35		
LU, 2010	1000		270		800		500	
NO, 2010	1000	15	400	70	800	18	500	30
PL, 2010	1050		650		780			
SE, 2010	1200	20	600	75		25	600	55
SI, 2010	1040	15	475	62	555	17		
UK, 2010	760	10	430	55	460	13		

The preliminary NDRLs values for Interventional Cardiology procedures obtained from TNS: "BG, 2017", as well as values for NDRLs from SNS: "BG 2013" and some foreign National surveys: for Coronary Angiography (CA) and Percutaneous Coronary Intervention (PCI) are shown in Table 3 and Table 4. respectively [10,19, 20].

TABLE 3 PRELIMINARY NDRLs VALUES FROMTNS AND DIFFERENT NDLRLs FOR CA

Country	**BG, 2017**	BG, 2010	AT, 2010	CH, 2010	DE, 2010	FI, 2010	IE, 2010	LU, 2010	NO, 2010	SE, 2010	UK, 2010	DE, 2010	AU, 2014
KAP [µGy*m^2]	**4600**	4000	6000	7000	3500	6000	5310	2300	4500	8000	3600	3500	5865

Table 4. PRELIMINARY NDRLs VALUES FROM TNS AND DIFFERENT NDLRLs FOR PCI

Country	**BG, 2017**	BG, 2008	IE, 2009	AU, 2014	GB, 2010
KAP [µGy·m^2]	**13400**	14000	8400	12900	4000

Mammography dose survey included 33 X-ray systems: 17 in hospitals and 16 in Ambulances or in smaller Medical Centres. Different systems were equipped with different detectors: 20 X-ray units with Film Screen Combinations (FSC); 5 with Computed Radiography (CR) plates and 6 with a Direct Digital

Radiography (DDR) detector. Distribution of Entrance Surface Air Kerma (ESAK), as per mammography system is shown on Fig. 1.

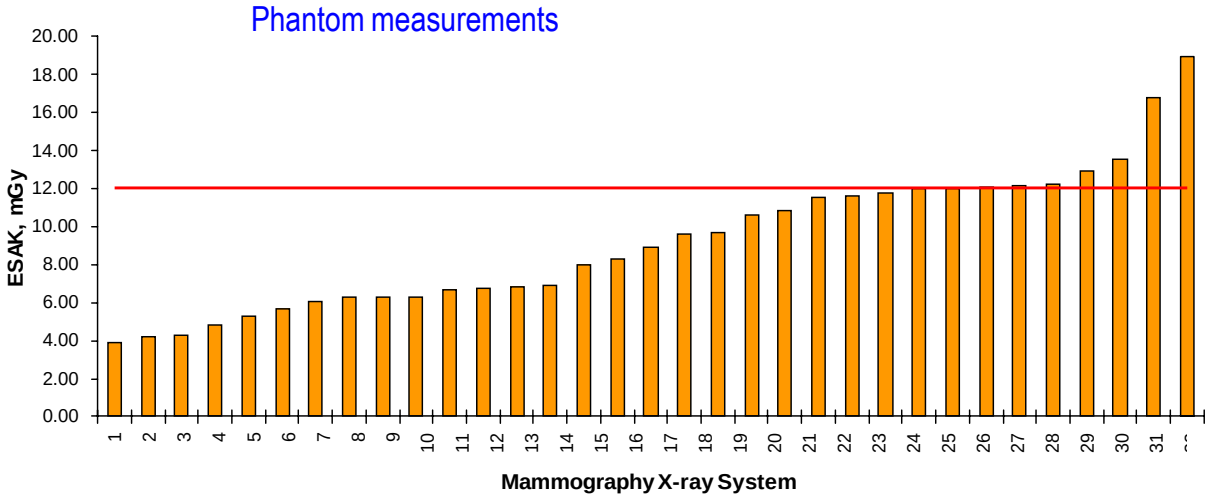

FIG. 1. Values of ESAK per X-ray mammography system

Table 5. shows main statistical data for calculated AGD from Patient and Phantom related mammography exposure data.

TABLE 5. STATISTICAL PARAMETERS OF DISTRIBUTION OF TYPICAL AGD OBTAINED AT PHANTOM AND PATIENTS STUDIES.

	Patients	Phantom
	AGD [mGy]	
Min	0.7	0.8
Max	2.7	3.2
Max/Min	3.8	4
Average	1.8	1.7
Median	1.9	1.5
3^{-th} Quartile	2.4	2.3

Preliminary NDRLs for paediatrics in frame of TNS are obtained for Chest X-ray radiography projection only. Their values are displayed at Table 6 along with other NDRLs obtained recently [21].

TABLE 6. PRELIMINARY NDRLs FROM TNS AND OTDER NDRLs FOR PEDIATRIC CHEST RADIOGRAPHY

	new-borns	0-1 years old.	1-5 years old	5-10 years old	10-15 years old
	KAP [μGy·m^2]				
BG, 2017	**6.3**	**6.1**	**6.4**	**9.5**	**16.8**
AT, 2010	17	23	26	37	73
DE, 2010	5	15	25	35	
FR, 2010		10	50	70	

4. DISCUSSIONS

Preliminary Bulgarian NDRLs values determined for Radiography projections and Fluoroscopy Barium Contrast studies are closer to other NDRLs with exception for Chest (PA). Higher DRL for Chest is due mainly to commonly used non-optimal "soft" technique with anode potential of the tube lower then recommended [22]. Decrease in NDRL values is observed in all examinations with few exceptions like CA and CT of Head. Increase in DRL value for those examinations is explained with smaller and not so representative sample of the TPD in the SNS in comparison with patient dose sample in TNS for those cases. For PCI for example this trend is not valid and during TNS we obtained lower DRL then it was found during SNS.

Difference in NDRL values for AGD obtained from phantom and patient exposure data is related to insufficient size of patient sample as well as to lack of information for Anode-Filter combinations on some of X-ray systems in study, which decreased the number of systems included in Phantom based AGD assessment. Additional information will be further collected and the final NDRL for AGD will be determined more precisely.

The smaller proportion of patient data submitted by the health establishments using the "on-line data collection platform" (Method A.) might be related to limited availability of Internet access in radiology departments as well as with its present user interface design and a need for further promotion, development and improvement.

5. CONCLUSIONS

Third national patient dose survey collected significantly bigger amount of data then first and second national surveys so far and hence appeared to be more representative for the country. Preliminary NDRLs are determined for more Diagnostic Radiology Examinations, as many of them are expected to remain unchanged till end of the survey and to become official NDRLs.

More precise final DRL values are expected to be determined for CA, PCI and AGD, as further data are being collected and expected to arrive at NCRRP at beginning of 2019.

ACKNOWLEDGEMENTS

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U.S. TRACKS DIAGNOSTIC X-RAY DOSES AND PRACTICES THROUGH SURVEYS OF FACILITIES NATIONWIDE

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Abstract

The Conference of Radiation Control Program Directors (CRCPD), an organization representing the state and territorial radiation control programs in the United States, has long partnered with the U.S. Food and Drug Administration to conduct the Nationwide Evaluation of X-Ray Trends (NEXT) program in the United States. The NEXT program looks at particular x-ray studies in depth providing an objective analysis of technique, dose, operator requirements and training, and workload. NEXT is a randomized study conducted across the United States. Over forty plus years, the program has looked at exams including dental, mammography, computed tomography (CT), chest, abdomen, pediatric chest and cardiac catherization. These studies are published by CRCPD and have been a valuable resource for both states and facilities. Over the years, the results of the NEXT studies have led to improvements in dose and lowering of technique in many instances. The studies provide a way for states to compare facilities at inspection to a national average and for facilities to self-evaluate. As imaging has changed, the NEXT program has also adapted; however, it continues to be a valuable source of information on imaging in the United States.

1. INTRODUCTION

The Conference of Radiation Control Program Directors (CRCPD), an organization representing the state and territorial radiation control programs in the United States (US), has long partnered with the U.S. Food and Drug Administration (FDA) to conduct the Nationwide Evaluation of X-ray Trends (NEXT). The NEXT program looks at particular x-ray studies in depth providing an objective analysis of technique, dose, operator requirements and training and facility workload. Over the last forty plus years, the program has looked at exams including dental, mammography, computed tomography (CT), adult and pediatric chest, abdomen and cardiac catherization. The information gathered during the NEXT studies has led to improvements made by lowering techniques and reducing radiation dose across the country [1].

2. DISCUSSION

The Conference of Radiation Control Program Directors (CRCPD) is a national non-profit non-governmental organization dedicated to radiation protection. The CRCPD membership consists of directors and staff of state and local radiation control programs plus others who are involved in radiation protection matters. CRCPD's mission is "to promote consistency in addressing and resolving radiation protection issues, to encourage high standards of quality in radiation protection program directors, and to provide leadership in radiation safety and education."

The U.S. Food and Drug Administration (FDA) Center for Devices and Radiological Health (CDRH) works collaboratively with the CRCPD Nationwide Evaluation of X-ray Trends (NEXT) Committee through a unique state and federal partnership to survey the radiation doses patients receive and document diagnostic radiology practices across the country [2]. The partnership was formed in 1971 with the first survey being conducted the following year, in 1972. This study focused on collecting data for 12 commonly performed x-ray procedures. It included documentation of exposure technique factors, radiation dose exposure to the patient and

facility workloads for these procedures. The 12 x-ray studies included three dental procedures, lower extremities (foot) and anterior posterior (AP) views of the cervical, thoracic, and lumbar spine, abdomen (to include kidneys, ureters and the bladder) and chest.

As the popularity of automatic exposure control (AEC) for x-ray imaging grew, the committee recognized the need to capture AEC date in the surveys. The studies done in the early 1980's incorporated attenuation phantoms used to simulate an average adult patient in the anterior-posterior lumbar spine and abdominal surveys. To begin capturing data on high-contrast spatial resolution and low contrast image performance, a test tool was developed to document the x-ray facility's clinical imaging conditions under normal viewing circumstances.

In 1984 the surveys changed to begin focusing on one specific imaging procedure at a time. This started with the AP chest study in 1984, which was repeated again in 1986. The AP lumbar spine and AP abdomen studies were done in 1987 and 1989. By changing the survey focus to one radiology procedure, greater comprehensive data has been collected to capture a better understanding of the elements that influence x-ray image quality and the radiation exposure received bypatients.

As x-ray imaging equipment technology improved and clinical practices evolved, the data collected during NEXT surveys documents positive changes over time through quality indicators. The test methods used to collect data during the 1985, 1988 and 1992 NEXT mammography surveys were closely modelled to inspections under the US federal Mammography Quality Standards Act in the early 1990's. The National Council on Radiation Protection and Measurements used NEXT data to develop a number of recommendations for radiation diagnostic reference levels [3].

Computed tomography (CT) studies have also been addressed by the NEXT program with surveys completed in 1990, 2000 and 2006 [4]. The surveys documented the advances in CT technology to include improved scanning speed, the transition from single slice to helical and multislice technology, and tube current modulation which is used to adjust the tube current to account for varying attenuation in the scan field due to changes in body habitus. Survey data captured significant growth of the use of CT imaging between each study.

In the US, there are federal performance regulations for diagnostic x-ray systems [5]. The federal standards do not address radiation dose or the safe use of x-ray equipment and is up to the individual states to establish these regulations. The data collected during NEXT surveys has been adopted by several state to establish maximum limits on entrance skin exposures for the 12 commonly performed x-ray procedures that were surveyed in the early years of NEXT [6] [7]. These limits have been instrumental in ensuring lower patient radiation exposures and establishing consistency across thenation.

The training provided to NEXT survey participants enhances the skill set of individual state inspectors as it exposes them to new test methods. Many of the test methods developed by NEXT have been incorporated by individual states into their standardized methods used to test x-ray equipment. The NEXT committee also produces information in simplified trifold format that state inspectors can share with the facilities they inspect [8]. The information allows the facility to see how their current clinical standards compare with other facilities across the country, allowing them to identify and address areas where improvements in their radiation safety program can be made.

3. CONCLUSION

The NEXT program has served the United States well as the CRCPD and individual state programs have been able to use the collected information to make positive changes in patient dose and radiation safety. NEXT continues to evolve by looking at x-ray studies which have not been previously surveyed, such as chiropractic x-ray exams. The committee has also improved accessibility to their training methods using webinars to reach a larger audience than face-to-face training sessions allow. NEXT has shared information with the International Atomic Energy Agency (IAEA), the American Association of Physicists in Medicine and the U.S. National Council on Radiation Protection and Measurements (NCRP) in an effort spread these positive changes even further. Collaboratively, efforts such as these will continue to have a positive impact on patient health and the radiation community.

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RESULTS OF THE INSPECTION PILOT PROGRAMME OF DIAGNOSTIC RADIOLOGY DEPARTMENTS

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Abstract

The results of a recent, complex survey of diagnostic radiology departments are presented in the paper. The survey was carried out by the inspectors of regional governmental offices' public health departments, while the evaluation was done by the experts of the National Public Health Institute. The survey included 21 radiology departments, and was done during 2016, having a scope to examine: the organisational aspects of each department, including QA systems; the actual status of the departments and the infrastructure available; the technical and radiological supervision of radiological devices; the radiation protection measures and the efforts done for optimisation and justification of exposures. Every department gave answers, but some of them clearly indicated that help is required from medical physicists in order to enhance patient care. The overall image about the quality of care is diverse. There is a need for a more stringent authority for radiation protection in healthcare. The lack of medical physicists lead to the disregard of optimisation. Due to the scarcity of the professionals, a centralised approach to establish a technical support organisation for medical physics is proposed.

1. INTRODUCTION

According to the current structure of the healthcare provision system of Hungary, the Ministry of Human Capacities (MHC) is responsible to provide the structure for healthcare provisions, just as legislations and infrastructure, while also giving support via the National Public Health Institute (NPHI) to the inspectors of the Regional Governmental Offices (RGOs), having regional competence under the Cabinet Office of the Prime Minister to carry out tasks related to the supervision of medical exposures. ‘Fig. 1.’ shows the relation of different organisations to the radiation protection of the workers, the public and patients, as marked within parentheses. This system was implemented in 2015 and the responsibility for the supervision of radiation protection of workers and the public was altogether consigned to the Hungarian Atomic Energy Authority (HAEA).

A survey was initiated by the National Public Health Institute (NPHI) in order to gain experience to plan an inspection programme and to identify issues with the supervision of medical exposures, although there were already reports and indications that the current system has defects [1]. This pilot programme also had the objective to monitor the conformance of radiology departments to established standards of care [2] and the regulation for medical exposures [3] which do not yet conform the 59/2013 EURATOM directive (EU BSS) [4], and to make arrangements for planning resource requirements to conform the directive.

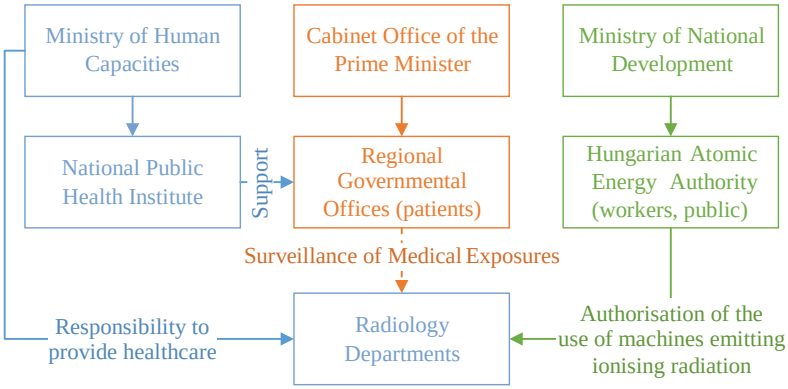

FIG. 1. Relation of different organisations to the radiology department.

2. MATERIALS AND METHODS

The questionnaire was prepared by the experts of the NPHI, and was divided into four sections, separated into sheets from 'A' to 'D'. Each of these had specific questions for the related aspects of:

(a) The organisation of the department, sheet 'A'.
  (i) Its exact identification, including: the leader of the department;
  (ii) The delegation of responsibilities;
  (iii) The quality assurance system (if any);
  (iv) Planning and management of human resources;
  (v) Internal and external auditing of conformance to current standards of care;

(b) The status of the workplace, sheet 'B'.
  (i) The status of the infrastructure at the department
  (ii) Availability of services, tools and equipment for maintenance, hygiene and radiation protection, including instrumentation for carrying out regular QC activities;

(c) Information about the radiological equipment - inventory, sheet 'C' – to be copied in appropriate number, according to the machines.
  (i) Its identification by modality, name, manufacturer, type and serial number;
  (ii) The date of manufacturing and the time of their commissioning;
  (iii) The provisions for daily QC;
  (iv) The frequency and extent of status tests (equivalent to [4] Art. 60. para. 1, d);
  (v) If periodic safety checks[1] are carried out and its frequency;
  (vi) If they are regularly undergoing maintenance and its mode;

(d) Information sheet on justification and optimisation.
  (i) The way of handling referrals and consultation;
  (ii) Identification of patients;
  (iii) The way of archiving and retrieving patient data;
  (iv) The way of how consent is sought on the risk of the radiological procedures;
  (v) The appropriateness of anamnesis and the findings of the final report;
  (vi) The steps taken (if any) for the optimisation of the exposure of patients;

The questionnaire had to be filled out during a personal interview with the head of the department and the documents had to be inspected, along a visit at each department. According to the recommendations of the NPHI, at least an independent radiologist, a medical physicist and personnel from the regional GO had to

[1] Periodic safety checks are done regularly as every X-ray device used in a hospital environment is also a medical device. These tests are done by private firms, usually the vendor, and has an extent according to the authorisation received from the National Healthcare Services Center, another subsidiary organisation of the MHC. The minimum requirement for such tests are mostly limited to mechanical and electrical safety checks and are not supervised or checked independently, nor their appropriateness is inspected by any authority. After each successful test, a decal is placed on the equipment to indicate that it has undergone a periodic safety check.

perform the interview, however it was not possible in every case. Altogether 21 workplaces were chosen, two of them as exclusive departments for children's hospitals, all of them financed by the state health insurance system.

3. RESULTS

Every workplace provided the basic data of the 'A' sheet, but some questions were misinterpreted or the answer has revealed that either the head of the department or the surveyor misunderstood the question, these are thus "indeterminate". In this section we summarise the findings of the survey divided into sub-sections, according to the 'A'-'D' sheets. With the description of each aspect, the number of respondents is noted in parentheses.

3.1. Evaluation of the organisation of the departments

According to the law it is mandatory to operate a Quality Assurance (QA) system at the hospitals [5]. The responses on the questionnaire indicated that ISO 9001 is employed at 19 departments, while one operated the HHS (Hungarian Healthcare Standards) and three of the workplaces planned their processes according to HHS in parallel with the ISO standard. One department did not have any sort of QA system.

The human resource planning and development is usually done in a written form (11 depts.), while at other workplaces it is discussed during the meetings with the management of the hospital (9), but it is not planned ahead at the rest. Those workplaces which plan their human resources are major, county or university hospitals and also employ residents. According to the observations of the interviews, the employment of residents is a beneficial factor for the occupancy of new workers. Except for one workplace, the workers are members of their respective expert societies (Hungarian Society of Radiologists or the Society of Hungarian Radiographers).

External audits are done occasionally with differing frequency. Internal audits are annual or bi-annual at every workplace which have an established QA system. The audits do not have a scope to examine radiation protection of patients and optimisation, no matter that a risk-based approach is assumed [7].

3.2. Evaluation of the status of the workplace

Except for a few (3), major issues regarding the establishment and infrastructure of the workplaces were not identified. The level of computerisation is satisfactory, as every workplace with digital modalities accommodate a Picture and Archiving Communications System, integrated in the Hospital Information System[2].

Regarding the equipment for QC, the answers could be separated into distinct groups. The minority (2) is well aware of how to check their radiological equipment's performance and does it according to the manufacturer's recommendations with the test objects received at commissioning. For another group, according to their responses it was clear that they are not aware of what QC is: 'The machine is a modern one and does a self-test on start-up, so it won't let you make an exposure until you solve its problem'; while another group was clearly misinterpreting the already mentioned periodic safety checks as they are the QC checks to be done and no daily QC checks are necessary for any equipment: 'It has the decal so it is still valid and is in good shape'.

3.3. Information on the inventory of radiological devices

According to the survey, even after the EEOP project, the average time of operation is 9 years. In 41 cases, due to the EEOP, warranty and servicing, including maintenance is still covered by the manufacturer, while in the rest of the cases (45), ad-hoc deals are made with private firms and companies to repair the machines. This is a serious issue as this raises downtime and may severely impact the cost of care.

It is important to mention that periodic safety checks are done every two years, according to the relevant regulation [6], but their scope is varying and limited, and are not independent.

[2] In the framework of the EU funded project 5.6.0 of the Operational Programme 'Environment and Energy' (EEOP), new X-ray machines were installed in many departments to enhance energy efficiency.

3.4. Evaluation of justification and optimisation

The data and findings from earlier examinations are occasionally difficult to be retrieved if the patient was not admitted into the same healthcare institution earlier and did not make arrangements to retrieve them (7). The way of referring the patients to examinations differ based on the progressivity level of the healthcare provider as outpatient departments get referrals on paper and consultation with the referrer could be rarely done (6). At one department only in vital cases do the staff question the referral, otherwise it could not be determined if consultation happens or could happen at all. The affirmation of the referral by a radiologist is seldom practiced.

The identification of patients is based on questioning, but it is always checked at the receptions by the 9-digit social security number. Wristbands are widely used to identify non-cooperative and unconscious patients.

The policy used for archiving the data is different from workplace to workplace. While some workplaces has already divested their film archives (7), to retrieve and issue data on the request of patients, usually has a cost of several EURs and the length of retaining the archives also vary.

Since there are no up-to-date referral guidelines, nor a professional handbook on appropriate imaging protocols, each workplace develop their own. Three departments indicated the necessity of national guidelines for imaging and referral. Not having national protocols occasionally leads to quarrels with other departments as the patients' routes are not the same as other departments also suffer from the lack of national protocols for care. Eight workplaces give advice on risks associated with the examinations only orally. The rest of the departments are more stringent as they are asking for the written consent of the patient, cross-checked with lawyers. Neither the forms, nor the oral statements communicate the expected risk of the examinations.

Only at six workplaces could we draw the conclusion that they took measures to optimise their imaging protocols, but only via regular discussions. The rest of them use the protocols of the manufacturer which is set up with an application specialist, indicating that the medical staff do not have expertise on optimisation. The responses are varying: 'It is neither necessary, nor required as there is an AEC built-in' or 'The machine has low dose procedures'. Only in children's hospitals are specific imaging protocols or technical tables developed, while paediatric patients may undergo a radiological procedure anywhere.

The reports and findings as they were evaluated by radiologists are satisfactory. Four departments are employing templates, while structured reporting is not adopted. Dose is not reported anywhere, nor any information on the parameters necessary for dose estimation.

4. CONCLUSIONS

None of the workplaces conform entirely the medical exposure regulation in [3]. According to the responses, it is obvious that in order to provide better care, medical physicists shall gain their role in healthcare, as it was identified earlier [9][4]. The appropriate solution would be the foundation of a centralised technical support organisation for medical physics to carry out the QC tests, and to give advice on optimisation, among other well defined roles [4]. The regulatory body responsible for medical exposures shall work together closely with this organisation and the HAEA to be effective. The current system for radiation protection for medical exposures does not fulfil the criteria described in the EU BSS as it does not foster competencies, nor accomplishments.

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MEDIRAD – IMPLICATIONS OF MEDICAL LOW DOSE RADIATION EXPOSURE

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On behalf of the MEDIRAD Consortium.

Abstract

The Horizon 2020 MEDIRAD project on implications of medical low dose radiation exposure has been funded by the European Commission in order to enhance the scientific bases and clinical practice of radiation protection (RP) in the medical field. Thereby MEDIRAD addresses the need to understand and evaluate the health effects of low dose ionising radiation exposure from diagnostic and therapeutic imaging and from off-target effects in radiotherapy (RT). Within the 4-year project a multi-disciplinary consortium in close interaction with European medical associations (EANM, EFOMP, EFRS, ESR and ESTRO) and platforms (MELODI, EURADOS and EURAMED), will pursue 3 major operational objectives: First, it will improve organ dose estimation and registration to inform clinical practice, optimise doses, set recommendations and provide adequate dosimetry for clinical-epidemiological studies of effects of medical radiation. Second, it aims to evaluate and understand the effects of medical exposures, focusing on the two major endpoints of public health relevance: cardiovascular effects of low to moderate doses of radiation from RT in breast cancer treatment incl. understanding of mechanisms; and long-term effects on cancer risk of low doses from CT in children. Third, it will develop science-based consensus policy recommendations for the effective protection of patients, workers and the general public.

1. INTRODUCTION

The evolution of medical science and the growing pace of innovation and deployment of medical technology have led to a situation where most of the artificial ionising radiation (IR) exposure of the European population is created by diagnostic imaging or radiotherapy procedures. Though most of these exposures result in low to moderate doses in most tissues, there is a need to evaluate the health effects of these exposures, optimise practices to reduce doses and develop dose evaluation tools that can be used in clinical practice to ensure adequate and improved radiation protection (RP) of patients and medical personnel.

MEDIRAD (European Commission Horizon 2020, Topic: NFRP-9) is a 10-Million Euro multi-disciplinary, cross-cutting project which aims to address this need by enhancing the scientific bases and practice of radiation protection (RP) in the medical field.

The 4-year MEDIRAD project started on June 1, 2017 and brings together 33 partner institutions from 14 European countries. The consortium includes a wide and complementary range of disciplines, including clinical experts, scientists and policy makers in the fields of medical, RP and nuclear research from hospitals, universities and major research centres across Europe (See TABLE 1). It is coordinated by Prof. E. Cardis (ISGlobal, scientific coordination), Prof. G. Frija (University Paris-Descartes, clinical coordination) and Ms. M. Hierath (EIBIR, project coordination).

TABLE 1. MEDIRAD CONSORTIUM

Institution	Country
EIBIR Gemeinnützige GmbH zur Förderung der Erforschung der Biomedizinischen Bildgebung	AT
Studiecentrum voor Kernenergie/Centre d'étude de l'Energie Nucléaire	BE
Universiteit Gent	BE
Université de Genève	CH
Otto-Von-Guericke-Universität Magdeburg	DE
Universitätsmedizin der Johannes Gutenberg-Universität Mainz	DE
Helmholtz Zentrum München Deutsches Forschungszentrum für Gesundheit und Umwelt GmbH	DE
Universitätsklinikum Würzburg - Klinikum der Bayerischen Julius-Maximilians-Universität	DE
Philipps Universität Marburg	DE
Klinikum rechts der Isar der Technischen Universität München	DE
Fundación Privada Instituto de Salud Global Barcelona	ES
Universitat Politécnica de Catalunya	ES
Universitat Autònoma de Barcelona	ES
Institut Català d'Oncologia	ES
Université Paris Descartes	FR
Institut de Radioprotection et de Sûreté Nucléaire	FR
B-COM	FR
Institut National de la Santé et de la Recherche Médicale	FR
Institut Claudius Regaud	FR
Panepistimio Kritis	GR
University College Dublin, National University of Ireland, Dublin	IE
Universita degli Studi di Roma La Sapienza	IT
Istituto Superiore di Sanità	IT
University Medical Center Groningen	NL
Vereniging voor Christelijk Hoger Onderwijs Wetenschappelijk Onderzoek en Patientenzorg	NL
Stichting het Nederlands Kanker Instituut-Antoni van Leeuwenhoek Ziekenhuis	NL
Instytut Medycyny Pracy Imienia Prof. Dra med. Jerzego Nofera w Lodzi	PL
Instituto Politécnico de Coimbra	PT
Associação para Investigação e Desenvolvimento da Faculdade de Medicina	PT
Vastra Gotalands Lans Landsting	SE
The Royal Marsden National Health Service Trust	UK
University of Bristol	UK
University of Newcastle upon Tyne	UK

2. AMBITIONS

MEDIRAD's ambitions are to:

- Improve organ dose estimation and registration;
- Evaluate the effects of medical exposures, focusing in particular on cardiovascular effects of low to moderate doses of radiation from radiotherapy and long-term effects of low doses from higher dose radiological procedures on the risk of cancer;
- Develop science-based policy recommendations for decision-makers and practitioners for the effective protection of patients, workers and the general public;

The overall MEDIRAD ambition is to bring together research and development teams of scientists and clinicians, in a joint collaborative effort to conduct research and to achieve innovative results that contribute to enhanced protection of patients and medical professionals.

Work under the project will include:

- Development of a tool to determine image quality to maximise optimisation of RP in medical imaging;
- Improvement and development of new individual organ/anatomical structure dosimetry from chest CT, I131 administration, fluoroscopy guided procedures, hybrid imaging, and radiotherapy (RT) for breast cancer and interlinks with image quality measures;
- Conduct of epidemiological studies of the consequences of RT and CT scanning;
- Identification of potential novel imaging and circulating biomarkers and mechanisms of radiation effects and radiation sensitivity;
- Development of innovative risk models;
- Development and implementation of a European repository of patient dose and imaging data for the first time;
- Development of science-based recommendations for medical radiation protection, building on the scientific results of MEDIRAD and other related national and international activities;

3. SPECIFIC OBJECTIVES

The MEDIRAD key research objectives are summarised in the three pillars below:

3.1 Pillar 1: Development of innovative tools to increase the efficiency of future RP research activities and support good clinical practice

The objective, focused on optimisation of RP in medical imaging and nuclear medicine, is to develop novel methodologies to monitor and reduce patient and staff IR dose and potential radiation-related risks while maintaining or improving diagnostic information with a focus on state-of-the-art computed tomography (CT), fluoroscopically-guided interventional procedures and hybrid imaging systems. Detailed image quality and dosimetric metrics will be produced with the aim of: developing an imaging and dose database prototype; providing a structured approach for storage of, access to and processing of imaging and dose data for quality improvement and research use; and paving the way for a harmonised approach in Europe. For nuclear medicine, the objective will be to establish the threshold absorbed dose required for a successful thyroid ablation and to develop novel tools to determine the range of absorbed doses delivered to potentially dose limiting organs to enable evaluation of short and mid-term risk. These data, which can be used to develop individualised risk/benefit personalised dosimetry based treatment planning, will also be included in the MEDIRAD dose repository.

3.2 Pillar 2: Improve the understanding of low-dose ionising radiation (IR) risks associated with major medical radiation procedures

The aim is to use different clinical cohorts, different exposure modalities (diagnostic and therapeutic), innovative imaging and circulating biomarkers, as well as preclinical mechanistic studies, addressing a wide range of low-dose patient medical exposure situations, to further develop dosimetric models and to improve risk estimates and mechanistic understanding. MEDIRAD will focus on the exploration of radiation-induced risks associated with medical IR protocols representative of situations commonly occurring in the European health systems. In particular, two cohorts will be studied assessing off-target cardiovascular risks in breast cancer radiotherapy. In the field of cancer, MEDIRAD will in particular focus on estimation of cancer risk following CT scanning in young people and identification of factors that may modify this risk, as CT scanning represents a major contribution to population doses from medical sources and because of RP concerns about paediatric exposures. Within nuclear medicine, MEDIRAD will determine absorbed doses delivered to healthy normal organs from incorporated I-131, paving the

way for a full-scale epidemiological study. An overarching aim will be to develop a unified basis for research on low-dose risks by establishing innovative tools for data collection, storage and analysis.

3.3 Pillar 3: Develop recommendations based on the scientific evidence emerging from MEDIRAD's research results and establish procedures and information exchange infrastructures to facilitate professional consensus

The aim is to formulate to decision-makers and practitioners science-based policy recommendations for the effective protection of patients, workers and the general public. Drafts will be presented and discussed with relevant stakeholder groups to stimulate the debate on possible refinement of procedures for the protection of concerned persons and formulate consensus recommendations to enhance RP in the medical field in Europe.

4. EXPECTED IMPACTS

The expected impacts of MEDIRAD are briefly summarised below:

- Additional and improved practical measures for the effective protection of people in the medical and nuclear sectors are MEDIRAD's long-term impact;
- Significant progress in the interaction between the RP and medical scientific communities at EU level, leading to cross-fertilisation of research efforts and the provision of more consolidated and robust science-based policy recommendations to decision makers in the respective sectors;
- A better evaluation of the risks from radiation and better quantification of the necessary precautionary measures, leading to a more robust system of protection of patients, workers and the general public, whilst not unduly penalising activities through unnecessary and costly measures;
- Modification of public perception of risks associated with IR thanks to the results of such combined nuclear and medical research;
- Finally, the involvement of different stakeholders in the development and validation of the MEDIRAD recommendations will have an impact on the capability of stakeholder representatives to participate better in Europe-wide dialogues about future research planning, expressing relevant societal priorities and needs which can be embedded in European Research Roadmaps developed in the frame of other EU projects, such as the EURATOM EJP CONCERT.

5. CONCLUSIONS

Medical radiation is an essential tool both in diagnosis and treatment in medicine. The use of ionising radiation in medicine has been steadily increasing, and this trend is set to continue, with obvious health benefits for the population thanks to improved diagnostic and therapy technologies. However, the increasing use of new modalities both for diagnosis and treatment also raises a number of issues in radiological protection of patients and medical workers, as the population's average medical exposure levels are continually rising.

For the first time, the EURATOM call NFRP9 has offered an explicit opportunity for medical and nuclear research teams to work together on RP oriented objectives. It is expected that MEDIRAD will enhance our understanding and estimation of the health effects of low dose ionising radiation exposure from diagnostic and therapeutic imaging and from off-target effects in radiotherapy, thus reinforcing the scientific bases and clinical practice of radiation protection in the medical field.

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ESR EUROSAFE IMAGING – TOGETHER FOR PATIENT SAFETY

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Abstract

ESR EuroSafe Imaging was launched at the European Congress of Radiology 2014 as an umbrella campaign to lead the ESR's radiation protection and quality & safety initiatives. Conceived as a multi-stakeholder alliance to promote a clinical approach to radiation protection, EuroSafe Imaging published a Call for Action in September 2014 setting out 12 actions to improve quality and safety in medical imaging. This call is designed to support the implementation of the Bonn Call for Action issued by the IAEA and the WHO in 2012. Since 2014, EuroSafe Imaging has become one of the ESR's flagship initiatives, and dedicated subgroups work on issues including paediatric imaging, appropriate image quality and clinical DRLs. The 'Ask EuroSafe Imaging' subgroup periodically publishes Tips & Tricks on the EuroSafe Imaging website in response to questions from visitors. In 2016, EuroSafe Imaging Stars was launched to create a network of institutions committed to best practice in radiation protection. EuroSafe Imaging is also a driver for other ESR initiatives, such as the ESR's clinical audit tool. The campaign has become a role model for other regions, and a global alliance of radiation protection campaigns (ISRQSA) was launched under the auspices of the International Society of Radiology in 2016.

1. INTRODUCTION

ESR EuroSafe Imaging was launched at the European Congress of Radiology (ECR) 2014 as an umbrella campaign to lead the European Society of Radiology's (ESR) radiation protection and quality & safety initiatives. Its mission is to support and strengthen medical radiation protection across Europe following a holistic, inclusive approach.

The campaign is conducted by a Steering Committee, on which the ESR, the European Federation of Radiographer Societies (EFRS), the European Federation of Organisations for Medical Physics (EFOMP), the European Society of Paediatric Radiology (ESPR), the Cardiovascular and Interventional Radiology Society of Europe (CIRSE), the European Federation of Neurological Associations (EFNA), the ESR Patient Advisory Group (ESR-PAG), and the European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry (COCIR) are represented. In addition, an observer from the European Commission is part of the Steering Committee. Bringing together different professions in this multi-stakeholder alliance reflects the ESR's holistic, inclusive approach to radiation protection.

2. METHODS

2.1. Call for Action

In September 2014, EuroSafe Imaging translated its mission into concrete projects by launching the EuroSafe Imaging Call for Action, focusing on justification, optimisation, education, research and professional and international collaboration. Designed to support the implementation of the Bonn Call for Action issued by the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO) at the 2012 Bonn conference, the EuroSafe Imaging Call for Action sets out 12 actions to improve quality and safety in medical imaging.This call will be updated soon.

The priority areas of the EuroSafe Imaging Call for Action are:

Justification: EuroSafe Imaging aims to promote the increased use of clinical imaging guidelines through the Clinical Decision Support (CDS) tool ESR iGuide developed by the ESR in partnership with the American College of Radiology (ACR), and National Decision Support Company (NDSC) as provider of the technical

platform. More specifically, EuroSafe Imaging will prepare guidance for the implementation of clinical imaging guidelines embedded in CDS based on currently on-going pilot studies in hospitals across Europe.

Optimisation: EuroSafe Imaging is promoting the development of local diagnostic reference levels (DRLs) based on clinical indications for adults (for which an application for a European Commission-funded tender project has been submitted) and is currently developing the same approach for paediatric imaging. In addition, EuroSafe Imaging is working on the concept of clinical image quality. Moreover, EuroSafe Imaging emphasises the importance of developing dose monitoring software and dose reduction systems and the related need to update medical imaging equipment.

Education: EuroSafe Imaging has developed a tips and tricks section for several radiation protection topics on its website and is preparing other educational materials. In addition EuroSafe Imaging organises a platform of exchanges between the different stakeholders through sessions, posters and meetings at the annual European Congress of Radiology.

Research: EuroSafe Imaging is strongly involved in the European Alliance for Medical Radiation Protection Research (EURAMED) as well as in MEDIRAD, a EUR 10 million research project dedicated to understanding the implications of medical low dose exposure funded by the European Commission.

Professional collaboration: EuroSafe Imaging activities are pursued in intense collaboration with medical physicists and radiographers promoting a multi-stakeholder approach, stressing in particular the clinical aspects of radiation protection.

International collaboration: EuroSafe Imaging has been adopted as a model across the globe, giving rise to numerous continental and regional quality and safety initiatives, and it has a strong role in the International Society of Radiology's (ISR) quality and safety alliance.

EuroSafe Imaging Call for Action:

Action 1: Develop a Clinical Decision Support system for imaging referral guidelines in Europe

Action 2: Develop and promote a clinical audit tool for imaging to increase the quality of patient care and improve justification

Action 3: Implement measures to maintain radiation doses within diagnostic reference levels (DRLs)

Action 4: Promote the use of up-to-date equipment and provide guidance on how to further reduce doses while maintaining image quality

Action 5: Establish a dialogue with industry regarding improvement of radiological equipment, the use of up-to-date equipment and the harmonisation of exposure indicators

Action 6: Organise radiation protection training courses and develop e-learning material to promote a safety culture and raise awareness of radiation protection

Action 7: Collaborate with research platforms and other medical professions to develop a strategic research agenda for medical radiation protection

Action 8: Develop data collection project „Is your imaging EuroSafe?“ and educational project on guidelines „Are you imaging appropriately?“

Action 9: Develop criteria for imaging procedures that use ionising radiation in specific exams and anatomical regions

Action 10: Improve communication with health professionals through EuroSafe Imaging Steering Committee, website, newsletters, conferences, training material and social media

Action 11: Improve information for and communication with patients regarding radiological procedures and related risks in order to ensure empowerment of patients

Action 12: Engage with other stakeholders and collaboration with related initiatives and regulatory authorities in Europe and beyond to contribute to a global safety culture in medical imaging

3. RESULTS

3.1. EuroSafe Imaging Subgroups

Since 2015, EuroSafe Imaging has focused on implementing its Call for Action by supporting a variety of relevant ESR projects, and through a number of self-developed activities led by dedicated subgroups. As of 2017, there are five EuroSafe Imaging subgroups: Appropriate Image Quality; Clinical Diagnostic Reference Levels (DRLs); European CT Dose Repository; Ask EuroSafe Imaging; and Paediatric Imaging.

The Appropriate Image Quality subgroup is charged with developing a definition of organ-based appropriate image quality for CT imaging examinations deemed to be clinically most relevant. To this end, the subgroup will work to identify criteria for judging the appropriateness of image quality for certain CT examinations, thereby enabling a grading or rating of completed CT examinations with regard to the appropriateness of imaging quality achieved in view of diagnostic confidence.

The Clinical DRL subgroup is working on developing a complete set of EuroSafe Imaging DRLs based on the results of EuroSafe Imaging surveys, for which it develops the methodology. Once the initial set of DRLs is completed, the subgroup will continue to better understand the application of DRLs and to update them in future.

The European CT Dose Repository group contributes towards achieving EuroSafe Imaging's mission by analysing tools for automatic dose monitoring, identifying the most frequent pitfalls in dose monitoring, providing recommendations for best practice in CT dose collection, and issuing guidance to reassure radiologists about the reliability of the data obtained from dose monitoring systems.

Ask EuroSafe Imaging was launched in 2015 to improve EuroSafe Imaging's interaction with radiology professionals, stakeholders, patients, carers and members of the public, giving website visitors the opportunity to submit enquiries to EuroSafe Imaging expert working groups in the areas of CT, interventional radiology and paediatric imaging. These working groups periodically publish FAQs and tips & tricks online. In future, selected tips & tricks will also be published in the ESR's Education on Demand platform as an e-learningtool.

The aims of the recently established subgroup on Paediatric Imaging are to develop a list of paediatric clinical indications for paediatric DRLs, identifying paediatric imaging departments and centres committed to best practice in radiation protection to establish a network and to create a CT checklist for paediatric imaging. EuroSafe Imaging will try to convince the European Commission to launch a tender for paediatric clinical DRLs in CT.

3.2. Focus on clinical practice

Establishing a clinically-driven approach to radiation protection is one of EuroSafe Imaging's overriding objectives, prioritising the clinical practice perspective in its activities to make sure that regulatory measures are

implemented to optimise the quality of daily practice and patient outcomes. This approach focuses on the four steps of clinically oriented radiation protection: justification and in particular balancing with non ionising radiations imaging techniques; clinically guided protocols, clinically evaluated image quality, and disease/symptoms-oriented (local) DRLs.

In the context of clinical practice considerations, EuroSafe Imaging has not only set itself the goal of developing useful concepts, tools and materials for healthcare professionals, but to actively promote the use of ESR and EuroSafe Imaging concepts in clinical practice, to collect and analyse data as a basis for continued improvement, and to support practitioners in applying available knowledge and tools. For this purpose, EuroSafe Imaging Stars was launched in 2016, creating a voluntary network of imaging departments committed to best practice in radiation protection. Eligible institutions can apply to become a EuroSafe Imaging Star by submitting a self-evaluation that consists of 26 quality & safety criteria the ESR considers important. These criteria are currently being evaluated and revised (status: June 2017). Based on this self-evaluation, participating organisations are awarded up to five stars. As of June 2017, there are 53 EuroSafe Imaging Stars from 18 countries, comprised of 32 five-star institutions, 17 four-star centres, and four departments with a three-star award.

Among the ESR initiatives supported by EuroSafe Imaging is the ESR's Clinical Audit Tool. This web-based tool is designed to facilitate the development of local audit across the spectrum of services provided by clinical radiology. It provides 26 level I audit templates, with further templates currently in development. In this context also, EuroSafe Imaging advocates a practical approach focusing on the four steps of clinically oriented radiation protection. In cooperation with the ESR Audit & Standards Subcommittee, EuroSafe Imaging supports tests of the audit templates through the EuroSafe Imaging Stars network. This testing scheme for the ESR's audit programme consists of 17 essential audits.

3.3. International Collaboration

EuroSafe Imaging has been invited to several IAEA or WHO meetings to present its views.

The success of EuroSafe Imaging has inspired radiology societies in other regions to follow suit and establish campaigns to promote radiation protection. In part taking EuroSafe Imaging as a role model, a number of campaigns have been launched in recent years:

- AFROSAFE, February 2015
- Canada Safe Imaging, December 2015
- LatinSafe, April 2016
- Japan Safe Imaging, June 2016
- Arab Safe, May 2017

Together with the US campaigns Image Gently and Image Wisely, a new global alliance was established at RSNA in December 2016: the International Society of Radiology Quality and Safety Alliance (ISRQSA).

4. DISCUSSIONS

5. CONCLUSIONS

The mission of EuroSafe Imaging is to support and strengthen medical radiation protection across Europe following a holistic, inclusive approach.

NATIONAL SURVEY OF COMPUTED TOMOGRAPHY RADIATION DOSES IN NIGERIA

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Abstract

Radiation dose surveys help recognise variations of radiation doses from different Computed Tomography (CT) centres where the same examination is carried out, justifying the need for optimisation of CT protocols. A CT radiation dose survey was carried out on 23 CT facilities across Nigeria. The study established diagnostic reference levels (DRLs) in terms of CT dose index (CTDI) and dose length product (DLP) values for adult patients at the 75th percentile as 69 mGy and 1827 mGy*cm for head CT; 16 mGy and 850 mGy*cm for chest CT and 20 mGy and 1592 mGy*cm for abdomen CT. Paediatric head DRLs were also established as 42 mGy and 1220 mGy*cm for <5yrs and 61 mGy and 1851 mGy*cm for 5-10yrs of age. DLP values for adults and paediatrics did not compare well with established data from other countries. Variation in doses between CT centres was noted, and centres having high radiation dose values were identified. Scan parameters impacting on dose indices were also identified. This calls for optimisation of the scan protocols to be in line with the As Low As Reasonably Achievable (ALARA) principle.

1. INTRODUCTION

Computed Tomography (CT) imaging is one of the procedures with high radiation doses in diagnostic radiology (1,2). Technical advancements have led to CT being used for both diagnostic as well as interventional procedures and have resulted in CT's increased use by many medical practitioners as a valuable clinical tool (3,4). This has led to the accumulation of radiation exposures which may cause stochastic effects such as cancer development either in the exposed individual or the patient's future offspring (5).

To limit radiation doses during diagnostic radiology, optimisation strategies have been developed (6). One such strategy is the use of Diagnostic Reference Levels (DRLs) for different CT examinations. DRLs are used to monitor the effectiveness of optimisation strategies (1,7). DRLs also serve as an investigative tool that helps to identify situations where there are unusually high radiation doses for the same radiological examinations (4).

CT radiation dose monitoring is required as part of routine quality control tests in every diagnostic radiology department (6). This is to ensure that the radiation dose for different CT examinations does not exceed the established DRLs. In Nigeria, no national radiation dose survey or monitoring has ever been carried out, nor have DRLs been established to assess CT radiation doses. Only regional CT DRLs have been established. Therefore, this study focused on achieving two main objectives: conducting a nationwide radiation dose survey in Nigeria and establishing DRLs from the data collected through the survey.

2. METHODOLOGY

Ethics clearance to conduct the study was obtained from the National Research Ethics Committee in Nigeria and the University Research Ethics Committee of the University of Malta (Ref UREC/002/2016). Permission was also sought and obtained from the participating centres and the Nigeria Nuclear Regulatory Authority.

The study adopted a quantitative methodology with a cross sectional research design that was conducted among 23 CT centres across six different regions of Nigeria (Northeast, Northwest, Northcentral, Southwest,

South-South, and Southeast). Retrospective radiation dose data for adult and paediatric patients, namely CTDI and DLP were obtained from the display CT console of the CT centres that agreed to participate in the study. Data was collected from a minimum of 15 patients for each of the CT procedures of head, chest and abdomen for adults, and head only in the paediatric category; these being the most commonly performed CT procedures in Nigeria (8). The data was taken from standard sized adult patients weighing 70 kg (+/- 10kg), and paediatric patients of <5yrs and 5-10yrs of age.

The data was collected using a well-structured and validated collection sheet (RER9132) adopted from the International Atomic Energy Agency (IAEA). The collected information included CT scanner specifications such as: scanner model, detector configuration, year of manufacture, year of installation and displayed CTDI and DLP values. Other information collected included: scan parameters such as kV, mAs, slice thickness, the number of slices, scan range, beam width, pitch factor and scan rotation time. Patient demographic information was also collected and this included: age, weight and gender.

2.1 Statistical analysis

Data was analysed using the Statistical Package for Social Sciences (SPSS) version 16 software. The CTDI and DLP DRLs were determined at the level of the 75th percentile. One way analysis of variance (ANOVA) was performed to determine statistically significant differences in radiation dose indices between CT centres. A p value ≤ 0.05 was considered as a level of significance at the 95% confidence interval. General linear regression analysis was performed to test the impact of scan parameters (mAs, kV, pitch etc.) on the radiation dose indices (CTDI and DLP). The impact was determined using the *Beta* values, and only those with a p value ≤ 0.05 were considered significant (9).

3. RESULTS

In this section, results for DLP values only will be presented because DLP correlates better than CTDI with the patient's absorbed radiation dose for CT examinations (10). Moreover, in the calculation of DLP, CTDI is also taken into consideration according to the formula:

$$DLP = CTDI \times L \quad (10)$$

Where L is the length of the scanned area

From the 23 CT centres across the country which participated in the survey, CT data from 1156 adult cases was taken for the three body regions namely head (n = 518; 45%), chest (n = 216; 19%) and abdomen (n = 422; 36%). Meanwhile, a total of 205 paediatric head cases were obtained for <5yrs (n=98; 47.8%) and for 5-10yrs (n=107; 52.2%) from seven CT centres who had complete data across the country.

3.1 Adult head CT data

Figure 1 is presenting the median DLP for adult head CT for each of the 23 CT as centres established by the survey. The DRL is calculated on the basis of the 75th percentile of these results, which in this case amounts to 1827 mGy*cm. The following CT centres: C2, C3, C4, C9, C11and C12 were identified as having DLP values above the established DRL.

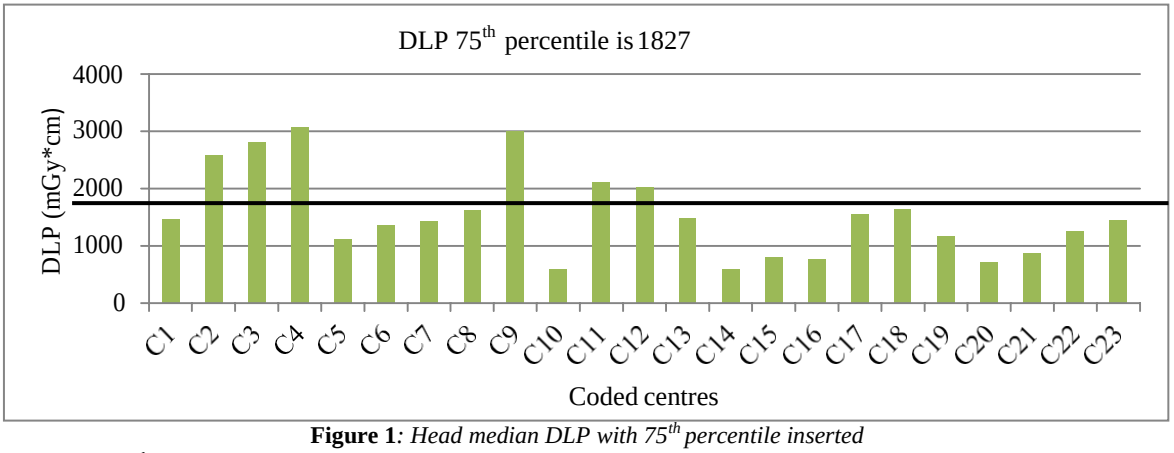

Figure 1*: Head median DLP with 75th percentile inserted*

The 75th percentile of head DLP was compared with established values in the literature. The findings of a one sample t-test indicate that this DLP DRL value did not compare well with most values from other countries as the DLP is 44% higher and statistically significant ($p \leq 0.0001$) than the compared values.

General linear regression analysis was performed to determine the effect of scan parameters on radiation dose indices. Analysis of Covariance (ANCOVA) regression identified three significant ($p \leq 0.05$) parameters, namely mAs, pitch, and slice thickness, as having an impact on the dose parameter DLP. Furthermore, one way ANOVA revealed a statistically significant difference ($p \leq 0.05$) in head DLP between 55% of the CT centres.

3.2 Adult chest CT data

Out of the 23 CT centres surveyed only 12 centres had complete data for chest imaging. The DLP DRL for chest CT was established as 850 mGy*cm on the basis of the 75th percentile of the median DLP values of the participating centres, as shown in Figure 2. Centres C6, C12 and C17 are identified as having DLP values above this DRL.

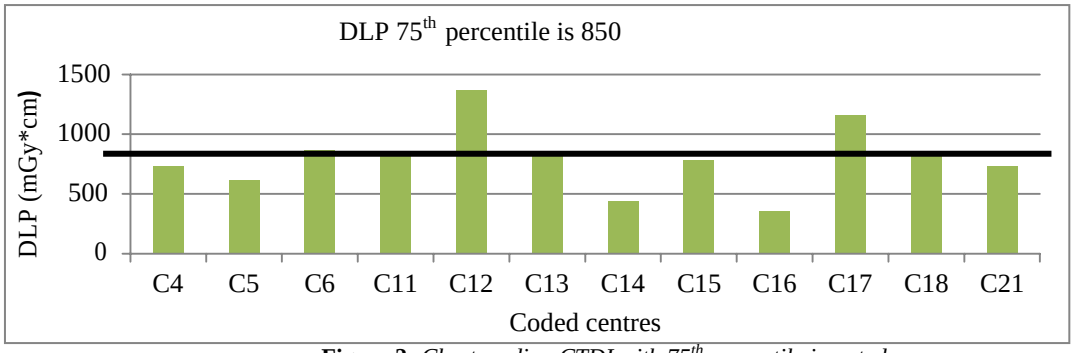

Figure 2: *Chest median CTDI with 75th percentile inserted*

The 75th percentile of the chest DLP was compared with values from other organisations and countries with established DRLs. The DLP DRL is 37% higher and statistically significant ($p \leq 0.0001$) than the values from other countries

Using ANCOVA regression, the mAs and pitch were found to have a positive and negative impact on the DLP respectively, with the values obtained being statistically significant ($p \leq 0.05$). One way ANOVA shows a statistically significant difference in mean DLP between 33% of the CT centres.

3.3 Adult abdominal CT data

Using the same methodology of establishing the DRL on the basis of the 75th percentile of the median DLP values across centres, the survey established the DLP DRL for adult CT abdomen as 1592 mGy*cm. The results are shown in Figure 3, with the 75th percentile included. Note that centres C6, C11, C12, C18 and C22 have DLP values above this reference level.

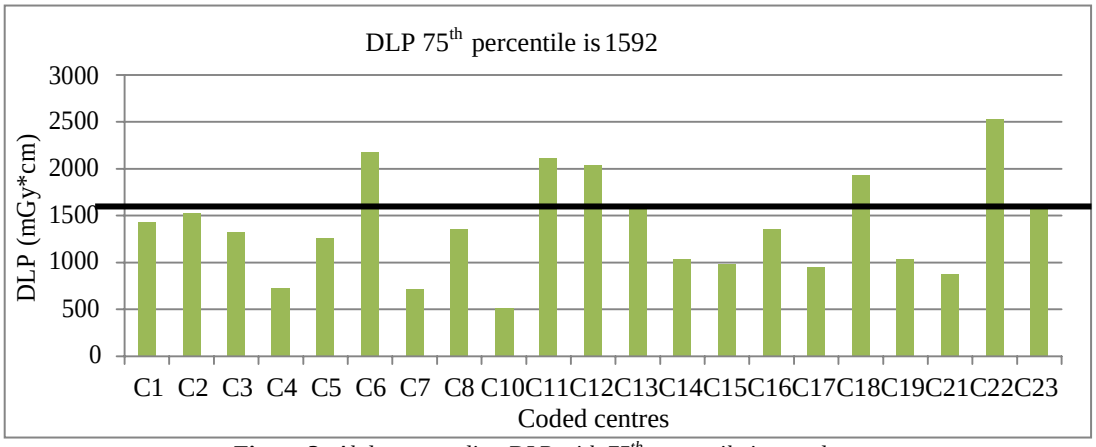

Figure 3: *Abdomen median DLP with 75th percentile inserted*

The 75th percentile in terms of DLP for abdominal CT was compared with established 75th percentile values available in the literature. The DLP DRL is 51% higher and statistically significant *($p \leq 0.0001$)* than the values from other countries.

ANCOVA regression identified four significant ($p \leq 0.05$) parameters, namely mAs, pitch, slice thickness and number of slices as having an impact on DLP. DLP variations between centres were assessed using one way ANOVA, where statistically significant ($p \leq 0.05$) differences were noted between 34% of the CT centres.

3.4 Paediatric head CT data

Paediatric head DLP DRLs were established as 1220 mGy*cm for <5yrs and 1851 mGy*cm for 5-10yrs of age. The DLP DRLs are shown in the median DLP bar charts of the 7 CT centres in Figure 4 and Figure 5. Centres P4 and P6 were identified as having DLP values above the reference level in the <5yrs and 5-10yrs age groups respectively (Figure 4 and 5).

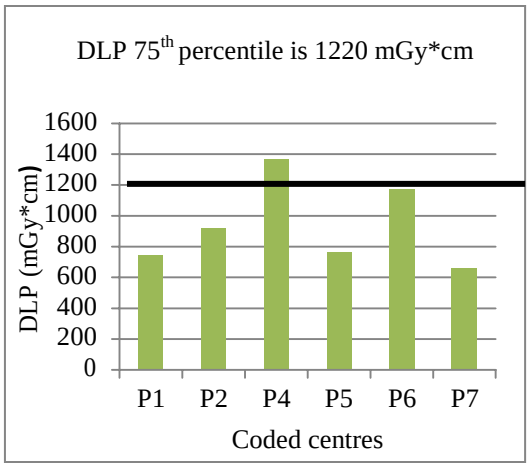

Figure 4: *Head median DLP in <5yrs age group with 75th percentile value inserted*

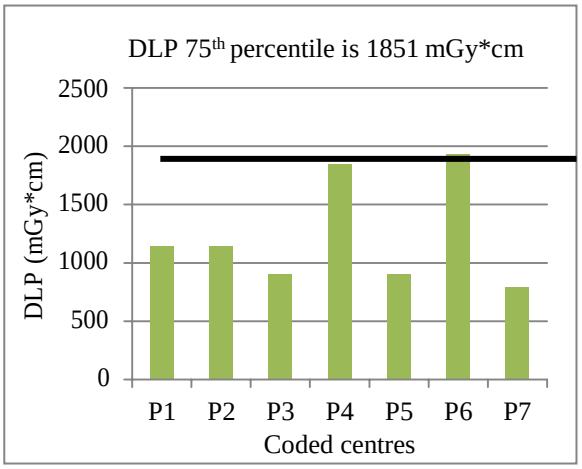

Figure 5: *Head median DLP in 5-10yrs age group with 75th percentile value inserted*

Head DLP DRLs were compared with established values in the literature using a one sample t-test. The DLP DRL values obtained are 56-60% higher and statistically significant *($p \leq 0.0.0001$)* than the compared values for both age groups. ANCOVA regression identified 3 significant ($p \leq 0.05$) parameters namely kV, mAs and number of slices as having an effect on DLP for paediatric patients. Using one way ANOVA, the results indicate that there was statistically significant difference ($p \leq 0.05$) in terms of DLP between only 20% and 38% of the CT centres in <5yrs and 5-10yrs age groups respectively.

4. DISCUSSION

This survey established DRLs in Nigeria based on radiation dose indices (CTDI and DLP) for adult and paediatric patients at the 75th percentile. The discussion will be solely focused on DLP values as indicated earlier. The study identified CT centres that have DLP values above the established adult DRLs: six for head CT; three for chest CT and five for abdominal CT. In the paediatric category two centres were identified (one from each category) as having DLP above the established head DRLs.

The variation of CT doses between the 23 CT scanners was investigated using one way ANOVA. The variation in mean DLP may be attributed to the use of different scan parameters (mAs, kV, pitch and scan length) or different scanner detector configurations as reported in other studies (11,12). These variations call for continuous training of radiographers in optimisation strategies followed by optimisation of the scan protocols across CT centres in the country to ensure that radiation doses are reduced in line with the ALARA principle.

In the present study, several parameters have been identified as significantly ($p \leq 0.05$) affecting CT dose namely: mAs, kV, pitch, the number of slices and slice thickness for both adult and paediatric groups. Many studies (13-15) have reported these same parameters affecting CT radiation dose indices, especially the mAs and pitch factor. In all the three body regions scanned, mAs was found to have a strong and statistically significant ($p \leq 0.05$) impact on the DLP. This parameter may therefore be used in radiation dose reduction strategies since it has the greatest impact on dose.

All established DLP DRLs for adult and paediatric CT examinations in the present study are significantly higher ($p \leq 0.0001$) than the compared DLP values from other countries (16-19). Other studies investigating the cause of higher DLP attributed it to a number of issues such as: the use of high scan parameter values (mAs, kV, number of slice) and multiple scan series (6,20-22).

4.1 CONCLUSION

This survey established DRLs in terms of CTDI and DLP values for adult head (69 mGy and 1827 mGy*cm), chest (16 mGy and 830 mGy*cm) and abdomen (20 mGy and 1592 mGy*cm) at the 75th percentile in Nigeria. Similarly, paediatric head DRLs were established as 42 mGy and 1220 mGy*cm for <5yrs and 61 mGy and 1851 mGy*cm for 5-10yrs of age. Variations in CT doses between centres and higher reported DRLs indicate the need for optimisation of CT scan protocols.

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NATIONAL SURVEY: PATIENT DOSE IN COMPUTER TOMOGRAPHY IN LITHUANIA AND APPLICATION OF NATIONAL DRLS

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Abstract

Each year Radiation Protection Centre assesses patient exposure levels from CT examinations made in Lithuanian hospitals. During the last 5 years patient exposure were assessed in 43 hospitals (more than 50 % of all CT scanners in Lithuania). Calculated average DLP values for standard size patients were compared with national diagnostic reference levels (DRLs). DRLs helps to identify inappropriate practice and to identify DRLs exceeding reasons and apply corrective actions to assure that these actions help optimize patient exposure. It is important, that hospitals would make patient exposure assessment because they are interested in the improvement of their own practice and in optimization of patient exposure, but not due to regulatory body control.

1. INTRODUCTION

Patient dose assessment is one of the ways to control practice and patient exposure. The concept of diagnostic reference levels (DRLs) is recognized as an efficient and powerful tool in optimization of diagnostic X-ray examinations. Patient exposures resulting from CT examinations are large, when compared to the most often preformed x ray radiography procedures. Therefore it is very important to have standards which help to control and unify the practice of CT examinations in different hospitals. National DRLs are the first level of this process.

Radiation Protection Centre prepared programs for patient exposure assessment due to different x ray diagnostic modalities in Lithuanian hospitals. Firstly, the goal was to evaluate patient exposure due to X-ray diagnostic examinations, based on different factors (gender and age) in Lithuania, secondly - to check how well the national DRLs, set in 2011, are used. Lastly, it was to encourage hospitals to evaluate their own practice and to optimize patient exposures.

Approximately 9 % of all medical x-ray examinations performed in Lithuania is CT examinations, but patient exposure due to these examinations makes up for 60 % of the whole population dose from medical x-ray imaging. CT technology is advanced and therefore has lots of tools to reach the best diagnostic value with less exposure. Therefore it is important to optimize parameters of these examinations. In order to achieve this goal, each examination must be adjusted for individual patient. DRLs help to identify inappropriate practice.

Patient dose monitoring should help to identify DRLs exceeding reasons, to apply corrective actions and to assure that these actions helped to optimize patient exposure. It is important, that the hospitals make these patient exposure assessments for their quality assurance program improvement and procedure optimization, not due to the pressure from the regulatory body control.

2. METHODS

With the purpose to assess the patient dose in Lithuania, and to encourage hospitals to optimize x- ray diagnostic procedures, a national survey of patient doses from CT examinations were performed from the year

2012 to 2016. Detailed data about patients and examination parameters (kVp, mAs, pitch and etc.) was collected from 43 hospitals (68% of hospitals in Lithuania which use CT scanners). Data was collected in two ways: (a) hospitals filled questionnaires and sent them to the Radiation Protection Center, or (b) -in some cases Radiation Protection Center specialists visited hospitals and filled questionnaires by themselves. Data was collected about the examinations for which DRLs are set in Lithuania: head, chest, abdomen, pelvis and spine (neck, thorax and abdomen parts) CT procedures. Summarized information about collected data is showed in 1 table.

TABLE 1. CT EXAMINATION DATA/INFORMATION

Procedure	Number of hospitals	Data amount	Average DLP*	National DRL	Number of hospitals where DRL exceeded
Head CT	31	1121	891±74	950	7 (23 %)
Chest CT	32	842	695±149	650	9 (28 %)
Spine CT:				300	
Neck part	23	644	408±101	No	15 (65 %)
Chest part	23	343	591±136	No	19 (83 %)
Abdomen part	35	990	517±97	No	30 (86 %)
Abdomen	29	653	1113±293	1200	7 (29 %)
Pelvis CT	17	363	617±132	550	6 (35 %)

- Average DLP value ± confidence level of 95 %

Average DLP was calculated and compared with national DRLs. If a DRLs were exceeded in the hospital, that particular hospital had to investigate their actions and identify reasons why the DLP values were exceeded, then apply appropriate corrective actions and repeat the patient dose assessment to ensure, that applied actions helped optimize patient's exposure during CT examinations. Patient exposure was assessed based on patient gender, age and procedure parameters. Detailed analysis of procedure parameters was not possible for the data collected in 2012, due to very basic data collection protocols used.

3. RESULTS

Average patient exposure is shown in table 1. Data analysis showed, that national DRLs were exceeded, in about 30 % of checked hospitals, for each type of procedure. It was observed, that the exposure is more frequently exceeded in small hospitals. National DRLs for head, chest, abdomen and pelvis CT procedures were approximately equal to the 3rd quartile of data set, but the national DRLs for spine CT procedures were much lower than the 3rd quartile of the data set. National DRLs for spine CT procedures were exceeded in more than 83 % of checked hospitals. Lithuanian DRLs for spine procedures is the smallest in all European countries. Data about the standard size patient exposure from abdominal spine CT procedures, in different hospitals, is shown in figure 1. It was determined that the national DRL for spine CT procedures must be revised.

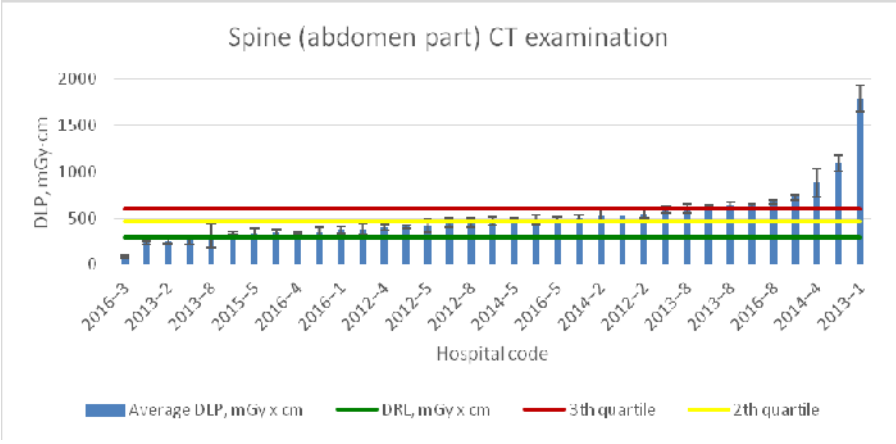

FIG. 1. Patient exposure due to performed abdominal spine CT examinations in Lithuania hospitals

Data was analyzed based on the standard size patient exposure levels from different CT scanner manufacturers. Data about DLP values for head CT procedures is shown in figure 2. Columns show the average exposure for certain CT scanner, middle line is the average standard size patient exposure for a certain manufacturer, the highest and the lowest lines - max and min standard size patient exposure for a certain manufacturer. It can be seen that DLP variation is very high between different CT scanners.

Whenever an average DLP for a group of standard patients exceeded the national DLP value, hospitals had to find out reasons why. Summary of all of the explanations showed, that it's the radiology technologist who has the most influence on the patient exposure. There were two cases where the CT scanner had influenced the exposure. Usually, radiology technologists don't use optimized parameters. Analysis showed that the procedure parameters are not always adapted for the individual patient. In one instance a hospital informed that the CT scanner is unable to decrease the patient exposure anymore and in another case, where DLP was lower than in other hospitals – that the radiologist was unsatisfied by image quality.

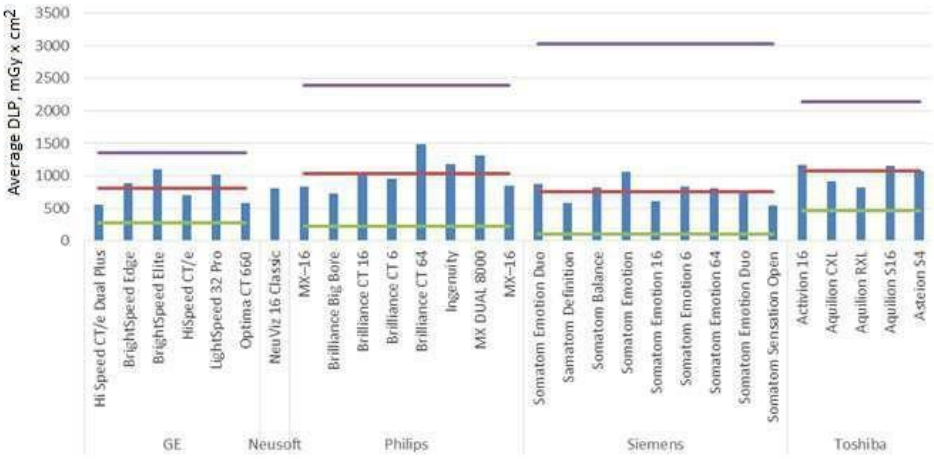

FIG 2. Patients exposure due to performed head CT examination using various manufacturer's CT scanners.

Data analysis based on gender showed, that there is no visible difference between the exposure during CT procedures. Exposure dependency on gender for chest CT procedures can be seen in figure 3. It was identified that the average female and male exposures in Lithuania are very similar. There was no clear tendency related to patient gender observed in any CT procedure. There were insignificant variations in female and male exposures in different hospitals.

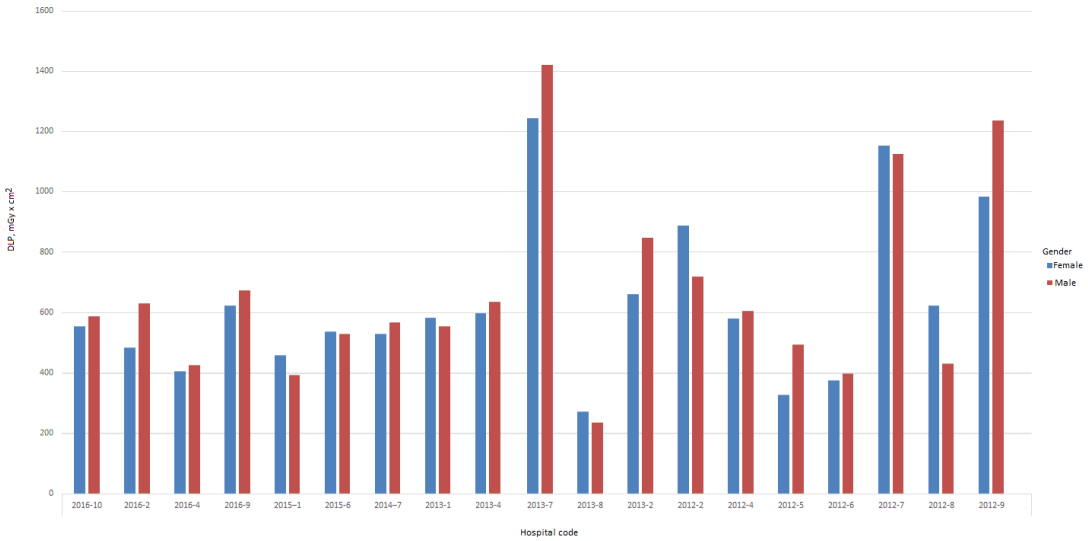

FIG 3. Patients exposure due to performed chest CT examination for female and male patients.

4. DISCUSSIONS AND CONCLUSIONS

National DRLs is one of the main factors for patient exposure optimization if they are set correctly. Data about performed CT examinations parameters were collected from more than 50 % CT scanners used in Lithuania. Data collection were performed in different levels of hospitals, therefore data analysis reveals real situation in Lithuania. Generally national DRLs are adjusted well in Lithuania but they are only the first step in optimization of patient exposure that is why hospitals are encouraged to establish local DRLs.

National DRLs were set in 2011, based on national survey. These levels are very similar to national DRLs in other countries (except for spine CT examinations). During the data analysis it was established, that practice in Lithuania did not change much during the last few years.

National DRLs for spine CT procedures are too low. These levels were exceeded in 83 % of checked hospitals in Lithuania. Since it is clear that these levels must be corrected, there was no need to investigate the reasons for exceeding of these levels.

Furthermore, there was ascertained importance of radiology technologist competence. All the hospitals, after the investigation of the reasons behind the national DRLs exceeding were complete, declared, that the main responsibility belongs to person, who performs the examinations. It shows that hospitals must pay more attention to the qualification of their radiology technologists.

There is an obligation for the hospitals to assess patient exposure periodically in Lithuanian legislation. So one of the tasks of Radiation Protection Centre was to encourage hospitals to make patient exposure assessment themselves – prompt the medical staff to improve quality assurance program and optimize patient exposures. For now we can assume, that taken actions such as workshops with medical physicists, radiologists and radiology technologists were effective and hospitals began to assess patient exposures on their own initiative.

OPERATOR EYE LENS DOSES IN CT FLUOROSCOPY-GUIDED PROCEDURES

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Abstract

Staff involved in CT-fluoroscopy guided procedures are among those for whom the exposure of the lens of the eye might be important. The purpose this study was to evaluate operators' eye lens doses and correlation with patient dose during fluoroscopy in routinely performed CT-fluoroscopy guided procedures. Three radiologists wore TLD dosimeters for one month during all CT-fluoroscopy guided procedures. The radiologists did a total of 52 procedures. Radiologist A received an eye lens dose of 0.97 mSv which is on average 28 µSv/procedure. Radiologists B and C received 0.26 mSv (22 µSv/procedure) and 0.10 mSv (20 µSv/procedure) respectively. The overall average eye lens dose per procedure was 26 µSv. The total DLP during fluoroscopy was 2264.7, 623.1 and 196.1 mGy·cm in all procedures performed by radiologist A, B and C respectively. There was a good correlation between fluoroscopy-DLP and the eye lens dose. Eye lens doses to operators in CT-fluoroscopy guided procedures are significant. Radiologists working in CT-fluoroscopy can approach the occupational dose limit for the lens of the eye if workload is high and lead glasses are not worn.

1. INTRODUCTION

In the last few years increased attention has been given to the radiation dose to the eye lens in medical workers. The threshold for tissue reactions in the lens of the eye which was previously considered to be 2 Gy [1] is now considered to be 0.5 Gy and in the year 2012 International Commission on Radiological Protection (ICRP) issued a statement on tissue reactions in which the recommended equivalent dose limit for the lens of the eye is 20 mSv/year, averaged over periods of 5 years, with no single year exceeding 50 mSv [2].

The International Atomic Energy Agency (IAEA) has since provided a guideline on the implications of this new dose limit [3]. According to those guidelines staff involved in computed tomography (CT)-guided interventional procedures are among those for whom the exposure of the lens of the eye might be important [3] but data on doses to the lens of the eye of these workers is limited.

CT-fluoroscopy is considered safe and effective method of image guided intervention although it is recognized that relatively high radiation doses to operators are possible [4].

In fluoroscopy guided intervention doses to the lens of the eye per procedure range from 10 µSv to few mSv, the highest values related to the over-couch X-ray tube geometry and the absence of radiation protection equipment aimed at protecting the eyes [3]. The few reports existing of eye lens doses in CT-fluoroscopy indicate similar dose values per procedure but more data is needed [5-7].

The aim of this study was to evaluate operators' eye lens doses and correlation with patient dose during fluoroscopy in routinely performed CT-fluoroscopy guided procedures.

2. MATERIAL AND METHODS

The dosimeter used is a TLD detector in a polyamide capsule; the Eye-d dosimeter (Radcard, Kraków, Poland), developed within the EU FP7 ORAMED project [8]. The TLD pellets consist of LiF:Mg,Cu,P (MCP-N) and are 4.5 mm (diameter) × 0.9 mm. In the absence of a cylinder phantom for calibration in terms of Hp(3) the dosimeters were calibrated on the ICRU slab phantom in the dosimetry laboratory of the Icelandic Radiation Safety Authority, in terms of Hp(0.07) using X-ray equipment with a RQR6 beam quality according to IEC 61267:2005. The reference dosimeter was PTW Unidose (PTW, Freiburg, Germany) with 0.6 cc ion chamber and a calibration traceable to a secondary standard laboratory. Conversion from air kerma to Hp(0.07) was made with a conversion factor obtained from ISO 4037-3, N-series (N-80) [9].

Three radiologists working with two different CT scanners in different institutions wore the dosimeters in all CT-fluoroscopy guided procedures they performed during a period of one month. They all wore eyeglasses (but not lead glasses) and for each of them one dosimeter was prepared. The capsule containing the TLD was attached to the arm of the glasses near the hinge, as close to the eye as possible, on the temple closer to the x-ray tube. These particular dosimeters were only used during CT-fluoroscopy guided procedures.

From a batch of 10 TLD chips, the three with the best reproducibility (<1.5 %) were selected for the personal dosimeters, three were irradiated for calibration and four were kept for background measurement. The chips were read in a Harsaw TLD Model 4500 Manual Reader (Thermo Scientific, Ohio, USA).

The CT scanners were Toshiba Astelion 32 detector row (scanner A) and Philips Brilliance 64 detector row (scanner B). One shot mode was used in both scanners for all interventional procedures and a tube potential of 120 kV.

For all interventions performed by the participating radiologists the type of intervention, anonymous patient size indicators (height and weight) and dose indicators (DLP) were recorded concurrently. The DLP displayed on the scanner console during and after each procedure was recorded in such way that the DLP for the CT-fluoroscopy part of the procedure (fluoroscopic-DLP) could be isolated. Only this part of the patient radiation dose is important in the context of this study because the radiologist was only present in the scanner room during fluoroscopy.

The average dose per procedure was found by dividing the total eye lens dose with the number of procedures performed. The sum of the fluoroscopic-DLP from all examinations (total fluoroscopic-DLP) for each radiologist was calculated as a reference for the scattered air kerma present.

Histogram showed that the DLP data was not normal distributed and Wilcoxon Rank Sum Test was used to compare the DLP in the two most common procedures ($\alpha = 0.05$, two-tail), Spearman's rank correlation for the relation of DLP and patients weight and t-test to compare patient groups in the two scanners (0.05 significance level).

3. RESULTS

During a measurement period of one month the three radiologists, A, B and C did a total of 52 procedures. Radiologist A received an eye lens dose of 0.97 mSv which is on average 28 µSv/procedure. Radiologists B and C received 0.26 mSv (22 µSv/procedure) and 0.10 mSv (20 µSv/procedure) respectively. Average eye lens dose per procedure in scanner A was 28 µSv and 21 µSv in scanner B. The overall average eye lens dose per procedure was 26 µSv.

Radiologist A did 35 spinal injections for pain management; including facet joint injections, single nerve root blocks and epidural injections, in scanner A. Scanner B was used for biopsies and ablations and the two participating radiologists did a total of 17 procedures as listed in Table 1.

TABLE 1. NUMBER OF PROCEDURES PERFORMED IN EACH SCANNER BY EACH RADIOLOGIST DURING A MEASUREMENT PERIOD OF ONE MONTH

	Radiologist A	Radiologist B	Radiologist C	Total
Procedure:	Scanner A	Scanner B		
Spinal injection	35			**35**
Abdominal biopsy		1	2	**3**
Thorax biopsy		8	2	**10**
Pelvic bone biopsy		1	1	**2**
Thorax ablation		2	0	**2**
Total	**35**	**12**	**5**	**52**

Average patient weight was significantly ($p < 0.05$) higher in procedures in scanner A (86.8 kg ± 19.7) than in scanner B (74.8 kg ± 13.6). The DLP for the fluoroscopy part of each procedure is shown in Table 2. There is a considerable variation in the fluoroscopic-DLP within each type of procedure, and while the thorax biopsies are generally performed with lower fluoroscopic-DLP than the spinal injections the difference is not statistically significant. The highest fluoroscopic-DLP in an individual procedure was during a spinal injection.

TABLE 2. DOSE LENGTH PRODUCT (DLP) FOR THE FLUOROSCOPY PART OF EACH PROCEDURE

Procedure:	n	median	min	max
Spinal injection	35	50.4	16.8	219.0
Abdominal biopsy	3	39.6	13.2	110.2
Thorax biopsy	10	16.6	2.2	53.0
Pelvic bone biopsy	2		26.5	49.5
Thorax ablation	2		128.9	145.7

In the 35 spinal injections, there was a mild positive correlation between patients' weight and fluoroscopic DLP ($r_s = 0.23$) but the correlation was minor and negative for the 10 thorax biopsies ($r_s = -0.13$).

The total DLP during fluoroscopy was 2264.7 mGy·cm in all procedures performed by radiologist A and 623.1 mGy·cm and 196.1 mGy·cm in all procedures performed by radiologists B and C respectively. Figure 1 shows the correlation between the total fluoroscopic-DLP and the eye lens dose ($r_s = 1$).

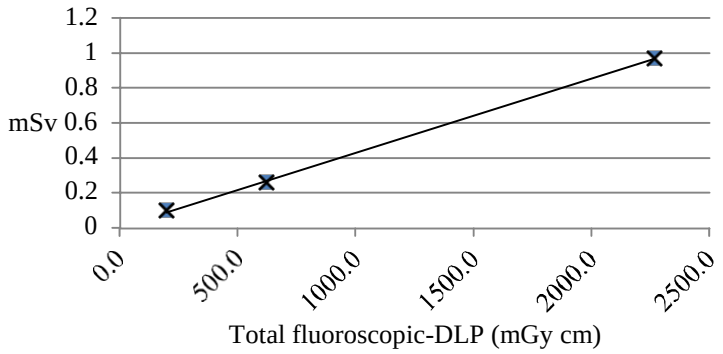

FIG. 1 Correlation of the eye lens dose in milliSievert (mSv) measured by each dosimeter and the sum of the fluoroscopic-dose length product (DLP) in mGy·cm for all respective procedures.

4. DISCUSSION

This study supports the assertion that eye lens doses to operators in CT-fluoroscopy guided procedures are significant, although for each procedure they may be small. For the radiologist with the highest eye lens dose during the measurement period the estimated annual dose given similar workload could approach 10 mSv.

The average eye lens dose measured in this study is similar to previously reported doses [5-7]. Lead glasses can reduce the dose to the eye lenses by up to 90% [10] and their use is the single most effective method to reduce operators' eye lens doses [11]. It is, though, of utmost importance to select lead glasses that fit well. When the scattered radiation strikes oblique from below, the transmitted dose is larger and the effect of the lead glasses varies considerably between the different models of lead glasses [12].

Other ways to reduce operators' dose during CT-fluoroscopy include proper planning of the procedure, adjusting the technique in each case, performing CT-fluoroscopy intermittently instead of in real time and optimizing needle visualization [13].

It is clear from the DLP recorded for each procedure that there is a considerable difference between procedures and this is consistent with results of others [14]. As the eye lens of the operator is only exposed to scattered radiation generated in the patient it is highly dependent on the patient radiation dose during the fluoroscopy part of the procedure. The correlation between the total fluoroscopic-DLP and the eye lens dose was good, although not statistically robust due to few data points. Regardless, the data does indicate that the total fluoroscopic-DLP of procedures performed by each individual is a reliable indicator of the eye lens dose given identical exposure setting.

The operators' position is an important determinant of the radiation exposure during CT fluoroscopy [15], together with fluoroscopy time. Operators' position during intervention is however primarily controlled by the nature of the procedure being performed which limits the possibility to utilize the shielding of the gantry.

Since the scatter air kerma is lower close to the gantry it is possible that the eye (and/or the dosimeter) on the scanner side is prone to less exposure than the other eye, but for that to be the case the radiologist would have to stand very close to the gantry and turn the head towards the gantry opening, rather than to the screen opposite. It is believed that in this study the dose to the more exposed eye was measured.

There were some limitations to this study. The optimal dosimeter calibration for eye lens dosimeter, Hp(3), was not available and thus not used. The position of the dosimeter on the left side of the head leads to a conservative overestimation (approximately 6%) of the eye lens dose, whereas a dosimeter over the eye or between them would underestimate the dose [12]. Dose was only measured to the eye closer to the gantry and fastening the dosimeter on a rim of glasses, but not tight on the skin, similar to the calibration conditions, will add a small error.

In conclusion, the eye lens doses to operators in CT-fluoroscopy guided procedures are significant and radiologists working in CT-fluoroscopy can approach the occupational dose limit for the lens of the eye if workload is high and lead glasses are not worn.

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MONTE CARLO STUDIES INTO STAFF DOSE: LEAD DRAPE AND PATIENT COVER USE DURING COMPUTED TOMOGRAPHY FLUOROSCOPYPROCEDURES

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Abstract

Reduction of staff radiation dose through the use of lead drape on the computed tomography fluoroscopy (CTF) gantry and lead cover on patients during CTF procedures have been investigated using the Monte Carlo MCNP6. Using already proven method of modelling point source, bowtie-filter and collimator, the Computed Tomography (CT) equipment at Korle-Bu Teaching Hospital in Accra was modelled. Computed Tomography Dose Index (CTDI) of the CT machine were measured using pencil ionisation chamber for verification of the model. A standing and supine Male Adult meSH (MASH) voxel phantoms were used to represent the staff and patient respectively. The lead drape and patient cover were modelled and used alternatively for the study. The dosimetry of the organ doses and effective dose to the staff were evaluated for the different scenarios of alternating lead drape and patient cover. The effective dose to staff when lead drape and patient cover were used simultaneosly was reduced by a factor of about 4. It is therefore recommended that apart from the conventional means of staff protection, the lead drape and patient cover should be used when possible.

1. INTRODUCTION

Computed Tomography Fluoroscopy (CTF) is an improved medical interventional procedure [1] due to its wide dynamic range to image air-filled, soft tissue and bony structures. Additionally, CTF provides acceptable image quality which is less affected by patient breathing and motion [2]. The presence of the medical staff is required to be in the room to manipulate the needle during CTF procedures [3, 4] for effective intervention.

Radiation doses to staff during CTF procedures are high [5-7], therefore the staff is required to protect themselves with lead aprons, goggles and thyroid shield [8]. Alternatively, dose reduction techniques like the use of protective gloves and needle holder [9-11], angular beam modulation application [12], and pulse CT fluoroscopy rather than continuous [13] have been investigated and recommended.

This paper presents Monte Carlo investigation into staff dose reduction technique through the use of lead drape and patient cover, apart from the use of conventional means and other suggested recommendations.

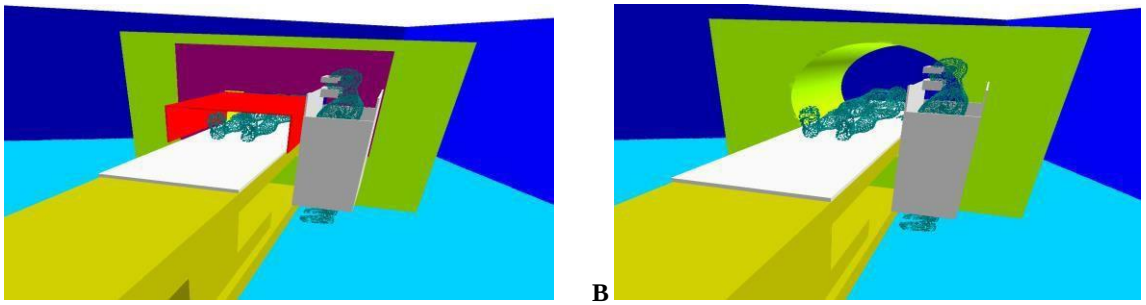
2. METHODOLOGY

A Toshiba Aquilion One 640 slice Computed Tomography (CT) scanner at Korle-Bu Teaching Hospital, Accra was modelled by modelling 36 point source at 10^{o} intervals, bowtie-filter and collimator using the method reported by Figueira *et al* [14]. A pencil ionization chamber was modelled as well for verification of the CT using specifications given by Gu *et al* [15]. The CT gantry block, patient table, CT room, lead drape (0.35 mm Pb equivalence) and lead patient cover (0.35 mm Pb equivalence) were also modelled using SimpleGeo [16]. A computational standing and supine mesh phantoms according to Cassola *et al* [17] were used to represent the staff and patient respectively. All the individual models were spatially put together on one platform using VOXEL2MCNP [18], an in-house software developed at Karlsruhe Institute of Technology (KIT). VOXEL2MCNP was subsequently used to export all the models to MCNP input files for simulation.

The photon energy spectrum was generated with the specifications of 120 kVp, a tungsten anode angle of 12 degrees, and a 2.5 mm thick aluminium filter using SpekCalc [19]. The mean energy of the spectrum amounted to 54.45 keV. The MCNP6 [20] radiation transport code with type 6 (F6:p) tally results (photon energy deposition per mass per particle) was used for the simulations. One billion five hundred million ($1.5x10^9$) number of particles were tracked in order to have a good compromise between relative error and reasonable computational time.

Computed Tomography dose index (CTDI) values were measured at 120 kVp, 100 mA, collimation of 40 mm, tube rotation time of 1 s (full 360 degree tube rotation) from the Toshiba Acquilion One 640 slice CT scanner using a perspex body phantom (32 cm diameter) and a CT Dose Profiler probe (pencil ionisation chamber) connected to a Barracuda X-ray multimeter, running the Ocean software on a computer [21].

In order to investigate the effect of the use of a lead drape and patient cover on the staff dose, a scenario of the use of both lead drape and patient cover as shown in Figure 1A was simulated. For control purposes, the scenario where none of the lead drape and patient cover was used as shown in Figure 1B was simulated as well. Investigative studies on the alternating use of lead drape and patient cover was conducted.



A **B**

FIG. 1. 3D model of scenarios during CTF procedure (A) Using lead drape and patient cover (B) Without lead drape and patient cover.

3. RESULTS AND DISCUSSION

The measured $CTDI_{100}$ in air was 27.01mGy/100mA, and the simulated energy in ionisation chamber in air was 5.97×10^{-8} MeV/g/particle. Hence the calculated conversion factor for MeV/g/particle to mGy/100mA was 4.52×10^8 mGy.g.particle/100mA/MeV. This conversion factor was used to convert all the F6:p tally results to absorbed dose per 100mA.

The verification result of the CT machine is shown in Table 1. The simulated CTDI at the centre of the perspex phantom was higher than the measured CTDI by 1.19 %. Similarly, it can also be seen that the simulated weighted CTDI ($CTDI_w$) is higher than the measured by 0.34 %.

TABLE 1: COMPARISON OF MEASURED AND SIMULATED CTDI

Tube Voltage (kVp)		CTDI (mGy/ 100mAs)		Percentage deviation (%)
		Measured	Simulated	
120	Centre	3.34	3.38	1.19
	Weighted	5.94	5.96	0.34

The thyroid, eye lens and effective dose to staff for scenarios when both lead drape and patient cover are used or when lead drape and patient cover are used alternatively and, or when lead drape and patient cover are not used are shown in Table 2. The study focused on the thyroid and eye lens doses due to their sensitivity to radiation and proximity to the plane of the CTF scan during the procedures. The relative error associated with the simulation of dose to organs of the staff varied from 0.6 % to 50.2 % depending on the size of the organ and proximity to the position of all the 36 point sources.

It can clearly be seen that the use of both lead drape and patient cover significantly reduced the thyroid, eye lens and effective doses by a factor of 5.8, 7.2 and 4.4 respectively. When only lead drape is used, there is a reduction in dose to the thyroid, eye lens and effective dose by a factor of 3.5, 5.1 and 3.1 respectively. Additionally, when only patient cover is used, there is a reduction in dose to the thyroid, eye lens and effecti ve dose by a factor of 1.7, 1.5 and 1.7 respectively. The contribution of the lead drape to staff dose reduction during CTF procedures is more when compared with that of the patient cover.

The radiation dose to the eye lens was lower than the effective dose by a factor of 1.4 for all the scenarios with the use of the lead drape. Contrarily, the eye lens dose was higher than the effective dose by a factor of 1.2 for all the scenarios without lead drape. Attention to the eye lens protection and dosimetry is very important [22, 23] due to the reduced annual dose limit proposed in the International Commission on Radiological Protection (ICRP) [24] from 150 mSv to 20 mSv average over 5 years. In this cases the eye lens dose would be the limiting quantity for occupational exposure.

It must be mentioned that the medical staff was modelled standing upright with head facing forward, hence considering only a fixed head position for this study. In a realistic scenario, the staff at a point in time may be looking at the patient or the monitoring screen for the procedure. Additionally, the hand of the staff may be holding a needle throughout the procedure. Employing a movable phantom to take into account realistic staff head and hand positions are planned for the future.

TABLE 2: EFFECTIVE AND ORGAN DOSE PER TUBE ROTATION TO STAFF FOR VARYING SCENARIOS

	Scenarios			
	Both lead drape and patient cover use	Only lead drape use	Only patient cover use	No lead drape or patient cover use
Thyroid dose (μGy)	0.18 ± 0.03	0.30 ± 0.05	0.60 ± 0.03	1.04 ± 0.08
Eye Lens dose (μGy)	0.68 ± 0.11	0.95 ± 0.16	3.18 ± 0.07	4.89 ± 0.14
Effective dose (μSv)	0.98 ± 0.13	1.36 ± 0.18	2.58 ± 0.09	4.27 ± 0.12

Values presented as mean ± standard error

4. CONCLUSION

The conribution of the use of lead drape and patient cover for staff dose reduction has been investigated. The use of both lead drape and patient cover significanlty reduced the thyroid, eye lens and effective doses by a factor of 5.8, 7.2 and 4.4 respectively. The alternating use of lead drape and patient cover exhibited dose reduction capabilties with lead drape contributing more. Apart from the use of conventional means (lead apron, thryroid shield and googles) of staff dose reduction, the use of lead drape and patient cover is recommended when possible. Additionally, the eye lens dose can be higher than effective dose and hence eye lens monitoring in CTF procedures is recommended.

ACKNOWLEDGEMENTS

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Correlation between the Exposure Parameters and Computed Tomography Dose Index

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Abstract

Computed tomography now days are most common investigations used in departments of radiology to assess various structures of many clinical requests. The aim of this study was to measure and compare the exposure doses from computed tomography, relative to gender, pathologic cases, age\BMI correlated to CTDI, mA correlated with $CTDI_{vol}$, number of images correlated with $CTDI_{vol,}$ exposure time correlated with $CTDI_{vol}$. The study was designed as retrospective data was collected from different hospitals and clinical centers and analyzed by using EXCELL software in forms of bars, and correlations. Calibrated CT machine (GE, Optima™ CT-660), (Phillips buckydiagnost). Frequency of patient referred to CT examination was higher in male than female (66% vs. 34%) .The CT examination, compromised sinuses, abdomen, renal, chest and the neck, while radiography compromised;The correlation analysis revealed that: the CTDIvol increases slightly following the aging of patients in a linear mannerand represented with the equation: y = 7.915x + 581.3.A strong correlation(r=0.90) existed between BMI in Kg/m^2 and the $CTDI_{vol}$and expressed as y = 2.24x + 4.4, And the correlations between milli-ampare (mA) versus $CTDI_{vol}$ showed that: there is insignificant linear relationship between the mA and $CTDI_{vol}$ R^2 = 0.1 while the correlations between the number of images versus $CTDI_{vol}$revealed that $CTDI_{vol}$decreased the number of images.

1. Introduction:

The evaluation of radiation doses is still remaining a challenge in radiologic departments.Exposure limits have changed over the years in step with evolving information about the biologic effects of radiation and with changes in the social philosophy within which recommended exposure limits are developed. In the 1930s, the concept of a tolerance dose was used, a dose to which workers could be exposed continuously without any evident deleterious acute effects, such as erythema of the skin (1). The request for radiographic examinations is increasing in the past two years. Therefore, the radiation risk should be considered carefully in this situation.

The maximum permissible dose was designed to ensure that the probability of the occurrence of injuries was so low that the risk would be readily acceptable to the average person. At about that time, based on the results of genetic studies in Drosophila and mice, the occupational limit was reduced substantially and a limit for exposure of the public introduced. Subsequently, the hereditary effects were found to be smaller, and cancer risks larger, than were thought at the time. The NCRP was comparing the probability of radiation-induced cancer death in radiation workers with annual accidental mortality rates in “safe” industries. Exposure standards therefore are necessarily based partly on observed effects, but with a great deal of judgment involved.

2. Materials and methods:

Study design and population: The design was retrospective study conducted in five major hospitals radiology department and diagnostic centers in Khartoum state.

.The medical records for CT dose and digital x-ray doses for 300 patients were reviewed, and the patient aged from child to 90 years. And all information and data about patients are safely kept.

2.1.Instrumentation:

Three types of radiographic system were used during this study:

GE, Optima™ CT-660, with kVp range up to 140 kVp, and mA up to 600 mA, with scanning modes: helical, axial, cine and scout, manufactured by GE Healthcare in 2010.

X-Ray Tube specifications:

-Performix™ 40 X-ray Tube Unit, Design optimized for exams requiring a large number of scans without tube cooling.

Maximum Power: 72kW ,Dual Focal Spots: ,Small Focal Spot: , 0.9* 0.7 IEC 60336: 2005 , 0.7* 0.6 IEC 60336: 1993, Large Focal Spot.

2.2.Data collection& analysis:

The data were collected from three types of x-ray diagnostic methods , computed radiography, routine radiography and digital radiography , relative to the following variables: gender, pathologic cases, age/BMI correlated to CTDI, mA correlated with CTDIvol), number of images correlated with CTDIvol, exposure time correlated with CTDIvol. The results were analyzed using EXCELL software in forms of bars, and correlations.

The dosimetric methods rely on the use of ionization chamber dosimeters or solid state dosimeters employing (TLDs). measurement in free air are mostly made with suitably designed ionization chamber dosimeters , whereas measurements on the surface of the patient are more conveniently made with small TLDs stucks to the skin , which are less

likely to obstruct useful information in the image and more completely measure the backscattered radiation. DAP is most easily measured by a specially designed ionization chamber instrument attached to the diaphragm housing , where it affords minimum interference with the examination . The chambers comprise square parallel plates set perpendicular to the beam axis and are of sufficient area to encompass the largest beam size. The plates are often made to be transparent to visible light to allow use of light beam diaphragm. The electrometer and display unit are connected to the chamber by a long cable so that the display can positioned for easy access to read and reset.

3. Results and discussion:

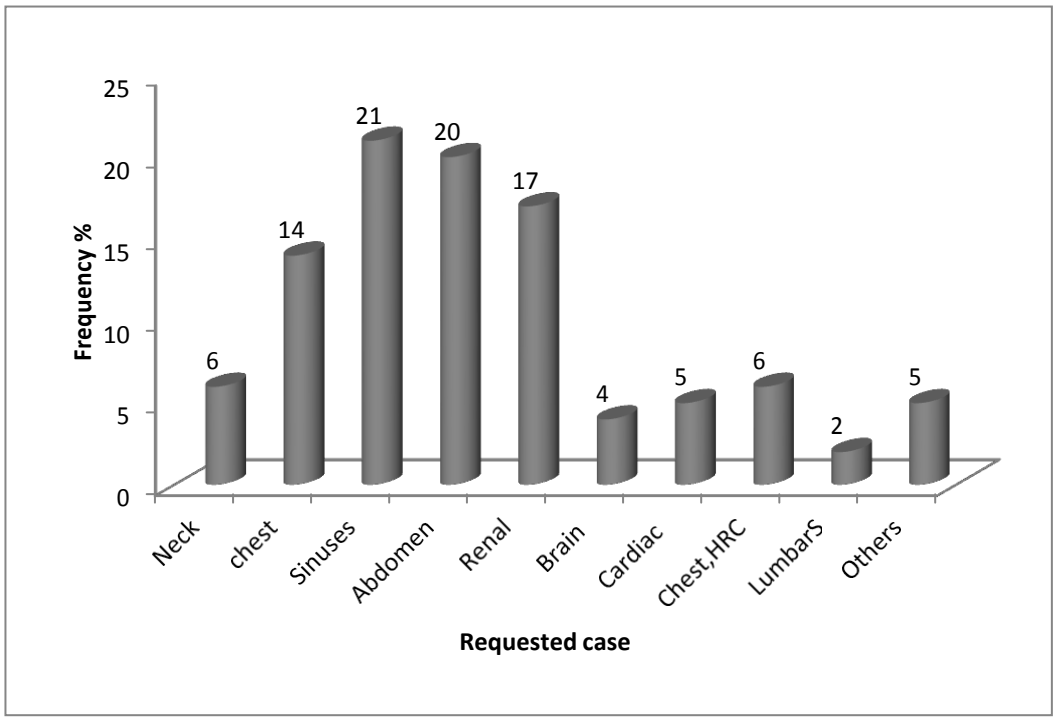

Figure 1.1 shows the frequency% of Requested cases for CT scanning.

Figure 1.1 shows the frequency% of pathological cases presented for CT scanning. The data shows that: the common cases referred for CT examination were the sinuses, abdomen, renal, chest and the neck that represents the following frequencies 21%, 20%,

17%, 14% and 6% respectively. Such high incidence among these cases could be ascribed to the common encountered with traffic accidents and the shortage of conventional x-ray to reveal and detects some related cases such as liver hematoma, pulmonary contusion, emphysema and sternum fracture due to exposure factors variation for the organ to be visualized.

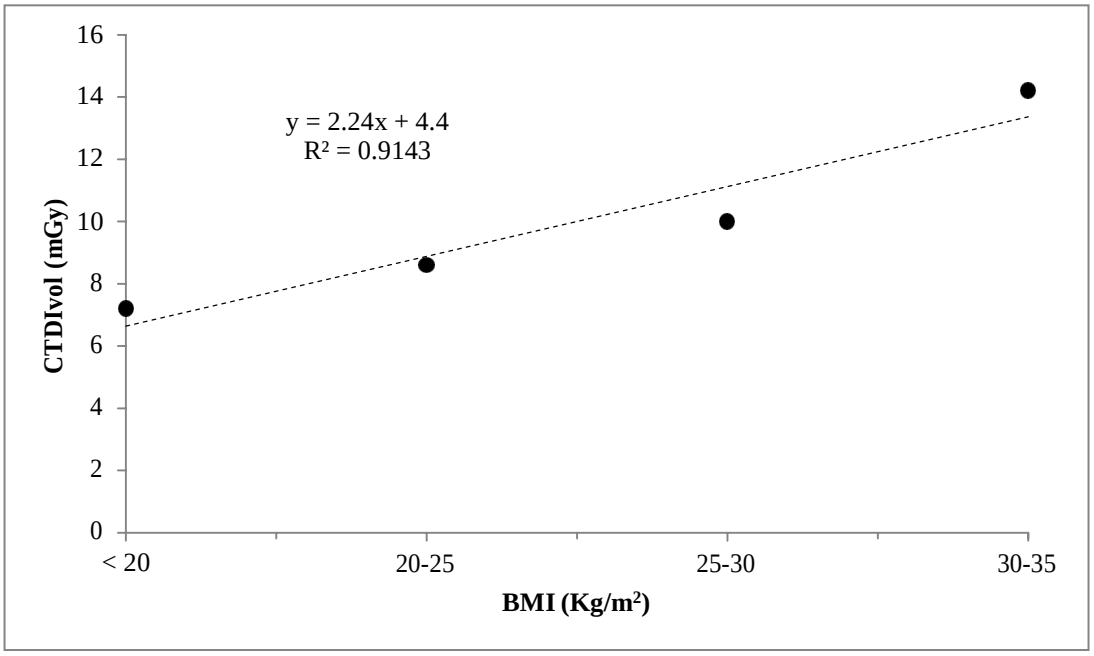

Figure (1.2) shows the correlation between the BMI in Kg/m^2 and the $CTDI_{vol}$.

Figure (1.2) shows the correlation between the BMI in Kg/m^2 and the $CTDI_{vol}$. The study shows that there is linear proportional relationship between the two parameters that could be fitted in the following equation: $y = 2.24x + 4.4$, where x refers to BMI in Kg/m^2 and y refers to $CTDI_{vol}$ which is so significant as $R^2 = 0.9$. And such increasing in the $CTDI_{vol}$ ascribed to the factors dependant such as the scattered radiation and the system output. Same result has been obtained by Boos et al, [(2)], in which they deduced that: the $CTDI_{vol}$ for the obese (30-35 Kg) and extremely obese (>35 Kg) has exceeded the National Diagnostic Reference levels.

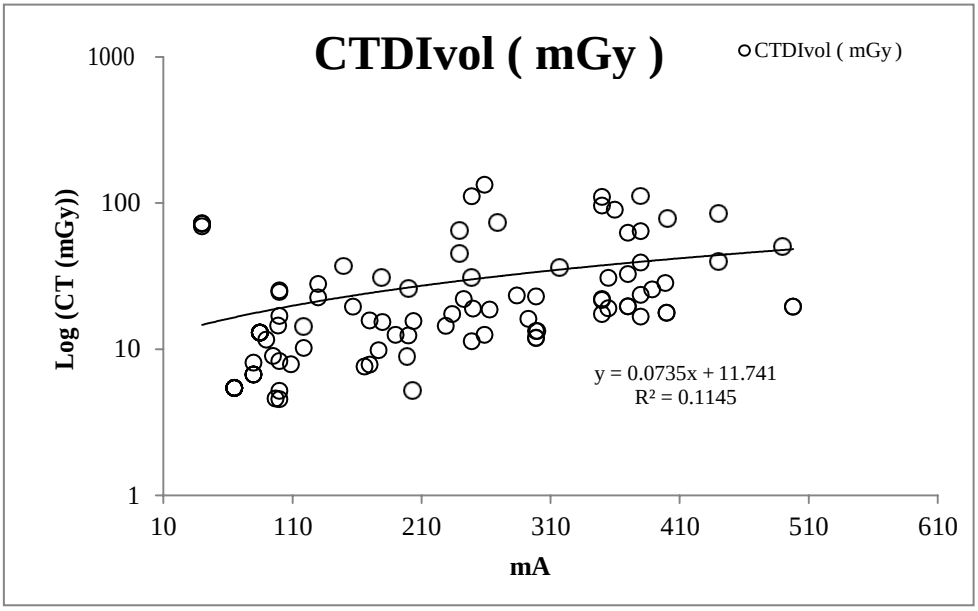

Figure 1.3 shows the correlations between mA and $CTDI_{vol}$.

Figure 1.3 shows the correlations between mA and $CTDI_{vol}$ and DLP in (mGy). It shows that: there is insignificant linear relationship between the mA and $CTDI_{vol}$ in (mGy) as $R^2 = 0.1$ & 0.09 which is agreed with the fact that mentioned by Dong F et al, [3] in conventional radiology and stated that: there is a linear relationship between the tube current-time product and the dose.

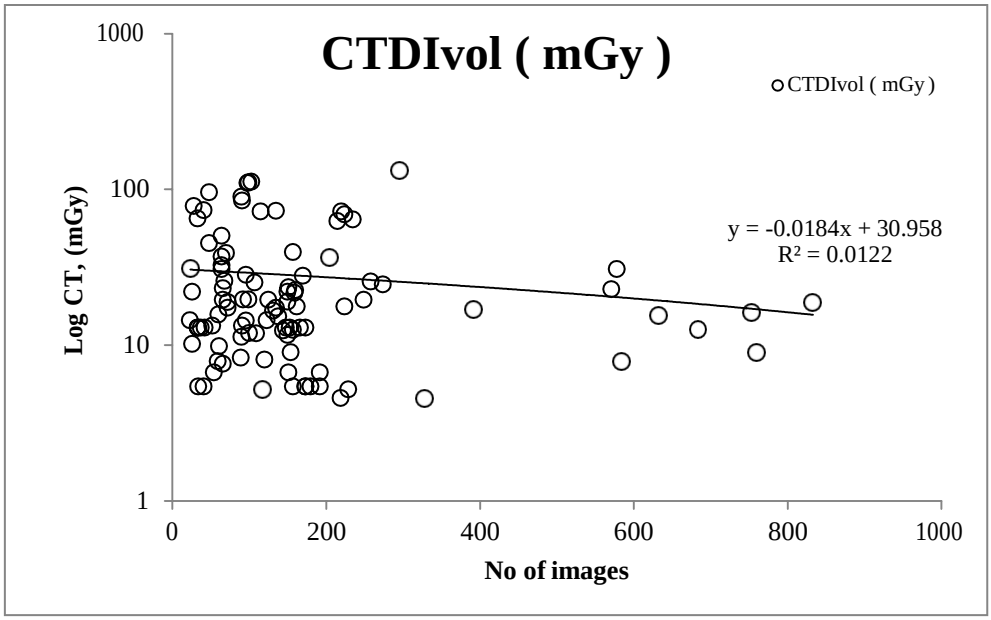

Figure 1.4 shows the correlations between No of images and $CTDI_{vol}$and DLP in (mGy/cm).

Figure 1.4 shows the correlations between the number of images and $CTDI_{vol}$. It reveals that both the $CTDI_{vo}$ decreased following the number of image done, however such relationship is insignificant as $R^2 = 0.00$ and the scientific justification for that is ascribed to the fact that: the number of images could be controlled by image reconstruction program

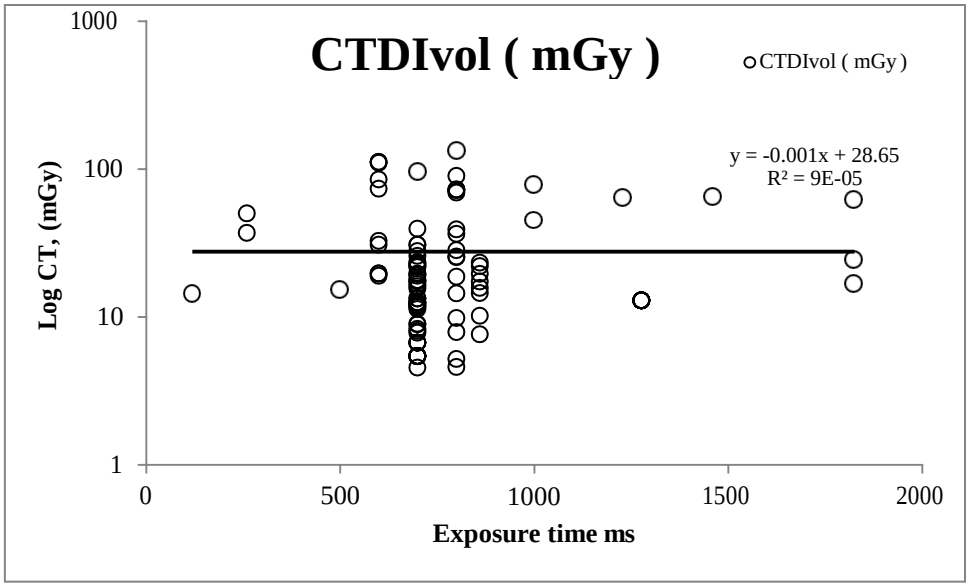

Figure 1.5 shows the correlations between exposure time and $CTDI_{vol}$ in (mGy).

Figure 1.5 shows the correlations between exposure time and $CTDI_{vol}$ in (mGy). It shows that, there is inversely linear relationship between $CTDI_{vol}$ and the exposure time in ms, which is not significant as $R^2 = 0.0$.

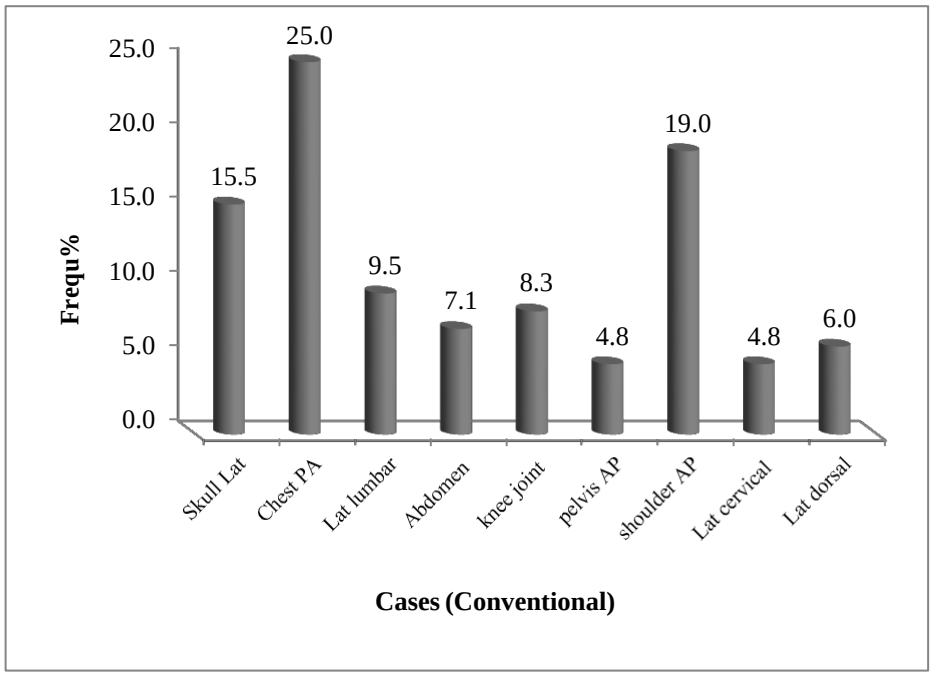

Figure 2.1 shows the frequency% of cases presented for conventional x-ray exams

Figure 2.1 shows the frequency% of cases presented for conventional x-ray exams. The data reveals that: the most common cases referred for conventional radiography was the chest x-ray, shoulder, skull, lumbar vertebrae and knee joint which represent 25%, 19%, 15%, 9.5% and 8.3% respectively. The common frequency of these cases ascribed to susceptibility of these anatomical organs to fractures in accidents as well the conventional x-ray is consider as direct, available, with acceptable possibility to reveal the pathologies at theses organs, and when x-ray fail to reveal the vague signs then CT is recommended. As has been mentioned by Abbas et al, [(4)], the conventional x-ray has high accuracy and sensitivity to detect the pathologies related to such organs.

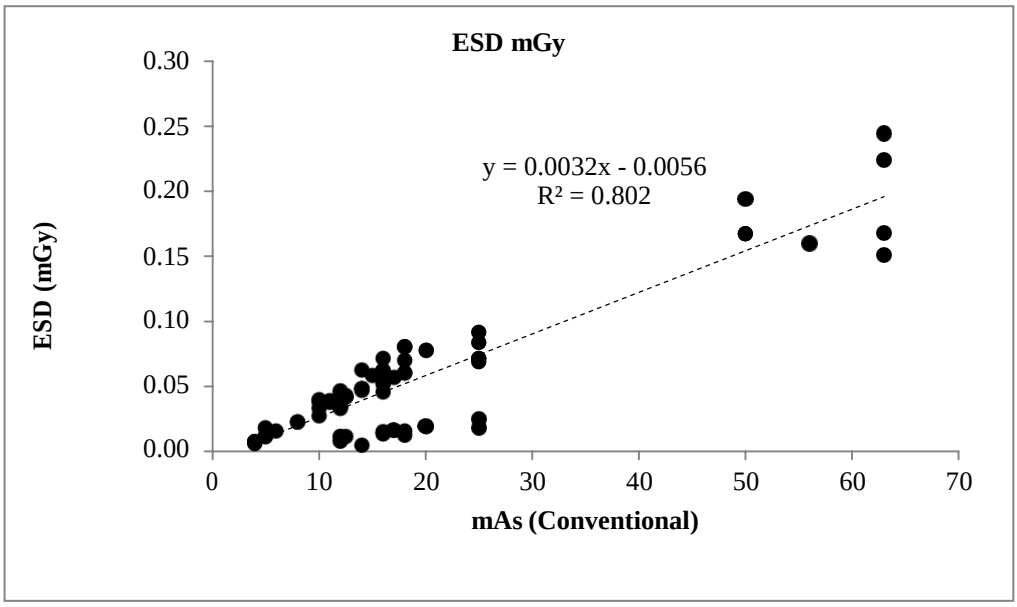

Figure 2.2 shows the correlation between the applied mAs and the ESAK (mGy) in conventional radiology.

Figure 2.2 shows the correlation between the applied mAs and the ESAK (mGy) in conventional radiology. The data reveals that: there is linear proportional relationship between mAs and the ESAK that could be fitted in the following equation: y = 0.003x - 0.005, where x refers to mAs and y refers to ESAK in mGy, such correlation is significant as $R^2 = 0.8$. Such fact is in agreed with the study carried out by Ofori et al, [5] and Taha et al, [6], in which they stated that: reductions in mAs affect both ESAK and effective dose by the same factor, where the ESAK was calculated in their work via entering parameters such as X-ray dose output, back scatter factor, focus to skin distance and physical parameters such as mAs and kVp in mathematical Equation No (x). Where BSF is the backscatter factor, Tube Output is beam output in μGy/mAs of the X-ray tube at different kVpp settings at distance of 1 m, mAs is the product of the tube current (mA) and the exposure time in seconds, FSD is the focus-to-skin distance used.

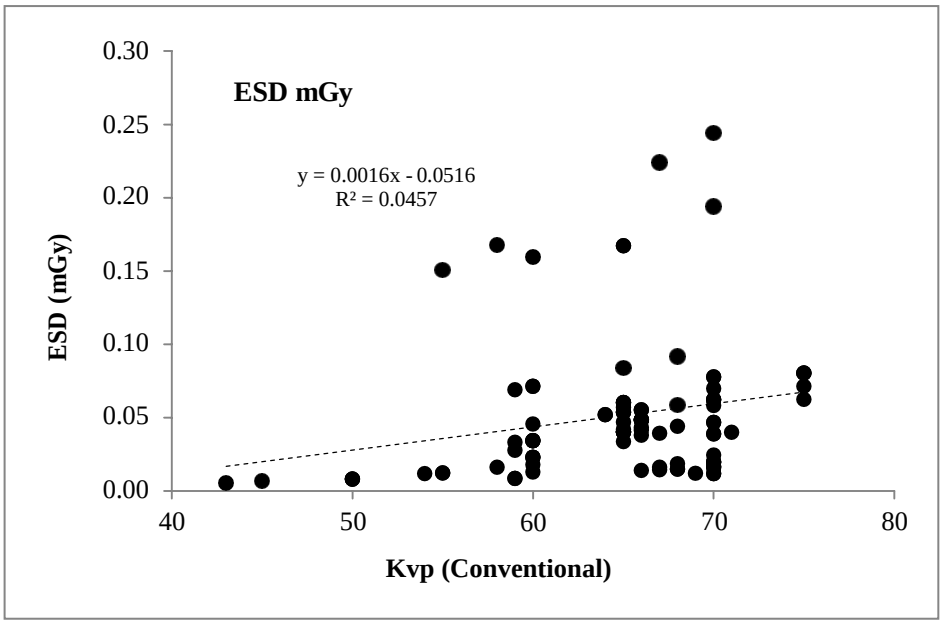

Figure 2.3 shows the correlation between the applied kVpp (kilovolts) and the ESAK (mGy) in conventional radiology.

Figure 2.3 shows the correlation between the applied kVpp (kilovolts) and the ESAK (mGy) in conventional radiology. It shows that: there is slightly increment insignificant (R^2 = 0) proportional linear relationship between the two parameters i.e. the kVpp&ESAK, that could be fitted in the following equation: y = 0.001x - 0.051, where x refers to kVpp and y refers to ESAK in mGy. Such result is in agree with the S Ramanaidu et al [7], in which they stated that a reduction of the ESAK for the same optical density of the film can be achieved by increasing the "penetration" of the X ray beam (increasing the tube potential). However, the extent to which ESAK may be reduced does not result in the same reduction in effective dose.

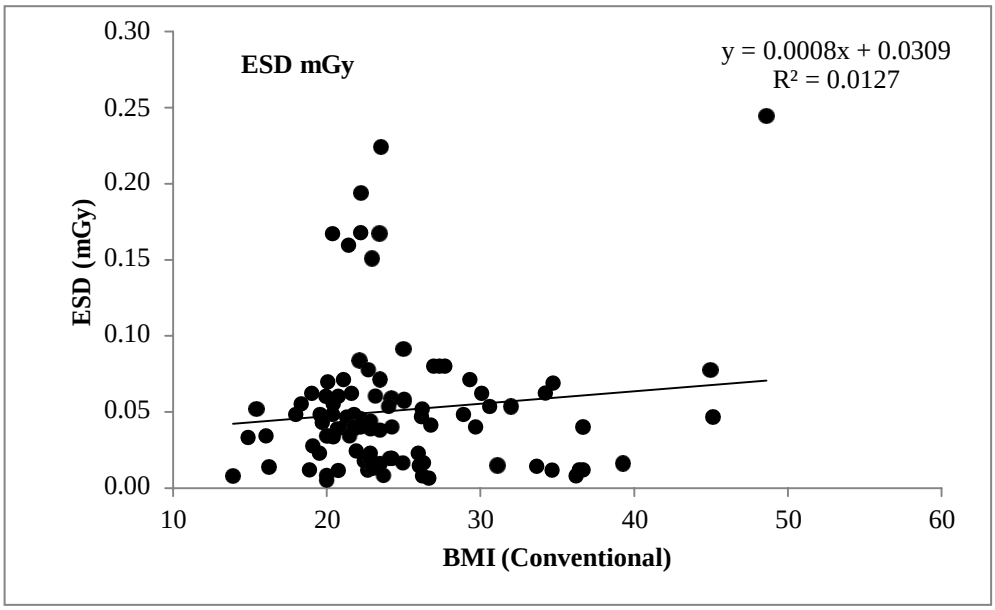

Figure 2.4 shows the correlation between the BMI and the ESAK (mGy) in conventional radiology**.**

Figure 2.4 shows the correlation between the BMI and the ESAK (mGy) in conventional radiology. The result reveals that: there is slightly (insignificant, $R^2 = 0$) proportional linear relationship between the BMI and ESAK i.e. the increasing of BMI would result in ESAK increment, which is ascribed to high density of high atomic number of the imaged organ. Same result has been mentioned by Matsumoto et al, [(8)] and Iida et al, [(9)], in which they stated that: a good correlation between ESAK and BMI has been obtained at significant point (r: 0.4 to 0.8) and r(2)= 0.910 respectively.

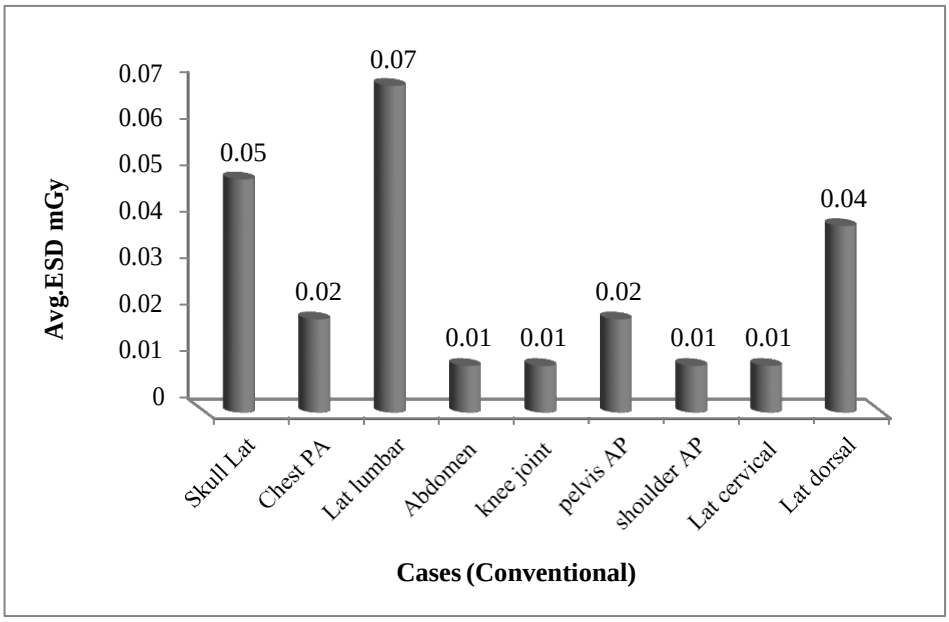

Figure 2.5 shows the average ESAK received in common cases presented for conventional x-ray exams.

Figure 2.5 shows the average ESAK received in common cases presented for conventional x-ray exams. It reveals that the high doses of entrance surface dose was observed in Lumbar vertebrae radiography, skull radiography and the dorsal vertebra radiography which represented 0.07, 0.05 and 0.04 mGy in addition to pelvic x-ray which received 0.02 respectively. The high doses in these cases ascribed to applied factors as well as the high density or atomic number of these organs.

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EVALUATION OF PATIENT DOSE & ASSOCIATED RISK FROM CHEST RADIOGRAPHY IN THE WEST BANK–PALESTINE

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Abstract

The need for using medical examinations is increasing around the world, particularly in diagnostics. One specific country that has shown an increase in the use of radiation in medicine is Palestine. This rapid increase in Palestine is accompanied with a lack of information about the radiation dose received by patients. Moreover, there is a lack of quality control, which should be undertaken to get better diagnostic information with minimal X-ray exposure. The study attempts to establish the diagnostic reference levels (DRLs) of patients' doses for the chest radiography in Palestine. The main focus within this study is to investigate and analyze the factors that affect patient radiation doses from chest radiography in Palestine, which is estimated as 53% of the total number of conventional X-ray examinations. The evaluation of patients' dosage and the associated risk factors were done using Monte Carlo simulations. The average effective dose and organ absorbed doses were evaluated in four medical centers in the West Bank and East Jerusalem – Palestine for a total of 668 patients. Patient samples were randomly taken from Nov 2014 to Feb 2015. All calculations were done by two commercial Monte Carlo simulation software: PCXMC-2.0 and Cal-Dose_X5.0. The average effective dose was estimated using geometric procedure data, which have been performed on patients. Factors considered include patient's height, weight, age , gender, X-ray tube voltage , electric charge (Milliampere-second), examinations projections (PA, AP, Lateral), filtration thickness in each X-ray machine, anode angle, focal source distance (FSD), and X-ray beam size. The average effective dose for 668 patients was 0.11 mSv for all chest X-ray examinations and projections in the four hospitals. The average effective dose in AP adult, PA adult, lateral adult, AP pediatric and PA pediatric were 0.14, 0.07,0.33, 0.09 and 0.06 mSv respectively.

Keywords: Chest X-ray, patient dose, effective dose, Monte Carlo simulation, PCXMC

1- INTRODUCTION

Medical application of radiation to man is defined as the most significant radiation exposure after the natural sources such as radon. It mainly comes from medical X-ray usage to patients in diagnostic and therapy. Low radiation dose researches indicate that there is an increase in the risk of stochastic detriment from diagnostic X-ray [1]. Therefore, radiation dose to patient must be kept as low as reasonably achievable (ALARA) [2]. Many studies evaluated radiation doses from medical X-ray examinations and risk assessment from their collective doses. It has been found that the effective dose, the basic dose which can be used for risk assessment, is the amount that should be absorbed in radiosensitive organs [3].

In Palestine, many doctors and medical professionals are not practicing the protection guidelines and some are not even aware of how grave the risk of medical radiation is. The study will assess patients effective dose and organ absorbed dose which determines the risk of radiation of chest radiography in the West Bank, and make it as low as possible without losing the quality in order to have a perfect diagnosis.

2- MATERIALS AND METHODS

Estimating the organ and effective doses is a solution to get a view of medical radiation exposure to patients. This solution is adopting Monte Carlo calculation software to provide an estimation of organ doses in patients undergoing X-ray examinations. In the study, the (CALDose_X_5.0) software used to calculate Incident Air Kerma (Ka,i) and the Entrance Skin Air Kerma (ESAK) values. The incident air kerma (Ka,i) is a value without the back scatter radiation, which was used as input data to calculate the organ doses and effective dose by PCXMC software. The study relies on the CALDose_X5.0 software to get the Incident Air Kerma (INAK), and PCXMC to get the effective dose and risk assessment. PCXMC program contains, among other data, conversion coefficients for 34 X-ray projections and 40 X-ray spectra; their conversion coefficients have been calculated using Voxel-based adult male and female phantoms" [4] [5].

Initially, in effective dose, ESAK and the INAK calculations have to be estimate from the X-ray tube output parameters. X-ray tube factors are recorded for each patient who undergoing chest X-ray examination. In the study, recorded factors are: Peak Tube Voltage (kVp), Exposure Current -Time Product (mAs), the Focus to Film Distance (FFD), patient age and gender. The average effective dose was calculated in four major facilities in Palestine for a total of 668 patients. The first is Al – Makassed hospital in Jerusalem; the second and third are located in Hebron; the forth is a digital center in Jerusalem. The effective dose was measured for a computed radiography (CR) machine at the latter. Patient samples were randomly taken from Nov 2014 to Feb 2015. For each patient has a chest radiography which is estimated as 53% of the total number of conventional X-ray examinations in Palestine.

3- RESULTS AND DISCUSSION

The highest average effective dose is found in adult lateral projection in hospital two as a result of short FFD (100) cm, which should be increased to 170 cm. The second high average effective dose recorded for AP pediatric projection at hospital three as result of using high exposure factors and short FFD. The third high average effective dose is found in Jerusalem CR-medical center in AP pediatric projection. The fourth high average effective dose found for AP adult projection in hospital one.

The highest total average patients' doses were recorded in hospital three for different projections, then in Jerusalem CR-medical center. While hospitals one and two have had very close patients doses except in lateral adult projections. Table 1. Summarizes all average doses for different projection and exposure factors at four hospitals. Fig. 1. Shows the Standard deviation (SD) ranges in the effective doses at four hospitals in all projections.

The highest SD found in hospital two of PA pediatric projections, which result from the small sample number. The second higher SD is found in hospital three of AP pediatric, which result of the high variation of exposure factors that were used. Hospital one where it has the high radiographers number gives a high SD in all projections, but it is still near of the total SD range. That means all radiographers use a closed exposure factors. The same quality factors in principles of exposure.

The European Guidelines regarding on the estimation of population doses from medical X-ray procedures reports have given the mean typical effective doses for the chest PA and Lateral view depending on exposure level group. Higher exposure group is given the typical effective dose which is

about 0.25 mSv, the average exposure group is given it about 0.10 mSv, and the lower exposure group is given it about 0.03mSv. All these quantities are different depending on exposure parameters in many countries of Europe [6] [7] [8]. The results shown in the paper are located in an average group which is registered in the European Guidelines.

TABLE 1. SUMMARIZES ALL AVERAGE DOSES FOR DIFFERENT PROJECTIONS AND EXPOUSRE FACTORES AT FOUR HOSPITALS

Chest X-ray projection and parameters for each projection	Average effectivedose (mSv) and meanexposure parameters in Hospital one	Average effective dose (mSv) and mean exposure parameters in Hospital Two	Average effective dose (mSv) and mean exposure parameters in Hospital Three	Average effective dose (mSv) and mean exposure parameters in CR-medical center	Total Average Effective (mSv) dose to each projection In four sites
AP adult	0.15	0.12	-	-	0.14
Mean kVp(KeV) Mean mAs	50-75 5-15	62-74 5-8			
PA Adult	0.04	0.04	0.11	0.1	0.07
Mean kVp(KeV) Mean mAs	100-120 1-4	75-95 5-6	70-95 10-25	109-133 3-9.5	
Lateral adult	0.12	0.39	-	0.14	0.33
Mean kVp(KeV) Mean mAs	105-125 4-12	88-105 16-25		120-133 4-14	
AP pediatric	0.03	0.02	0.16	0.15	0.09
Mean kVp(KeV) Mean mAs	40-55 3-8	55-60 2-5	50-70 4-14	60-70 3-7	
PA pediatric	0.04	0.08	0.08	0.06	0.06
Mean kVp(KeV) Mean mAs	100-115 1.3	70-85 5-6	66-75 10-20	100-125 2.8-4	
Total average effective dose for different chest X-ray projections in four hospitals is 0.11 mSv.					

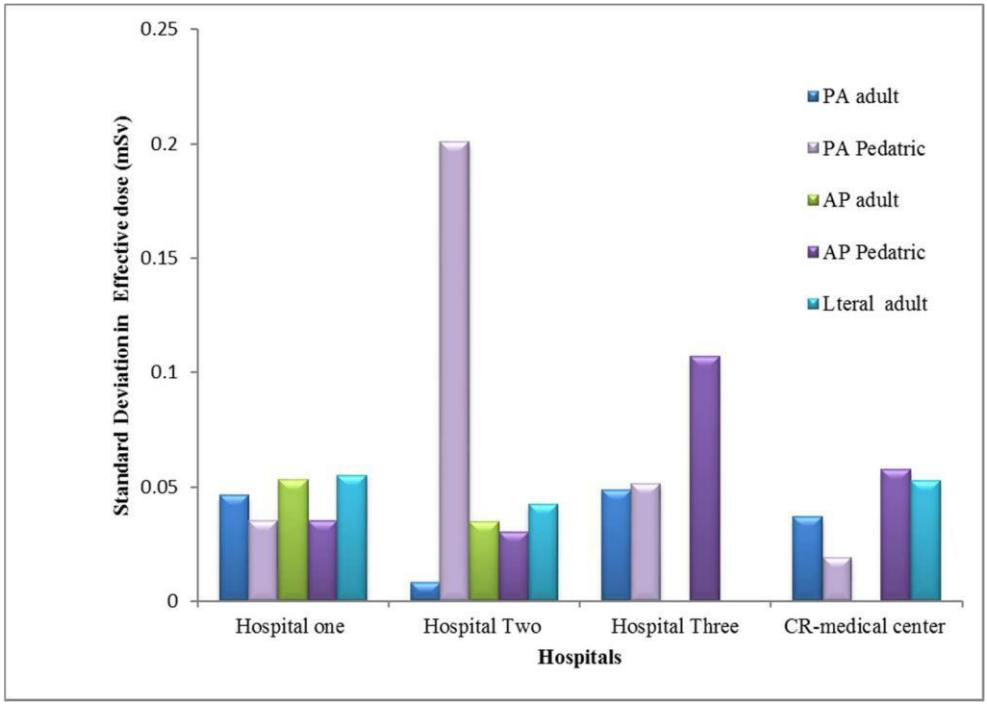

FIG. 1. Standard deviation in effective dose at four hospitals in all projections.

4- CONCLUSION

The results obtained in the study for average effective dose from the 668 patients are: ~0.11mSv in all chest X-ray examinations and projections for four hospitals. The average effective dose in AP adult, PA adult, lateral adult, AP pediatric and PA pediatric were 0.14, 0.07,0.33, 0.09 and 0.06 mSv respectively.

The geometric input data is different from one site to another in this study. A mistake in the procedure parameters directly influences the effective dose. The mAs value and the FSD are the strongest exposure factors to make a real change in effective dose. The SD has given a value of the radiographers' radiation protection quality depending on the exposure factors which they have been used. The place where the SD is too close means high quality radiographers work.

ACKNOWLEDGMENT

Authors would like to thank administrative and other personnel working at the investigated medical centers for facilitating our research and providing all means of help and support and for supplying all required data.

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DESIGN OF EXPOSURE FACTORS BY APPLYING OPTIMUM KV TECHNIQUES IN COMPUTER RADIOGRAPHY SYSTEMS AS EFFORTS TO MINIMIZE EXPOSURE DOSAGE

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Abstract

Background and Objective. In Indonesia, there is negative side in using advanced technology of CR. The ease with which technology grows a work culture that rests the yield on the machine, reduces its professional attention to the process. Material and Method. The effort to decrease the exposure value is done by changing the exposure factor by the method of "Ten kV Rule". The technique of "Ten kV Rule" is done by raising the value of 10 kV higher, by offsetting the decrease of mAs ½ from the original mAs value. Result and Discussion. Exposure dose is more decreasing for every single examination from factual exposure to designed exposure value and optimum kV value. Optimum kV set to the exposure more than 70 kV only. If 100% is the factual exposure dose, so designed dose exposure will be lower and optimum kV dose will be lower. Conclusion. The results showed the dose decrease as follows: a. By applying the design exposure factor, the decrease rate of exposure dose on average was 52.92 %. b. By applying ten kV rule, the rate of decrease in exposure dose averaged 61.67%.

Keyword: optimum kV technique, ten kV rule, Computerized Radiography.

1. BACKGROUND AND OBJECTIVE

Computer Radiography, or Computed Radiography, abbreviated CR, is a digital imaging technology that was introduced in response to the uncertainty of image quality generated on conventional radiographic technology [1][8]. CR replied with computer technology that can process images before printing, so that can be sure the results meet the expected imejing quality.

Besides the quality of radiograph, also in the image production process obtain ease that is very helpful for radiographers in carrying out their profession. Ease of process is obtained from the selection step and the application of exposure factors that are guaranteed not to experience errors, because CR machines facilitate the exposure limit value that must be used.

In Indonesia, towards the use of this advanced technology, there is a negative side that develops in line with the work culture and professionalism of the radiographer. The ease with which technology grows a work culture that rests the yield on the machine, reduces its professional attention to the process, so that the analytical and corrective attitude of the acquired technology does not develop.

The presence of CR as an advanced technology responded solely as a technological preparation that makes it easy, and accepted without effort to do a study on the profit and loss from various sides [2][9]. The growing knowledge in the field of CR technology, its source only from the product, through the technological information offered by the suppliers. In such cases, often the technology users (Radiographers) are treated with excellence alone, without the need to know other things that have a negative impact.

There is no study in depth about radiation safety of CR technology in Indonesia yet, which in turn provides greater radiation exposure than conventional radiography technology [3][4]. Above that, various information from the developed world, CR technology is not recommended. It is certainly the negative

side to be solved. Do not let technological advancements are not accompanied by an in-depth understanding of the modalities being counterproductive radiology services [5].

The objectives of this research is to produce an adequate exposure values for producing radiographic images with good image quality. And to generate exposure factor guidelines for a variety of radiographic examination [6][7].

2. MATERIAL AND METHOD

Factual exposure is an exposure factor that has been used in running computer radiography exposure techniques at the hospital. From the preliminary observations the value of exposure that has been given is still high, and can be attempted to reduce it.

The effort to decrease the exposure value is done by changing the exposure factor by the method of "Ten kV Rule". The technique of "Ten kV Rule" is done by raising the value of 10 kV higher, by offsetting the decrease of mAs ½ from the original mAs value. The optimum kV is the highest relevant value of kV used for the type of radiographic examination performed.

The purpose of applying "Ten kV Rule" is in order to make a good radiographic image, but the dose value exposed to the patient becomes smaller. The design exposure value derived from the factual exposure value, as well as the factual exposure value, can be calculated in the exposure dosage using the exposure formula as follows [10]:

$$E = P \frac{(KV)^2}{FSD^2} mAs$$

Note that; E = Exposure value / exposure received by body surface in milliroentgen; P = multiplier factor on utilization of diagnostic irradiation, magnitude = 15; KV = the value of the X-ray tube voltage used in irradiation; mAs = tube current (mA) x duration of irradiation done (second); FSD = the radiation distance from focus to the skin surface of the body.

The result of the acceptance of the exposure dose to the factual exposure as well as the exposure of the design changes will be used to explain the value of the dose reduction in the use of the optimum kV technique. The results are expected to show that the design exposure (exposure factor design) is more advantageous in terms of the magnitude of the exposure dose, so it is good to use.

3. RESULT

The survey was conducted by observing and recording radiological examination activities on various types of conventional radiographic examinations. Observations were made of radiological facilities and facilities, particularly those related to computer radiography systems, as well as techniques employed in the imaging, including exposure factors, radiation distance, irradiation fields and grid use. The survey results obtained the recording of 1644 examination from various computer radiography examinations [11].

The results include: A. Comparison of factual exposure, design exposure and optimum kV exposure on each type of examination, are listed in table 1; B. Comparison between factual exposure doses, design exposure doses and optimum kV exposure dose, are listed in table 2; C. The decrease rate of exposure doses from factual exposure doses and design exposure doses, is listed in table 3.

TABLE 1. COMPARISON OF FACTUAL EXPOSURE, DESIGN EXPOSURE AND OPTIMUM KV EXPOSURE ON EACH TYPE OF EXAMINATION

No	Type of examination	kV-mAs max factual	kV-mAs max design	kV –mAS max kV optimum
1	Thorax PA	81-10	75-5	80-2,5
2	Thorax supine	68-10	70-8	80-4
3	Manus	66-8	54-4	

4	Wrist	74-9	54-4	
5	Antebrachi	74-8	55-4	
6	Elbow	74-8	55-4	
7	Humeral	73-32	58-5	
8	Shoulder	80-28	72-8	
9	Pedis	70-10	58-4	
10	Ankle	70-10	60-4	
11	Cruris	70-20	58-5	
12	Genu	78-20	60-5	
13	Femur	90-40	76-10	
14	Abdomen / BNO	103-80	90-28	100-14
15	Pelvis	85-39	85-28	95-14
16	Head	85-36	74-26	84-13
17	Cervical	85-32	70-12	80-6
18	Thoracal	100-63	76-18	86-9
19	Lumbal	110-100	80-30	90-15

Note: factual exposure level is higher than designed exposure level. There is decreasing of factual exposure level to designed exposure level. Optimal kV exposure shows a higher kV value, while mAs value is lower.

TABLE 2. COMPARISON BETWEEN FACTUAL EXPOSURE DOSES, DESIGN EXPOSURE DOSES AND OPTIMUM KV EXPOSURE DOSE

No	Type of examination	Factual exposure doses (mR)	Design exposure doses (mR)	Exposure doses at kV optimum (mR)
1	Thorax PA	64,67	36,06	27,34
2	Thorax supine	84,02	55,03	48,98
3	Manus	34,53	18,22	-
4	Wrist	36,3	17,89	-
5	Antebrachi	26, 17	20,3	-
6	Elbow	47,61	20,32	-
7	Humerus	168,35	26,55	-
8	Shoulder	260,82	72,02	-
9	Pedis	45,1	27,52	-
10	Ankle	59,58	28,13	-
11	Cruris	54,41	32,09	-
12	Genu	88,25	28,4	-
13	Femur	199,51	90,49	-
14	Abdomen / BNO	1053,73	596,64	371,79
15	Pelvis	1088,89	529,2	334,04
16	Head	456,51	265,03	195,95
17	Cervical	485,98	149,31	-
18	Thoracal	2381,14	775,77	486,78
19	Lumbal	2432,57	890,62	611,35

Note: exposure dose is more decreasing for every single examination from factual exposure to designed exposure value and optimum kV value. Optimum kV set to the exposure more than 70 kV only.

TABLE 3. THE DECREASE RATE OF EXPOSURE DOSES FROM FACTUAL EXPOSURE DOSES AND DESIGN EXPOSURE DOSES

No	Type of examination	Factual doses rate (%)	Decrease rate of design exposure doses (%)	Decrease rate of kV optimum (%)
1	Thorax PA	100	44,24	57.72
2	Thorax supine	100	34,5	41,7
3	Manus	100	47,22	-
4	Wrist	100	50,5	-
5	Antebrachi	100	22,43	-

6	Elbow	100	57,32	-
7	Humerus	100	84,23	-
8	Shoulder	100	72,39	-
9	Pedis	100	38,98	-
10	Ankle	100	52,79	-
11	Cruris	100	41,02	-
12	Genu	100	67,92	-
13	Femur	100	54,64	-
14	Abdomen / BNO	100	43,38	64,72
15	Pelvis	100	51,4	69,32
16	Head	100	41,94	54,06
17	Cervical	100	69,28	-
18	Thoracal	100	67,42	69,28
19	Lumbal	100	63,39	74,87
average rate of doses decrease			52,92%	61,67%

Note: if 100% is the factual exposure dose, so designed dose exposure will be lower and optimum kV dose will be lower.

4. DISCUSSION

4.1. The relationship between exposure factor, radiographic image quality and exposure dose in computer radiography system.

The exposure factor is designed to produce images of desired quality. In the computer radiography system was not linear between the exposure factors with the image quality. As long as the given exposure is above the minimum required to format the image on the computer, the computer will be able to format the image properly. This situation tends to give more exposure, in order to obtain certainty of the image, which can be manipulated by the computer. In conjunction with exposure doses, greater exposure value will contribute to larger exposure doses. In the practice of radiographic services, such thinking is not well understood, so this study yields facts that show a tendency to make excessive exposure factors.

4.2. Relation between pre-edit exposure index, post-edit exposure index and exposure factor in computer radiography system

The pre-edit exposure index shows the amount of x-ray photon energy that can be captured by the imaging plate, while the post-edit exposure index is the amount of data used to format the image display on computer radiography. If the sent data is overloaded then more data will be deleted. In this case, the pre-edit exposure index value is greater than the post-editexposure index. But if the amount of data from the imaging plate is insufficient, then in the image view edit system, the computer can add shortness as long as not too big. If the deficiency is too large, the image display fails, or does not meet the expected quality. In this case, the pre-edit exposure index is less than the post-edit exposure index. Larger exposures, resulting in a larger index of pre-edit exposure index. Thus, indirectly, the index of pre-audit exposure indicates a relationship with the dose. In the practice of radiographic services, by giving factual exposures, the index of pre-edit exposures is in the range between 1500 and 2500. But after the exposure decrease inthis study, the index of pre-edit exposure can be below 2000.

4.3. Serious threat of radiation hazard in computer radiography system.

Given the fact that the exposure factor can be derived at least 50% (table 2), or in fact exposure can be done only with 50% of the exposure that has been given. It is very dangerous for the workers, because it means that every time exposure, already excess 50%. In fact, the dose of

exposure also contributes to the dose of radiation workers. If every 50% excess exposure then how cumulatively if the workers do exposure tens or even hundreds of times?

5. CONCLUSION

The assumption that the factual exposure factors have been undertaken so far can still be derived proven to be true.

In this study conducted efforts to decrease exposure factors, to try to give the dose of exposure to a minimum.

Efforts to lower the exposure factor, done with two methods, namely: *a*. Proportional to patient posture and image display needs. *b*. Ten kV rule, by raising 10 kV offset half-mAs preoccupation, applies to 70 kV and above exposure.

The results showed the dose decrease as follows: *a*. By applying the design exposure factor, the decrease rate of exposure dose on average was 52.92 %. *b*. By applying ten kV rule, the rate of decrease in exposure dose averaged 61.67%.

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PATIENT DOSE REDUCTION IN CHEST AND LUMBAR SPINE X-RAY PROJETIONS

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Abstract

The implementation in general radiology of a new software let us obtain the data of all the examinated patients. These include the technical parameters and also the dosimetric indicators. The analysis has been made with the two most frequent examinations in the four rooms available in our hospital: PA Chest and LAT Chest and also with the two highest dose examinations: AP Lumbar Spine and LAT Lumbar Spine. The election of new parameters combined with the evaluation of the quality image supervised by the radiologist has been able to reduce the doses until more than 20% in PA Chest examinations and until more than 15% in LAT Chest examinations. In Lumbar Spine, the reduction of the entrance surface doses averaged has been decreased in all the rooms achieving until more than 20% in one room. Also, it has been made an analysis using excel pivot tables to detect exposures above the nominal conditions of the X-ray tube assembly considering the maximum rating charts provided by the manufacturer.

1. INTRODUCTION

The Spanish legislation establishes that there must be procedures for evaluation of the dose indicators to patients in the most frequent examinations [2]. In our hospital these include the Thorax PA and Thorax LAT. Our general radiology equipment has a dose area meter product at the exit of the X-ray tube. The implementation of new software has also allowed a management of the technical parameters of patients, including the capture of dosimetric indicators. This has made possible a very realistic determination of diagnostic reference levels (DRL) allowing the optimization of technical parameters for dose reduction.

In addition to the most frequent projections referred, this reduction has been made too in the projections which the highest doses to the patient in general radiology: AP Lumbar Spine and LAT Lumbar Spine.

2. MATHERIALS AND METHODS

The Rey Juan Carlos University Hospital is a leading hospital located in Madrid. It's provided with the highest technology including digital radiology. In general radiology there are four X-ray machines of the Spanish firm Radiologia. The X-ray tubes are manufactured by Toshiba.

In the output of the X-ray tube there is a dose area product meter of the firm IBA KERMA X-plus, model 120-131 CAN TinO. With every meter a calibration certificate signed by Iba Dosimetry GmbH is provided with the correction factors in different kVp all of them normalized al 100 kVp.

In January of 2016 a new software tool is installed by Radiologia. Until that date all the DRL were obtained manually obtaining the technical parameters and the dose indicators directly for every exposure. Length and width of every field were measured manually too. With all these information the entrance surface doses (ESD) were obtained for all the patient exposures in some kind of projections. Unfortunately the DRL obtained were the average of a short sample (between 10 and 20 exposures in every evaluation).

From January of 2016 the new tool let us export all the data including dosimetric indicators to an excel file. Doing this, it is possible to manage a large amount of patients obtaining more realistic DRL and being able to optimize the patient dose modifying the X-ray operationtechnics.

All the data of PA Chest, LAT Chest, AP Lumbar Spine and LAT Lumbar Spine were collected and evaluated from one period of four months. Once the DRLs were obtained it has been decided to review the operation techniques to try to reduce the patient doses in these four projections. These modifications were made the 31/10/16. From the 01/11/16 and for three months a new data export with the new DRLs were obtained.

These modifications were based in an increase of the kVp, new selection of the focal size and decreasing the signal step selector (SNR selector).

3. RESULTS

The starting DRLs in Chest examinations (Table 1) are obtained averaging the DAPs (Dose Area Product) of the exposures for the four months previous to the modification of the operation techniques. In the sample all the exposures lower or higher that the average of the whole sample minus or plus one standard deviation respectively have been rejected.

TABLE 1. DAP IN CHEST BEFORE THE MODIFICATION OF OPERATION TECHNIQUE

CHEST PA	ROOM 1	ROOM 2	ROOM 3	ROOM 4	ROOM 1	ROOM 2	ROOM 3	ROOM 4	CHEST LAT
kVp	120	120	120	120	125	125	125	125	**kVp**
mA	160	160	160	160	160	160	160	160	**mA**
mAs	3,22	3,61	3,67	2,35	12,51	11,32	12,77	11,77	**mAs**
DAP ($mGyxcm^2$)	228	221	---	160	801	737	---	712	**DAP ($mGyxcm^2$)**

The DRL chosen has been the Dose Area Product (DAP) and the values obtained before the modification of the operation techniques in Lumbar Spine examinations are represented in Table 2.

TABLE 2. DAP IN LUMBAR SPINE BEFORE THE MODIFICATION OF OPERATION TECHNIQUE

LUMBAR SPINE AP	ROOM 1	ROOM 2	ROOM 3	ROOM 4	ROOM 1	ROOM 2	ROOM 3	ROOM 4	LUMBAR SPINE LAT
kVp	80	80	80	80	90	90	90	90	**kVp**
mA	500	500	500	500	500	500	500	500	**mA**
mAs	84	109	102	75	69	87	76	97	**mAs**
DAP ($mGyxcm^2$)	2834	3958	3312	2652	3991	4594	4342	5151	**DAP ($mGyxcm^2$)**

The use of pivot excel tables has given us useful information and has been able to detect some failures during the exposure. In Fig. 1 it is represented the histogram with the mAs in the projection of Lateral Chest in room 1. It can be seen that unexpectedly there are a large number of exposures between 32 and 33 mAs. Reviewing the maximum rating charts of the X-ray assembly provided by the manufacturer [4] it is possible to detect that the use of small focus can make the conditions are usually in the limit of the chart using 125 kVp .

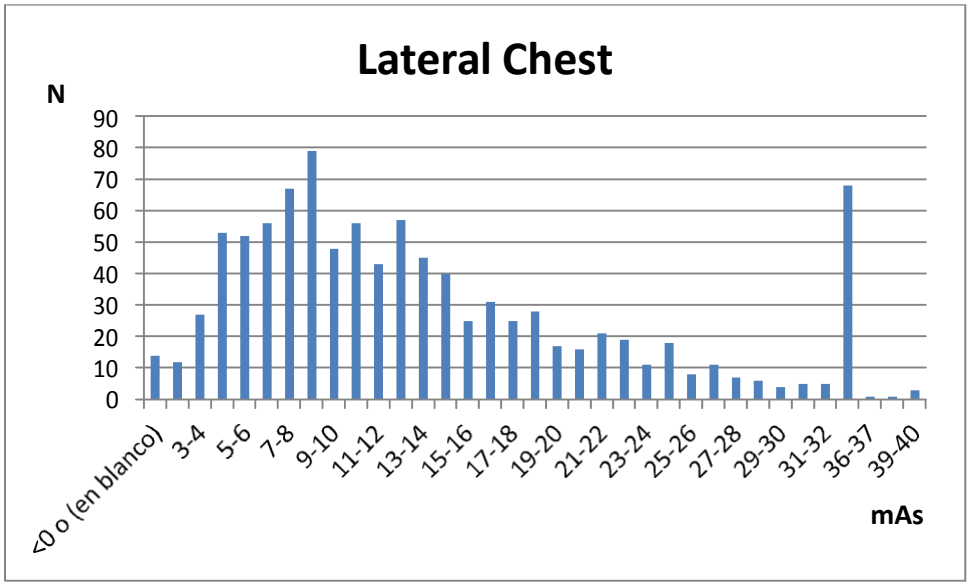

FIG.1. Histogram in Lateral Chest (number of exposures / mAs)

Some modifications in operation technics are introduced in the four evaluated projections:

- PA Chest: to increase the radiographic voltage from 120 kVp to 125 kVp and the use of large focus.
- LAT Chest: to decrease the SNR selector from 1 to 0, to increase the mA from 160 to 250 and the use of large focus.
- AP Lumbar Spine: to decrease the SNR selector from 1 to 0.

- LAT Lumbar Spine: to decrease the SNR selector from 1 to 0.

It has been necessary the evaluation of the image quality by the leading field radiologist of the Dose Committee of our hospital once the modifications have been implemented because the signal noise reduction has been changed and also it's necessary to test in PA Chest if the use of a nominal focal spot of 1,2 instead of 0,6 can influence the image.

In European Guidelines on Quality Criteria for Diagnostic Radiographic Images [1], as example of good radiographic technique it is established a nominal focal spot value ≤1,3 and a radiographic voltage of 125 kVp.

In all cases the evaluation of the images by the radiologist after adjustments has been favorable.

Analyzing the exposures from the day after the adjustments for a period of four months it can be shown in Tables 3 and 4 that in general the patient doses have been reduced in the four projections evaluated as it can be seen in the row Difference of every table. The only exception of no reduction is obtained in room 4 that is dedicated to emergencies and in these cases there is a high variability in the techniques selected.

TABLE 3. DAP IN CHEST AFTER THE MODIFICATION OF OPERATION TECHNIQUE

CHEST AP	ROOM 1	ROOM 2	ROOM 3	ROOM 4	ROOM 1	ROOM 2	ROOM 3	ROOM 4	CHEST LAT
kVp	125	125	125	125	125	125	125	125	**kVp**
mA	250	250	250	250	250	250	250	160	**mA**
mAs	2,79	2,17	2,10	2,33	11,67	7,79	10,03	10,99	**mAs**
DAP ($mGyxcm^2$)	179	180	216	195	654	579	713	709	**DAP ($mGyxcm^2$)**
Difference	**-21,5%**	**-18,6%**	**---**	**21,9%**	**-18,4%**	**-21,4%**	**---**	**-0,4%**	**Difference**

TABLE 4. DAP IN LUMBAR SPINE AFTER THE MODIFICATION OF OPERATION TECHNIQUE

LUMBAR SPINE AP	ROOM 1	ROOM 2	ROOM 3	ROOM 4	ROOM 1	ROOM 2	ROOM 3	ROOM 4	LUMBAR SPINE LAT
kVp	80	80	80	80	90	90	90	90	**kVp**
mA	500	500	500	500	500	500	500	500	**mA**
mAs	82	73	66	70	63	59	68	82	**mAs**
DAP ($mGyxcm^2$)	2470	3145	2885	2771	3342	3473	4297	4946	**DAP ($mGyxcm^2$)**
Difference	**-12,8%**	**-20,5%**	**-12,9%**	**4,5%**	**-16,3%**	**-24,4%**	**-1,0%**	**-4,0%**	**Difference**

4. CONCLUSIONS

The implementation of software to analyze the data of a large sample of patient allows a realistic determination of dose reference levels. Only in this way it is reasonable to introduce changes in the operation technical parameters to reduce the patient doses always considering the evaluation of the image quality performed by a radiologist.

One first projection election to start the evaluation has been to take account the most frequent projections and the highest dose projections. In our hospital these have been, PA Chest, LAT Chest, AP Lumbar Spine and LAT Lumbar Spine.

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CANADA SAFE IMAGING:
IMPLEMENTING A RADIATION SAFETY CAMPAIGN IN CANADA

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Abstract:

Canada Safe Imaging (CSI) has been formed to address the need for a national strategy and action plan as it relates to radiation safety for medical imaging in Canada. Its mission is to provide Canadian contextualized tools for patient radiation safety and to align Canada with the Bonn Call-for-Action recommendations.
CSI represents a collaborative undertaking between government agencies, professional associations, universities, colleges, industry, national research institutions and hospitals. Founding members are the Canadian Association of Radiologists, Canadi an Association of Medical Radiation Technologists and Canadian Organization of Medical Physicists.
CSI belongs to an international network of similar initiatives such as Image Wisely, Image Gently, EuroSafe Imaging, AfroSafe, and LatinSafe, under the auspices of the International Society of Radiology Quality and Safety Alliance (ISRQSA).
We will review in this article the rationale for a Canadian radiation safety strategy, the steps which led to the creation of Canada Safe Imaging, the achievements over the past year, and the challenges moving forward.

1. INTRODUCTION:

With the exponential increase in medical imaging, and commensurate patient radiation exposures, understanding and harmonizing patient radiation safety practices across Canadian healthcare jurisdictions should be a priority. In Canada, the delivery of health care is a provincial responsibility but a focused national strategy and a unified effort is needed to ensure radiation safety in medical imaging for all Canadians.
Canada Safe Imaging (CSI) has been formed to address the need for a national strategy and action plan as it relates to radiation safety for medical imaging in Canada. Its mission is to provide Canadian contextualized guidelines and tools for patient radiation safety. One impetus for this new Canadian initiative was to align with the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO) initiative, the "Bonn Call-for-Action", drafted after the 2012 meeting to which Canada did not participate.

2. METHODS:

2.1 History:

Launched in December 2015, CSI represents a collaborative undertaking between government agencies, professional associations, universities, colleges, industry, national research institutions and hospitals. Members include, but are not limited to: the Canadian Association of Radiologists (CAR), Canadian Association of Medica l Radiation Technologists (CAMRT), Canadian Organization of Medical Physicists (COMP), Canada Health Infoway (CHI), Canadian Association of Nuclear Medicine (CANM), Ontario Association of Medical Radiation Sciences (OAMRS) and MEDEC, a national organization representing Canada's innovative medical technology industry.
CSI's vision is to focus on strengthening medical radiation protection in patients and fostering a culture of ra diation safety in healthcare in Canada.
CSI's mission is to develop awareness and adoption of current and emerging radiation patient protection strategies for Canadians, promote procedural appropriateness that attains greatest medical benefit, support evid ence-based best

practice guidelines and facilitate a strategic approach to conduct scientific inquiry on the effects of radiation on human health.

CSI belongs to an international network of similar initiatives such as Image Wisely, Image Gently, EuroSafe Imaging, AfroSafe, and LatinSafe under the auspices of the International Society of Radiology Quality and Safety Alliance, in an effort to make patient radiation safety a global cause.

2.2 Milestones

- Canada Safe Imaging officially announced December 2015
- Terms of Reference finalized
- Governance structure in place
- Oversight Organization confirmed
- Website launched
- Membership and fee structure defined

2.3 Governance:

Membership is open to relevant stakeholders who are engaged in the provision, professional oversight, monitoring, research and regulation of medical imaging in Canada. The members ensure a multidisciplinary and all-inclusive approach to radiation safety and protection.
CSI's Executive Committee provides executive oversight for the day-to-day operational aspects of the Coalition. It is composed as follows:

- Three representatives of national radiology organizations;
- Three representatives from academic or non-academic health sciences centres, research organization or university representative;
- One representative of industry.

The Executive Committee Members serve a two-year term, renewable for another term.

3. RESULTS:

In the past year, CSI has had a number of accomplishments raising awareness in Canada and internationally. CSI has launched a website in English and French where it relays relevant information and links to pertinent medical radiation safety websites, including the recommendations of the Bonn Call-for-Action. The website is available at http://canadasafeimaging.ca

CSI has completed two environmental scan, surveying all the organizations involved with medical imaging and hospitals in Canada. The goal of this environmental scan is to understand the role of the different organizations involved in medical radiation safety at the national, provincial and regional levels.

CSI has presented updates at a number of conferences including International Congress of Radiology 2016, Radiology Society of North America 2016, and European Congress of Radiology 2017. CSI had an education session at the Canadian Organization of Medical Physicists (COMP) Winter School in February 2017 and will run a session at the Canadian Association of Radiologists (CAR) Annual Meeting in 2018.

Recently, CSI has joined forces with two respected organizations with extensive expertise in radiation safety, the Radiation Safety Institute of Canada (RSIC) and the Centre d'Expertise Clinique en Radioprotection (CECR) to offer a new and free service, respectively in English and French, to answer concerns from the general public and health professionals related to radiation safety. Answers are given by trained medical physicists, and questions can range from simple risk assessment, such as an expectant mother who had an X-ray of the ankle at 6 weeks pregnancy and wants to know what is the risk for the fetus, to much more complex questions around X-ray tubes performances or safety. Based on the questions received, a Frequently Asked Questions (FAQ) will be developed and shared with the international community, as problems are similar worldwide.

In 2017, in partnership with the Canadian Agency for Drugs and Technologies in Health (CADTH), CSI is conducting a survey of all hospitals in Canada to determine how they align their practices and goals with the Bonn - Call-for-Action. The results of this study will provide CSI with a better understanding of how well Canadian hospitals are following the Bonn-Call-for-Action and where CSI should focus its efforts in the coming years. In addition, the results will provide insight as to if certain provinces or territories are more aligned than others.

The results of the CADTH survey, in conjunction with the results from the environmental scans already performed, will be used to determine how well Canada as a whole has done in addressing the Bonn-Call-for-Action, and will be published.

In addition, pilot projects within individual provinces will continue to be formed to develop collaborations with the regulators so that CSI becomes a key advisor to provincial concerns and guidelines regarding patient radiation protection.

4. DISCUSSION:

A challenge for CSI has been to secure the financial support required to sustain and expand its operations. CSI is working on a new strategic plan taking into consideration the inter-professional approach that CSI has adopted, a close collaboration with radiation technologists and medical physicists. To extend its reach and raise more awareness from government and funding agencies, CSI has to promote its vision to a large audience, including new partners such as Choosing Wisely Canada, a campaign to help clinicians and patients engage in conversation about unnecessary tests and treatments.

For 2018, CSI is planning to accomplish the following:

- Expand membership and support base;
- Promote and develop awareness about Canada Safe Imaging both nationally and internationally;
- Provide training tools and resources (*Action 4 & Action 9 Bonn Call-for-Action*).
- Work with regulators and accreditors to create a framework for medical radiation safety, to start with a pilot project in Manitoba.

5. CONCLUSION:

There was a need in Canada to organize a medical radiation safety campaign to coordinate the multiple disparate initiatives in the country, identify the gaps with the international recommendations of the Bonn Call-for-Action, and propose a national strategy to provide Canadian contextualized guidelines and tools. As a result, CSI was formed and includes members from the majority of the national professional organizations that are involved with medical radiation.

RADIATION PROTECTION: AN INITIAL ASSESSMENT OF LEVEL OF COMPLIANCE AMONGST RADIATION WORKERS IN AHMADU BELLO UNIVERSITY TEACHING HOSPITAL ZARIA, NIGERIA.

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Abstract

Medical use of ionizing radiation can result to deleterious effects such as undesirable somatic and genetic modifications, although less radiation dose is involved in diagnostic radiology. This necessitates the need for radiation safety practices, to bring to the barest minimum possibility of these risks. This study was aimed at assessing the knowledge and radiation safety practices amongst radiation workers in ABUTH Zaria, Nigeria.The study was conducted amongst the radiologist/radiology resident doctors, radiographers nurses and technicians, with the use of questionnaire for assessment of knowledge, attitude and covert monitoring of personnel's for assessment of implementation. Data was analyzed with SPSS. Assessment of knowledge was quite impressive with average score 91% and 78% for the radiologists/ residents and the radiographers respectively, while the group of "Others" (i.e. nurses and technician) was abysmal with a score 42\%. Radiation protection gadgets were either lacking, old or obsolete. Application of shielding devices such as gonad shield for protection and TLDs were neglected by about 56% of the personnel's. The x-ray imaging machines were quite old with no quality assurance tests performed for quite some time.Excellent knowledge of radiation protection was exhibited by the majority of radiation workers in ABUTH, though from self efforts, however compliance with the standard radiation protection guidelines is appalling. The need for improved and sustained efforts by both the management and the personnel in radiation protection can never be over emphasized in other to avoid deleterious effects of X-radiation on both the personnel's and patients.**Keywords:** Radiation protection, X-ray, Radiologists, Radiographers

1. INTRODUCTION

Radiation protection involves all those activities aimed at protecting man and his environment from the deleterious effects of ionizing radiation. In medical practice, it is all those processes followed to ensure minimal but optimal radiation exposure to both the patient and the radiation worker during a radiological procedure [1].The ultimate aim of radiation protection is to protect the human race against the potential risks of ionizing radiation[2]. . Despite the fact that less radiation dose is involved in diagnostic radiology, medical diagnostic use of ionizing radiation can result to deleterious effects such as undesirable somatic and genetic modifications. This necessitates

the need for radiation safety practices, to bring to the barest minimum possible; these risks. [3].
Diagnostic imaging encompasses conventional x-ray imaging, fluoroscopy, mammography, ultrasound (US), computed tomography (CT), magnetic resonance imaging (MRI), nuclear medicines (NM) and computed tomography; these are an essential diagnostic tool of contemporary medicine. Regarding radiation protection we are concerned with all the above modalities except MRI and ultrasound which do not use ionizing radiation. In the hospital settings the radiation workers have an increased risk for radiation exposure than the general hospital population[4]. Precision in the diagnosis and management of patients' health condition depends on the production of good quality radiographic images and expert interpretation of these images.
Radiation protection is based upon the basic principles of justification, optimization and limitation. These principles are such that; 1; On no occasion should an individual be exposures to ionizing radiation except where a maximum benefit is assured and the possible risk is outweighed (justification). 2; Radiation doses from diagnostic exposures should be kept as low as reasonably achievable just sufficient to achieve the needed diagnoses (optimization), and 3; reducing the patients' exposure time to ionizing radiation (limitation). These are means of achieving radiation protection, and hence inculcate the use of tissue compressors, immobilizers, positioning aids, collimators, so also are the make and state of the machines of utmost importance in radiation protection. [5]. Availability of installed radiation protection instruments, namely area survey meters and personnel dosimeters for staffs and periodic quality assurance checks on the x-ray machine are also essential part of radiation protection measures.
There are few available hospital based studies on the level of radiation safety awareness and compliance amongst radiation workers in the country all in southern region.[3,6] However no study of such is available to me from northern Nigeria. The study was carried out to determine radiation workers awareness and performance about radiation safety in Ahmadu Bello University Teaching Hospital Zaria Nigeria and also to assess the work place safety gadgets.

2. METHODS

This descriptive, cross-sectional study was conducted in Ahmadu Bello University Teaching Hospital Zaria in North-western Nigeria, it is the largest tertiary hospital in region and second largest in the country. A total of 41 respondents which comprises of 19 Doctors (mainly resident doctors),16 Radiographers (including interns) and others (namely technicians (4) and nurses (2)) were involved in the study.
The questionnaire focused on six major research questions. focused on the following issues: 1) Radiobiology; 2) Relative radiation dose of various imaging modalities; 3) Use of individual TLD badges by workers; 4) participation in annual training courses; 5) utilization of lead shields for patients and use of mechanical support for immobilizing patients during radiographic procedures, if necessary; and 6) adherence to the ten-day rule in radiobiology.
A covert monitoring of personnel's for assessment of implementation.
Three radiography rooms were involved in the study
A checklist was completed with respect to the availability of the following devices in each radiography room: 1) lead glass windows, 2) lead aprons, 3) lead goggles, 4) lead gloves, 5) gonad shields, 6) thyroid shields, 7) patient immobilization devices, 8) radiation area signs, 9) illuminated signs indicating "no entry", 10) Safety written policy, 11) safe lead doors/ walls, 12)Personnel monitoring records,13) Environmental monitoring records. Data analysis was done by SPSS20

3. RESULTS

A total of 41 respondents aged between 22 – 57years partook in the study. The respondents were 19 Doctors, 16 Radiographers, 2 Nurses and 4Technicians; only seven females were involved in all, as shown on table1. The youngest professional group was the radiographers with a mean age of 32.4 years; the oldest group was the "Others" 54.3years while the doctors group has a mean age of 38.8years. Sixty-one percent (61%) of the respondents are aged between 30-40 years while 85% were aged less than 40years .About 75% of the respondents were 10years or less in service as a radiation worker.
The result for knowledge of radiation safety see the doctors scoring 91% , the radiographers 78% and Other scoring 42%, while on attitude the doctors score 95%, radiographers 83% and Other 76%, however the recorded scores on practice were 16%, 62% and 83% for the doctors, radiographers and Others respectively, as depicted in figure1. However the scores for practice were based on covert monitoring of wearing of TLDs in the department. In the appropriate section for radiation safety practice in the questionnaire only three respondents (about 7.3%) responded negatively to appropriate and regular use of TLDs.
Assessment checklist of the radiation protection devices and gadgets within The three radiography rooms in the

department were subjected to a checklist of radiation protection devices and gadgets; the results are depicted in table 2.

4. DISCUSSION

The increasing use of ionizing radiation technologies in medical practice exposes radiation workers to increased radiation related hazards; hence knowledge of radiation safety can never be over emphasized. [7] Radiation protection is based upon the basic principles of justification, optimization and limitation. Such that; On no occasion should an individual be exposures to ionizing radiation except where the maximum benefit is assured and the possible risk is outweighed. Radiation doses from diagnostic exposures should be kept as low as reasonably achievable, just sufficient to achieve the needed diagnosis and reducing the patients' exposure time to ionizing radiation. [8,9]

This study is aimed at assessing the radiation workers in knowledge, attitude and practice of radiation safety in ABUTH Zaria. The results shows an impressive performance with regards to knowledge especially amongst the doctors then the radiographers, the least impressive performance was observed in the 'Others' group which comprises of mainly technicians and nurses, this observation will not be unconnected with the facts that the earlier two groups are populated with resident doctors who are in a rigorous training to become specialists and are actively in search of knowledge, and the intern radiographer who just graduated and the knowledge is still unsullied, however on the other hand the technicians and nurses are amongst the oldest staffs in the department, who after their qualifying certificate course several years ago, have not had any formal training on radiation safety hence rusty of knowledge. Evaluation of attitude also follow a similar trend as the knowledge, however there is improvement to a satisfactory level on the attitude of radiation safety amongst the 'Others' when compared to the knowledge of the same group. This indicates an impressive attitude to work in radiation environment, and its similar to the findings of Adejumo *et al* in their study amongst radiographers in Southwestern Nigeria,[3] although the group in which belong the nurses shows a satisfactory result in its attitude to radiation protection, it is the least of the three groups, similar studies on nurses working in cardiac catheterization laboratories[10] and mobile diagnostic radiology[11] shows an abysmal result as they down play the potential health hazards of radiation exposure and hence careless about safety measures. Failure of the human senses to perceive radiation energy in the diagnostic range and the fact that majority of the deleterious effects of radiation more often than not, arise after protracted exposure, some workers indeed finds it difficult to relate them to the exposure.[7] These are the major source of the false impression about radiation[7,12]. All these culminate into undue ignorance, failure to adhere to radiation protection principles and concerns or fear of radiation, with a consequent negative influences on the quality of health of both the radiation workers' and their patients. [7]

Although in- service training is almost non-existent amongst the respondent which is responsible for the low level of knowledge and attitude amongst the group of "others" in this study, but on contrary the group of doctors which comprises of mainly resident doctors are actively acquiring knowledge for the purpose of their specialty training and the young graduate interns who are still basking from their unsullied knowledge were more than satisfactory, this depicts the essence of constant reminder and updates on radiation protection for the staffs. This assertion is also collaborated by Alavi *et al* in their study on medical radiation workers, [7] The most important aspect in medical radiation is the adherence to radiation protection principles and this cannot be achieved except after acquiring adequate knowledge of the mechanisms and provisions of radiation safety. Therefore constant tutoring for medical radiation workers to improve their knowledge and capacities of radiation safety issues, and also aptly manage radiation exposure can never be over emphasized.'[7,13]

We also observed that the number of years of practice did not show any significant influence on the level of knowledge and attitude of safety standard, but in fact a negative correlation was established in the group of "Others" who incidentally form the oldest group both in age and practice. This result is possible, as the last entrant amongst the doctors are over two years in training, so that they have acquired lots of knowledge and a positive perception, while the fresh graduate intern radiographers who are just about one year in the department have had this training in their undergraduate years. This finding was inconsistent with those of previous studies by Alavi *et al* and Ayoob *et al* which shows a positive correlation, [7,14] however the findings of Adejumo *et al*. [3] in their assessment of radiographers is a similitude.

The radiographers and the radiation doctors who are graduates and postgraduates respectively in the radiology field had better knowledge than other radiation workers who were co-opted from other fields of medicine i.e. nurses and those with a sub degree qualification i.e. the technicians. The study conducted by Alavi *et al*. showed that other

medical professionals who are in contact with radiation in the course of their work performed poorly to their counterparts who are primarily radiology workers in terms of radiation protection knowledge. We also noted that the more the educational status of the respondents, the better their score in knowledge and attitude. Conversely a negative relationship was however noted between practice (wearing of TLD) and levels of education in this study, some other studies also observe a similar trend[7]. Although all the respondents believe in the use of personnel radiation monitors in this case the TLD (thermo luminescence device) and its importance, however on verification only 44% had their TLDs on and were mainly the radiographers and the technicians, the doctors were the worse culprit as only three had their TLD's on as at the time of inspection. Though six of the resident doctors complained that their TLDs have not been return after the last collection for reading about a year now, another set of five revealed that the results of the irregular periodic readings has never been made known to them hence their loss of interest, while a third group of 3, were of the opinion that since the break down of the fluoroscopy machine they have no direct contact with x-rays hence no need to always wear the TLD and the last group has no specific reason. Both Nigerian Nuclear Regulatory Authority (NNRA) and The International Commission on Radiological Protection (ICRP), requires, all radiation workers to use personnel dosimeter, [8,9] therefore their various reasons are untenable.

The department have no active or functional radiation safety officer available; as such no active radiation safety program is in place. The assessment of the three radiography rooms revealed they all have radiation protective devices such as lead lined walls and doors, lead windows, lead aprons and some mainly improvised immobilizers, however only one (the main unit) had an inbuilt but nonfunctioning caution light, a stiff non flexible lead glove, a clouded lead goggle, a digitizer, thyroid and gonadal shields, while none has environmental radiation monitor, radiation warning in local language, routine quality assurance checks. A similar situation was also observed by Ayoob *et al* in their assessments of level of protection in some radiology departments, which is quite inimical to the radiation worker in his line of duty especially during fluoroscopic examinations. [15] In a study by Adejumo *et al*[3] in Southwestern Nigeria they reported an impressive institutional provision of radiation protection gadget in the private centre's while its abysmal in the government establishments like our index institution. Several other studies have also reported deficiencies in radiation protection gadgets in radiology departments. [15,16] In which they consider this unthoughtfullness could be secondary to the carelessness and inattention of departmental powers that

be, radiographers' failure to heed to radiation protection principles, and hospital managers' deficient knowledge. [15,16]

5. CONCLUSION

The authorities and to some extent the workers are not showing the deserved interest on the principles of radiation safety. Although the majority of the respondents (doctors) had self training, the inapt in-service training is a probable reason for the pretty pitiable knowledge and attitude amongst the other participants. This is furthermore aggravated by poor supervision of radiation safety activities by the appropriate local agency responsible for regulation of radiation use (NNRA).

Profession		Doctors		Radiographers		Others	
		Radiologist	**Residents**	**Radiographers**	**Interns**	**Nurses**	**Technicians**
Sex	**M**	**4**	**12**	**4**	**9**	**1**	**4**
	F	**0**	**3**	**0**	**3**	**1**	**0**
Total		**19**		**16**		**6**	

Table 1: Distribution of respondents by profession and sex

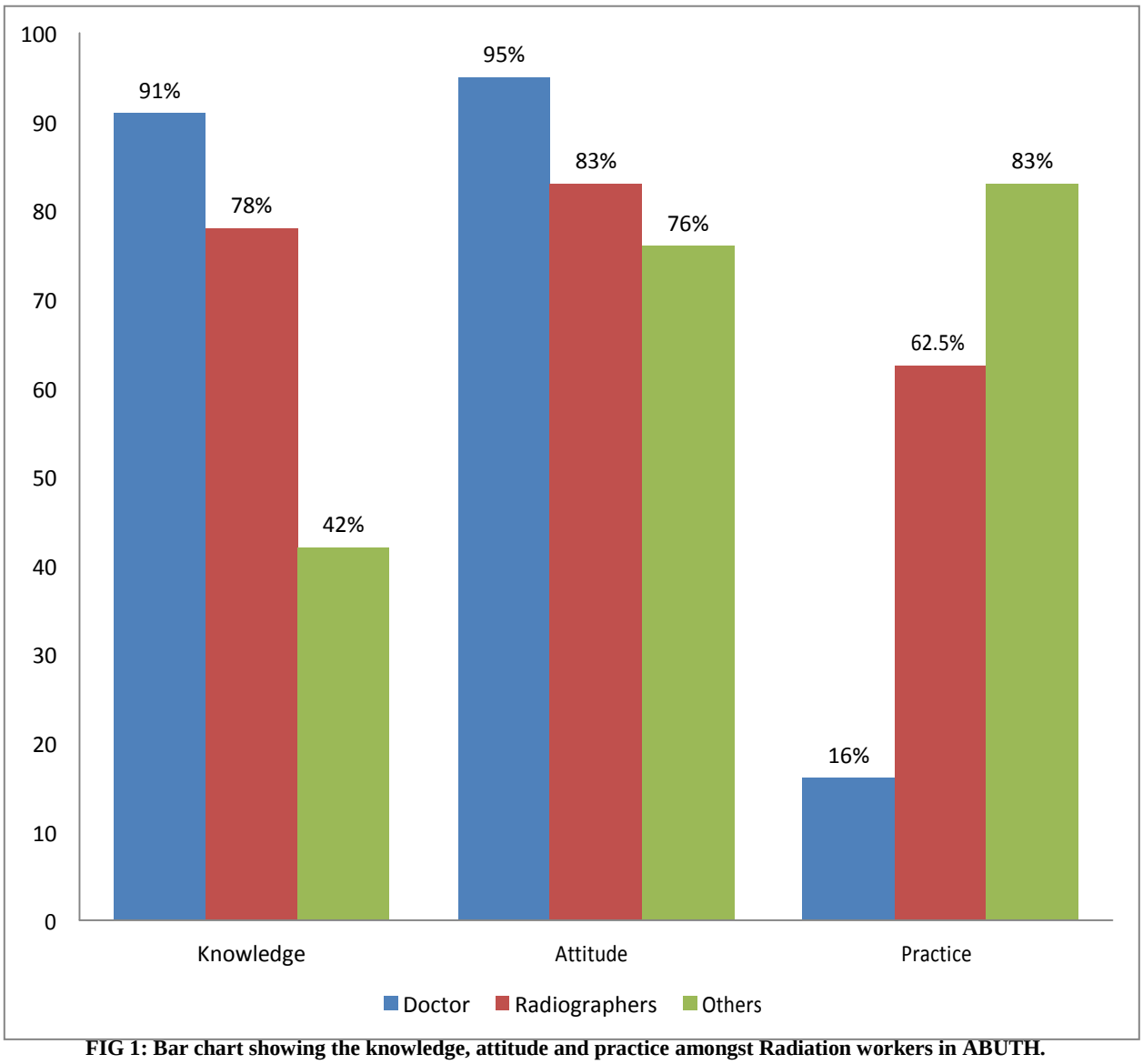

FIG 1: Bar chart showing the knowledge, attitude and practice amongst Radiation workers in ABUTH.

Parameters	Room 1	Room 2	Room 3
Personal monitoring records	No	No	No
Environmental monitoring records	No	No	No
Lead lined walls & doors	Yes	Yes	Yes
Lead glass windows	Yes	No	No
Lead aprons	Yes	Yes	Yes
Gonadal shields	Yes	No	No
Written safety policy	No	No	No
Radiation warning signs	Yes	Yes	Yes
Caution lights	Yes	No	No
Thyroid shields	Yes	No	No
Lead gloves	Yes	No	No
Lead goggles	Yes	No	No
Patient immobilization devices	Yes	Yes	Yes

Table 2: Assessment of work place safety requirement in Radiology Department ABUTH

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EVALUATION OF CONVERSION COEFFICIENTS RELATING AIR-KERMA TO *H**(10) USING PRIMARY, SECONDARY AND TRANSMITTED X-RAY SPECTRA IN THE DIAGNOSTIC RADIOLOGY ENERGY RANGE.

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Abstract

Brazilian regulation establishes the value 1.14 Sv/Gy as the conversion coefficient to convert air-kerma into the operational quantity ambient dose equivalent H*(10) disregarding its beam quality dependence. The present study computed mean conversion coefficients from primary, secondary and transmitted x-ray beams through barite mortar plates used in shielding of dedicated chest radiographic facilities in order to improve the current assessment of H*(10). To compute the mean conversion coefficients, the weighting of conversion coefficients corresponding to monoenergetic beams with the spectrum energy distribution in terms of air-kerma was considered. The maximum difference between the obtained conversion coefficients and the constant value recommended in national regulation is 53.4%. The conclusion based on these results is that a constant coefficient is not adequate for deriving the H*(10) from air-kerma measurements.

1. INTRODUCTION

Ambient dose equivalent, *H**(10), is adopted in Brazil as a reference quantity to establish dose restriction limits and to calculate the shielding in rooms that use X-ray imaging equipment [1]. The calibration of radiation monitors to represent their readings in the magnitude *H**(10), by its formal definition, should make use of aligned and expanded radiation fields [2], which produces a complexity in the calibration process. To facilitate the determination of *H**(10), the dosimetric quantity air kerma is used and it can be correlated with *H**(10) by mean of a conversion coefficient. Conversion coefficients for mono-energetic beams were published in the ICRU report 57 [3], which present a dependence with the beam energy. However, Brazilian regulation [1] establishes 1.14 Sv/Gy as a unique conversion coefficient between air kerma and *H**(10) disregarding the coefficient dependence with the beam energy. ICRU report 57 recommends that, for poli-energetic beams, the correct assessment of *H**(10) from air kerma should performs using mean conversion coefficients obtained from weighting the coefficients related to mono-energetic beams with the energy distribution of the corresponding poli-energetic beam. Kharrati and Zarrad [4] determined mean conversion coefficients for primary X-ray beams obtained from polynomial mathematical models. In the present work, the methodology used by Kharrati and Zarrad was extended to primary, secondary and transmitted (through barite mortar plates) experimental x-ray spectra. Experimental methodologies for measurements of primary [5], secondary and transmitted spectra [6] to determine the respective mean conversion coefficients were developed. The experimental set-up attempted to reproduce conventional radiology rooms dedicated to chest examinations. Barite mortar was chosen because it is a material commonly used in Brazil to shield conventional radiology rooms [7]. The thoracic region was chosen because, in Brazil, chest examination is the most common procedure in conventional radiology rooms [8].

2. MATERIALS AND METHODS

The formulation of Kharrati and Zarrad [4] was adequate to determine mean conversion coefficients from experimental spectra expressed in terms of air kerma. Equation (1) shows the formulation used.

$$\bar{C}_k = \frac{\int_0^{E_{max}} C_k(E)\Phi(E,\theta)E\left(\frac{\mu_{en}(E)}{\rho}\right)_{air} \exp(-\mu(E)x)dE}{\int_0^{E_{max}} \Phi(E,\theta)E\left(\frac{\mu_{en}(E)}{\rho}\right)_{air} \exp(-\mu(E)x)dE} \quad (1)$$

$C_k(E)$ are the conversion coefficients from Table A.21 of the ICRU report 57. $\Phi(E,\theta)$ is the photon fluence spectrum defined as the photon fluence of energy E at scatter angle θ per energy interval, for a primary x-ray spectra the angle, $\theta=0$. $\mu_{en}(E)/\rho$ is the mass-energy absorption coefficient, being equivalent to the mass energy transfer coefficient for diagnostic energies. The term $exp(-\mu(E)x)$ is the attenuation factor as a function of the barite mortar plate thickness, x, with linear attenuation coefficient $\mu(E)$. The primary radiation emitted by a Philips X-ray tube (Philips N.V., Amsterdam, Netherlands) model MCN 421 reached an anthropomorphic simulator object Rando® Man (Alderson Research Laboratories, USA) to produce the radiation transmitted and scattered by the simulator. The Radcal ionization chamber model 10x5-1800 (Radcal Co., Monrovia, CA) and a CdTe detector (Amptek Inc., Bedford, MA, USA) were used to measure the air-kerma and the energy distribution of the photons respectively. For the energy calibration, sources of 152Eu, 241Am and 133Ba were used, which have photons with energies in the range used in medical diagnostic radiology. The methodology used for the correction of the spectra is based on the stripping procedure [9]. For the energy range used in medical radiodiagnosis, the most important effects on correcting the detector response are the X-ray escape correction of the K-type characteristic of the Cd and Te, the Compton scape, and the detector efficiency correction [9], [5].

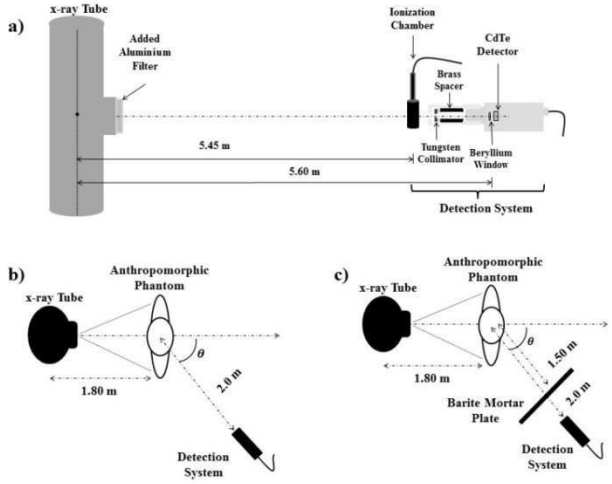

FIG 1 – Experimental setup used to measure (a) primary x-ray spectra, (b) secondary x-ray spectra and (c) transmitted x-ray spectra through a barite mortar plate. The representations of the setup components for each case are not in the real scale [10].

Figure 1.a shows the experimental arrangement used for measurements of primary spectra. In order to control the dead time of the detector and the stacking effects, which affect the measurement of the spectrum due to the high fluence rate, the detection system was positioned at 5.60 m from the X-ray tube. Figure 1.b shows the experimental arrangement used for secondary spectra measurements at angles of 30°, 60°, 90°, 120° and 150°, defined with respect to the direction of the primary beam. With the experimental arrangement used during the measurements, the radiation field reached the entire thoracic region of the anthropomorphic simulating object. The barite mortar plate was at 1.50 m from the center of the scatter object and the measurements were performed at the 30°, 60°, 90°, 120° and 150° angles, relative to the direction of the primary beam, and each of the 4 plates having thicknesses of approximately 10, 15, 20 and 25 mm.

3. RESULTS AND DISCUSSIONS

The spectra were measured with additional 3.04 mmAl filtration in the X-ray tube. As shown in Figure 2.a, the inherent 2.2 mm filtration of Be and the additional 3.04 mm filtration of Al modifies the energy distribution of the spectrum by removing almost all the photons of energy less than 15 keV.

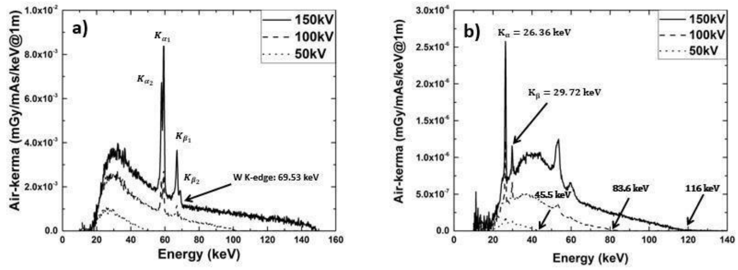

FIG 2 – (a) primary spectra at 50, 100 and 150 kV. The characteristic peaks corresponding to 57.9, 59.3, 67.2 and 69 keV is presented as well as the influence of the auto-absorption of the tungsten K-edge at 69.53 keV over 150 kV x-ray spectrum. (b)Secondary spectra at 50, 100 and 150 kV and 90° degrees of scatter angle. The 51Sb Kα and Kβ characteristic x-ray is showed as well as the higher-energy photon for each spectrum predicted by the Compton scattering angle.

Figure 2.b shows a comparison between 3 secondary spectra measured at 90 degrees for the tensions of 50, 100 and 150 kV. The secondary spectra of Figure 2.b shows the characteristic lines Kα and Kβ of the antimony, 51Sb, corresponding to the energies 26.36 keV and 29.72 keV, which are the lines of greater intensity. Although the antimony represents only 0.16% of the total mass of the anthropomorphic simulator object, its presence in the secondary spectrum stands out due to the low absorption in the scattering object. Figure 3 shows the spectra transmitted through a barium mortar plate of approximately 10 mm thick, B10, with a voltage 150 kV in the X-ray tube. The end points of the spectra are affected by the leakage radiation from the tube, which directly reaches the detection system without crossing the barite mortar plates and at angles greater than 90. The characteristic Barium radiation is in the form of the Kα and Kβ rays.

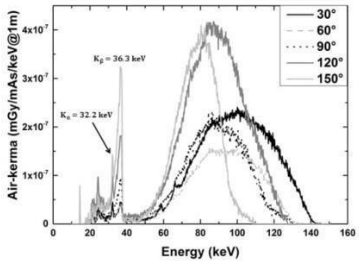

FIG 3 – Transmited x-ray spectra through B10 barite mortar plate at 30°, 60°, 90°, 120° and 150° of scatter angle corresponding to 150kV. The detached characteristic lines are barium Kα and Kβ emissions corresponding to 32.2 and 36.3keV, respectively.

Figure 4 shows the mean coefficients calculated from primary, secondary and transmitted spectra as a function of the HVL. The uncertainty corresponding to each coefficient was determined by considering the Poisson distribution for each channel of the corresponding spectra [11]. Figure 4 shows that the conversion coefficients related to secondary and secondary beams transmitted are greater than the value 1.14 Sv/Gy, established in Ministerial Order 453. The maximum difference between the conversion coefficients obtained and the recommended constant value In national regulation is 53.4%.

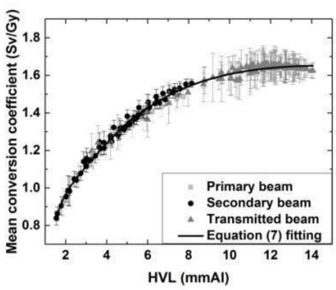

FIG 4 – All mean conversion coefficients computed in this work as a function of the half value layer, HVL.

Equation 2 was used to fit the mean conversion coefficients

$$\bar{C}(E) = \frac{z(E)}{a[z(E)]^2 + b\,z(E) + c} + d \times \arctan\{g\,z(E)\} \qquad (2)$$

In equation 2, $z(E) = \ln(E/E')$, E is the mean energy or (HVL) in keV or (mmAl), and E', a, b, c, d and g are the parameters Function adjustments that were obtained using regression methods and statistical weights. Table 1 shows the values of the parameter estimates.

TABLE 1. FITTING PARAMETERS OF EQUATION (3) REPRESENTING THE MEAN CONVERSION COEFFICIENT AS A FUNTION OF THE HALF VALUE LAYER (HVL)[9].

Parameters	The fit parameters Refereeing to Figure 3 Value
E'	0.97(8)
α	0.0021(4)
β	0.013(7)
γ	0.055(5)
δ	-21(8)
g	0.6(1)
	R^2=0.99

Note: the number in brackets represent uncertainties in the last decimal place.

4. CONCLUSIONS

Mean conversion coefficients were calculated from experimental X-ray spectra. The results show a strong dependence of the coefficient as a function of the average energy and the beam quality. This means that the best method to be used to estimate $H^*(10)$ must consider the corresponding beam quality. Therefore, values of $H^*(10)$ derived using the coefficient 1.14 Sv/Gy do not adequately represent the operational magnitude that should be used to verify the dose restriction limits or the compliance of shields in conventional radiology rooms.

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Conflict of interest

The authors declare that they have no conflict of interest.

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DETERMINATION OF COMPUTED TOMOGRAPHY QUANTITIES USING A NEW PEDIATRIC PHANTOM

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Abstract

A computed tomography pediatric head phantom that uses special materials to simulate the cortical and the cancellous bone was developed. This paper shows its behavior to determine the specific computed tomography radiation quantities at two calibration laboratory, the LCI-IPEN, Brazil and LMRI-IST, Portugal. The specific quantities measured were: air kerma index(Ca,100), weighted air kerma index (Cw), average volumetric air kerma index (C_{vol}) and the air kerma-lenght product (P_{KL}). The reference radiation qualities used in both laboratories were the radiation qualities recommended by the norm IEC 61267 (RQT8, RQT9 e RQT10) to computed tomography dosimetry measurements. The calculated values of C_W show attenuation of 11%, 13% and 10% for the qualities RQT 8, RQT 9 and RQT 10, respectively, from cortical to cancellous bone.

1. INTRODUCTION

The main specific quantities applied to computed tomography (CT) dosimetry are: air kerma index(Ca,100), weighted air kerma index (Cw), average volumetric air kerma index (C_{vol}) and the air kerma-lenght product (P_{KL})[1]. To determine or evaluate these quantities it is necessary to use physical or computational phantoms. The phantom must be able to reproduce as close as possible the absorption characteristics and scattering of some part of human body in the presence of a field radiation [2][3]. At the Insituto de Pesquisas Energéticas e Nucleares (IPEN), a pediatric phantom was developed for CT dosimetry considering the cranial bone. Several tests were done in specific standardized quality beams for CT in the Instruments Calibration Laboratory (LCI) of IPEN. In order to compare the results obtained from the tests done, the pediatric phantom was subjected to the same tests in standardized beams at the Ionizing Radiation Metrology Laboratory (LMRI) which is part of the Technical Superior Institute (IST), Lisbon, Portugal. The objective of this study is to present the results obtained using the new phantom and checks its behaviour in two different laboratories, but to the same radiation qualities.

2. MATHERIALS AND METHODS

2.1. Pediatric cranial phantom construction

The developed phantom is constituted of four parts, all in cylindrical form: two cylinders built in PMMA (the external with dense material and the intern with space for water addition or other materials), a cylinder built in aluminum (SP_{AL}) and other in PVC (SP_{PVC}), these last two simulate the skullcap and are used one at a time[4]. Fig. 1 shows its project with dimensions and Fig. 2 shows the constructed pediatric phantom, with all pieces separately and coupled. The aluminum cylinder simulates the cortical bone and the PVC cylinder simulates the cancellous bone.

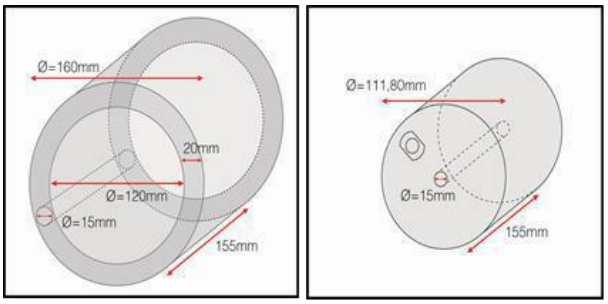

FIG. 1. Pediatric phantom project

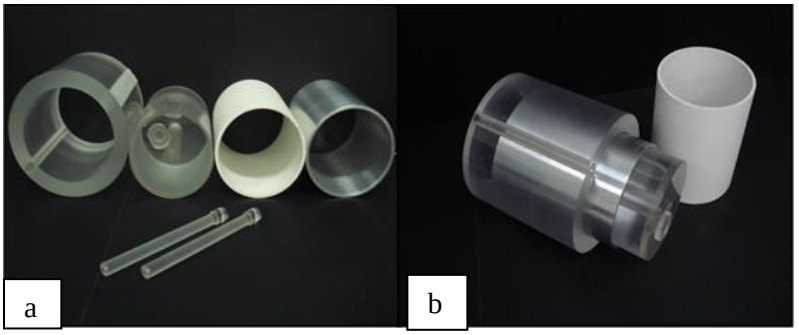

FIG. 2. Pediatric head phantom: a) separated pieces and b) mounted with the aluminum cylinder; the PVC cylinder is outside

2.2. Dosimetric systems

2.2.1. LCI-IPEN, BRAZIL

The IPEN reference dosimetric system is a Radcal Corporation ionization chamber, model 10x5-3CT, with the volume of 3 cm^3, attached to the Radcal electrometer, model 9015. The X radiation system used was a Pantak/Seifert, model Isovolt HS 160, MXR–160/22 tube model; its range of operation is from 5 kV to 160 kV

2.2.2. LMRI-IST, PORTUGAL

The LMRI-IST dosimetric system was a PTW ionization chamber, model 77336, with 73 cm^3 of volume, attached to an electrometer PTW, model UNIDOS E. The X radiation used was a Philips, model MGC 41 and tube model MCN 165. The maximum operation voltage of the X radiation system is 160 kV.

2.3. Radiation qualities

The reference radiation qualities used in both laboratories (IPEN and LMRI-IST) were the Computed Tomography radiation qualities recommended by the norm IEC 61267 (RQT8, RQT9 e RQT10)[5]. Prior to the measurements, the reference dosimetric systems were calibrated in terms of air kerma-lenght product (P_{KL}) for all the qualities. All measurements were corrected to the environmental conditions.

2.4. Specific CT quantities determination

For each radiation quality (RQT8, RQT9 and RQT10) it was calculated the CT free in air kerma ($C_{a,100}$) according to the equation:

$$C_{a,100} = \frac{1}{NT} \overline{MN}_P \, {}_{,Q} \, k_Q k_{TP}$$

where NT is the nominal width of irradiated beam, M is the obtained measurement with the dosimetric system, N_{PKL} is the calibration coefficient in terms of P_{KL}, k_Q and k_{TP} are the corrections factors for energy and environmental conditions, respectively.

After that, the air kerma index using the phantom was measuring inserting the ionization chamber in the peripherical hole ($C_{PMMA,100,p}$) and in the central hole ($C_{PMMA,100,c}$). In all measurements the empty hole was filled with a PMMA rod.

With those values it was possible to determine the weighted CT air kerma index, C_W, that combines the values of $C_{PMMA,100}$ measured at the centre and periphery of a CT dosimetry phantom by (1):

$$C_W = \frac{1}{3}\left(C_{PMMA,100,c} + 2C_{PMMA,100,p}\right)$$

3. RESULTS

The obtained results for CT specific quantities measured in both laboratories (Brazil and Portugal) can be seen in the next tables. Table 1 show the CT free in air kerma index. Those values were used to derivate the other quantities.

TABLE 1. CT free in Air Kerma index (Ca,100) obtained in both laboratories, IPEN (Brazil) and IST (Portugal).

Radiation Quality	$C_{a,100}$ (mGy/min)	
	LCI/IPEN	LMRI/IST
RQT 8	22.72 ± 0.21	23.81 ± 0.32
RQT 9	33.21 ± 0.32	35.11 ± 0.22
RQT 10	55.41 + 0.50	59.12 + 0.31

From those values and using the new pediatric phantom with the pencil ionization chamber were determined the air kerma index quantities. Tables 2 and 3 show the air kerma index obtained inserting the ionization chamber in the central hole ($C_{PMMA,100,c}$), for aluminium and PVC cylinder.

TABLE 2. CT air kerma index in the central hole ($C_{PMMA,100,c}$), using the new pediatric phantom with the aluminium cylinder (cortical bone), SP_{AL}

Radiation Quality	$C_{PMMA,100,c}$ (mGy)	
	LCI/IPEN	LMRI/IST
RQT 8	1.66 ± 0.31	1.06 ± 0.21
RQT 9	2.45 ± 0.21	1.69 ± 0.32
RQT 10	4.27 ± 0.10	2.88 ± 0.31

TABLE 3. CT air kerma index in the central hole ($C_{PMMA,100,c}$), using the new pediatric phantom with the PVC cylinder (cancellous bone), SP_{PVC}

Radiation Quality	$C_{PMMA,100,c}$ (mGy)	
	LCI/IPEN	LMRI/IST
RQT 8	2.02 ± 0.31	1.17 ± 0.21
RQT 9	3.12 ± 0.12	1.78 ± 0.31
RQT 10	4.82 ± 0.41	2.98± 0.22

Tables 4 and 5 show the air kerma index obtained inserting the ionization chamber in the peripherical hole ($C_{PMMA,100,p}$), for aluminium and PVC cylinder.

TABLE 4. CT air kerma index in the peripherical hole ($C_{PMMA,100,p}$), using the new pediatric phantom with the aluminium cylinder (cortical bone), SP_{AL}

Radiation Quality	$C_{PMMA,100,p}$ (mGy)	
	LCI/IPEN	LMRI/IST
RQT 8	2.85 ± 0.23	3.37 ± 0.10
RQT 9	4.48 ± 0.31	4.66 ± 0.20
RQT 10	7.48 ± 0.12	7.25 ± 0.30

TABLE 5. CT air kerma index in the peripherical hole ($C_{PMMA,100,p}$), using the new pediatric phantom with the PVC cylinder (cancellous bone), SP_{PVC}

Radiation Quality	$C_{PMMA,100,p}$ (mGy)	
	LCI/IPEN	LMRI/IST
RQT 8	3.11 ± 0.42	3.44 ± 0.41
RQT 9	4.75 ± 0.31	4.64 ± 0.41
RQT 10	7.80 ± 0.21	7.21 ± 0.31

Using the $C_{PMMA,100,c}$ and $C_{PMMA,100,p}$ obtained values it was possible to calculated the weighted CT air kerma index values, C_W. The calculated values of C_W show attenuation of 11%, 13% and 10% for the qualities RQT 8, RQT 9 and RQT 10, respectively, from cortical to cancellous bone, as can be seen in Tables 6 and 7.

TABLE 6. Weighted CT air kerma index C_W, using the new pediatric phantom with the aluminium cylinder (cortical bone), SP_{AL}

Radiation Quality	C_W (mGy)	
	LCI / IPEN	LMRI / IST
RQT 8	2.46 ± 0.21	2.60 ± 0.31
RQT 9	3.80 ± 0.22	3.67 ± 0.12
RQT 10	6.41 ± 0.42	5.79 ± 0.32

TABLE 7. Weighted CT air kerma index $C_{W,}$ using the new pediatric phantom with the PVC cylinder (cancellous bone), SP_{PVC}

Radiation Quality	C_W (mGy)	
	LCI / IPEN	LMRI / IST
RQT 8	2.74 ± 0.10	2.68 ± 0.41
RQT 9	4.21 ± 0.41	3.69 ± 0.30
RQT 10	6.82 ± 0.21	5.81 ± 0.31

4. CONCLUSIONS

It was possible to determine, in both laboratories, the specific quantities for CT: $C_{a,100,}$ $C_{PMMA,100,c}$, $C_{PMMA,100,p}$ and $C_{W.}$ Since these measurements were made in pre-established standard beams in each laboratory, it was used the scanning length of each one, causing a meaningful variation in the values of C_W and C_{vol}, which

takes into account the helical pitch or axial scan spacing, in this case the helical pitch is 1, so C_W and C_{vol} are equals.

ACKNOWLEDGEMENTS

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EVALUATION OF COLLIMATION IN CHEST IMAGING AND ASSOCIATED DOSE IMPACT

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Abstract

Introduction: Literature indicates the importance of X-ray beam collimation for patient dose and image quality. Actively collimating to the area of interest reduces the overall integral dose to the patient and thus minimizes the radiation risk; resulting in improved subject contrast and image quality. **Purpose:** To assess current practice in optimization of patient dose & assess beam collimation in chest x-rays in the Primary Health Care at Dubai Health Authority. To identify an optimal collimation distance for chest x-ray as best practice. **Method:** Review of 330-adult chest X- ray images performed between January and July 2016 to; 1. Determine evidence of collimation 2. Measure distance of collimation. 3. Dose Area Product measurement. Results: 24% of studies demonstrated evidence of collimation. Measured distance was divided into 3 categories; 2cm (3%), 5cm (39%) 10cm (58%). Data shows increase in the DAP (Dose Area Product) as collimation distance increased; from 8.31 to 17.16 µGym2 **Conclusion:** Chest Collimation and lack thereof is an area of concern which negatively affects image quality, patient dose and practice standardization.

Key words: Collimation, Radiation protection.

1. INTRODUCTION

"Radiation protection in the context of medical exposure is an effective measure to optimise and safe guard patients from unnecessary and unintentional exposure to ionizing radiation" [1] which could possibly result in negative biological effects. Beam collimation is an essential parameter in dose reduction to patients. "Collimation is the restriction of radiation to the area under examination by confining the beam with metal diaphragms or shutters with high radiation absorption power"[2]

Collimator is the best x-ray beam restrictor and it defines the size and shape of the x-ray field that emerge from the x-ray tube [3]. The collimator assembly is attached to the tube housing at the tube port. A collimator consists of two sets of shutters which can be moved independently. Each shutter consists of four or more lead plates which can absorb x-rays completely to provide a well-defined x-ray field and has a light arrangement to illuminate the x-ray field. [4]. Thus, collimation restricts the shape and size of the x-ray beam, image quality and reduces patient exposure. Good collimation will minimize the dose to the patient and improve image quality, because the amount of scattered radiation will increase if a large volume of tissue is irradiated [5], [6]

The International Commission on Radiological Protection (ICRP) recommends that exposure of the patient must be kept to the lowest practicable value, consistent with clinical objectives and without loss of essential diagnostic information[7].

Chest radiography is an important diagnostic method for evaluation of the airways, pulmonary parenchyma and vessels, mediastinum, heart, pleura and chest wall. Chest x-ray examination was reported to be one of the most frequently conducted diagnostic procedures in clinical practice and may be implemented in screening programs for large populations. Chest radiography accounts for approximately 25% of all x-ray examinations performed in Dubai Health Authority- Primary Healthcare Clinics.

Purpose:

To assess current practice in optimization of patient dose & assess the x-ray beam collimation in chest x-rays in the Primary Health Care Service Sector (PHCSS) at Dubai Health Authority (DHA).

To identify an optimal collimation distance for chest imaging as best practice.

2. METHODS

A total of 330 adult chest X- ray images (performed using digital Radiography Modalities) were retrospectively assessed for good collimation practice over a 6-month period (January to July 2016) from 4 main primary health care centres in Dubai Health Authority.

The Chest X-ray (CXR) images for all the 4 health centres were analysed according to the visible collimation line on each side of the primary (pre-processed) image (Superior, Inferior, Right and left lateral)

The analysis system involves

(a) 2 cm visible measured collimation line seen on all sides of the Chest X-rayimage

(b) Identify what % of chest X-rays have visible measured collimation on all 4 sides of the primary image irrelevant of collimation size.

(c) Analyse correlation between radiation dose and collimation.

Due to the variables in the audit, 2cm collimation compliance was only 3% across all clinics, thus decision taken to expand the audit to include 5cm and 10cm chest collimation compliance.

3. RESULTS

(a) 3% complied to 2cm visible measured collimation line, 39% complied to 5cm collimation & 58% complied to 10cm collimation.

TABLE 1. 2/5/10 cm visible measured collimation line seen on all sides of the Chest X-ray image

Collimation 2cm	Collimation 5cm	Collimation 10 and above cm	Total images
10 (3%)	130 (39 %)	190 (58%)	330

Further analysis found the superior border showed 43%, inferior border 71%, Right lateral (78%) and Left lateral 84% compliance.

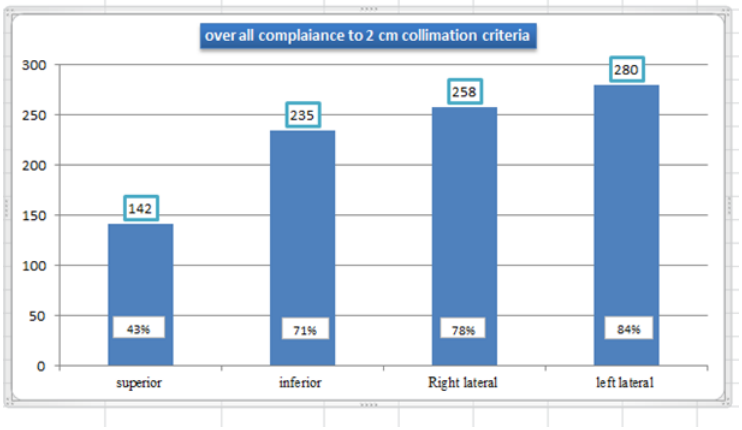

FIG. 1. Chart showing the overall compliance to 2 cm collimation.

(b) 76% of chest images did not demonstrate any visible measured collimation line on all four sides of the analysed chest x-ray image.

TABLE 2. Visible measured collimation line seen on all four sides of the Chest X-rayimage

Total images	Collimation 4 sides of the image	Collimation line seen on 3 or less sides
330	79 (24%)	251 (76%)

(c) The average dose for the total collimation in each radiograph analysed and concluded that- As collimation increases the DAP (Dose Area Product) also increases from 8.3 µGym2 to 17.16, µGym2

TABLE 3. DAP (Dose Area Product), Collimation Correlation

Collimation range (Total sides added)	Average Dap Value
4-8 cm	8.3 µGym2
8-12 cm	10.4 µGym2
12-15 cm	11.38 µGym2
15-18 cm	13.29 µGym2
18-20 cm	14.39 µGym2
20-25 cm	17.16 µGym2

4. DISCUSSIONS

This study shows there is inadequate beam collimation practice amongst radiographers which increases the patient dose and minimises the image quality. The contributory factors include; Light beam misalignment/malfunction, staff experience and confidence, limited clinical auditing and inaccurate source image distance (SID) utilisation.

5. CONCLUSIONS

Beam collimation is an important tool in radiation protection to reduce unnecessary patient exposure and increase image quality by eliminating scatter radiation. Current clinical practice needs continual monitoring and auditing to ensure compliance amongst radiographers to beam collimation in the most frequently performed study. Improving chest collimation directly improves image quality and reduces patient dose. Further expansion of this study across all DHA PHC facilities is warranted to determine the scope of practice and implement improvement strategies.

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Radiation protection of the Tajikistan population during the diagnostic irradiation

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The problem of effective radiation protection of the population of Tajikistan during X-ray medical research is one of the priority state tasks[1, 2].

In Tajikistan, despite the trend of decreasing of population exposure levels through diagnostic medical research over the last decade, the frequency and dose of population radiation exposure in standard radiological procedures (RLP) are still higher than in a number of countries[3].

Purposeful development of measures to optimize the radiation protection of patients and medical personnel is carried out on the basis of a comprehensive analysis of the material and technical support of radiation diagnostics, including the use of IRS, the number and structure of X-ray studies, levels and structure of radiation doses to the population.

The conceptual approach to optimization of radiation protection of patients consists, first of all, in the application of the reference diagnostic levels of patients exposure in X-ray and radionuclide diagnostics. Usage of these levels in developed countries allowed to reduce the dose of medical exposure of patients for several times.

The article presents following results:

- the comparative complex radiation-hygienic characteristic of the instrumental park of domestic radiation diagnostics is outlined. Negative tendencies of hardware equipment of X-ray and radiology diagnostics anda backwardness in the field of innovative technologies are revealed;

- the levels of exposure of patients and the population of the Republic of Tajikistan due to X-ray studies have been studied and systematized. It was shown that the maximum dose loads for patients are characterized by X-ray examinations.

The data and analysis of external exposure monitoring of the personnel of the customs service of the Republic of Tajikistan for 2010-2013 is presented in the article too.

We analyzed the data and analyses of personnel's average annual external exposure doses monitoring via the thermoluminescent dosimetry method used for

Radiologist personnel in dental polyclinics of Dushanbe, Tajikistan Republic for 5-year period (2010—2014). Out of 42 registered medical institutions dental polyclinics amounted up to only just 14 per cent. For this work thermoluminescent dosimeters were used (with LiF: Mg, Ti) with the thermoluminescent dosimetric installation "Harshaw — 4500" as the reader device. Monitoring results comparison of individual dose equivalent Hp10 values was conducted for two groups of medical workers: medical doctors and X-ray lab technicians. It is demonstrated that radiological technicians' professional exposure doses are on the average by 23 per cent higher than those for medical doctors.

The average individual exposure doses over the above indicated period amount to 0,93 mSv and 1,3 mSv for doctors and X-ray lab technicians, respectively, and are in the range from 0,45 mSv to 2,39 mSv. The doses include contribution from the natural background. The values of doses recorded for the personnel in dental polyclinic correspond to those recorded for the workers in the routine X-ray rooms.

The measured values of doses turned out to be significantly lower than the normative values and totally correspond to similar dimensions of doses of other categories of personnel in X-ray departments performing x-ray examinations in general X-ray diagnostics.

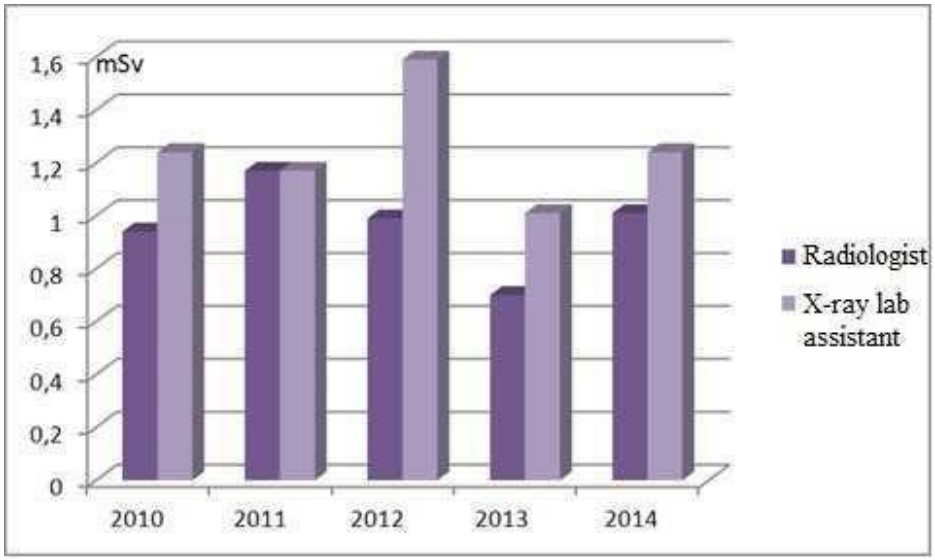

Figure 1.

Average annual irradiation doses of Radiologists and X-ray laboratory assistants of Dushanbe dental polyclinics for 2010-2014.

Among the technical means using by customs authorities, in particular, include X-ray examination television, fluoscopic technique, technical means of customs control of fissile and radioactive materials, as well as a number of other technical means.

Employees of customs authorities conducting radiation monitoring are referred toirradiated persons (personnel of group A)according to the "Radiation safety standards" (RSS-06).

For the purpose of the maximum possible reduction of potential radiation doses and not exceeding the established limits, we constantly monitor individual doses ofgroup “A” personnel:69 people from Customs Service under the Government of the Republic of Tajikistan and 64 people in State Unitary Enterprise "International Airport of Dushanbe".

Based on the data obtained by measuring the individual dose of personnel exposure, a table of average annual doses for the period from 2010 to 2013 was compiled.

Table. Average annual doses of exposure to customs personnel assigned to group "A"

Organization name	Position	2010 Dose, mSv	2011 Dose, mSv	2012 Dose, mSv	2013 Dose, mSv
International Airport	Shift Head			1,44	1,02
	Computer wizard engineer	0,93	1,04	1,15	0,73
	Communication technician	0,98	1,04	1,51	0,87
	Inspector	1,16	1,18	2,04	1,21
Customs Service under the Government of RT	Inspector	2,23	1,89	2,38	1,9

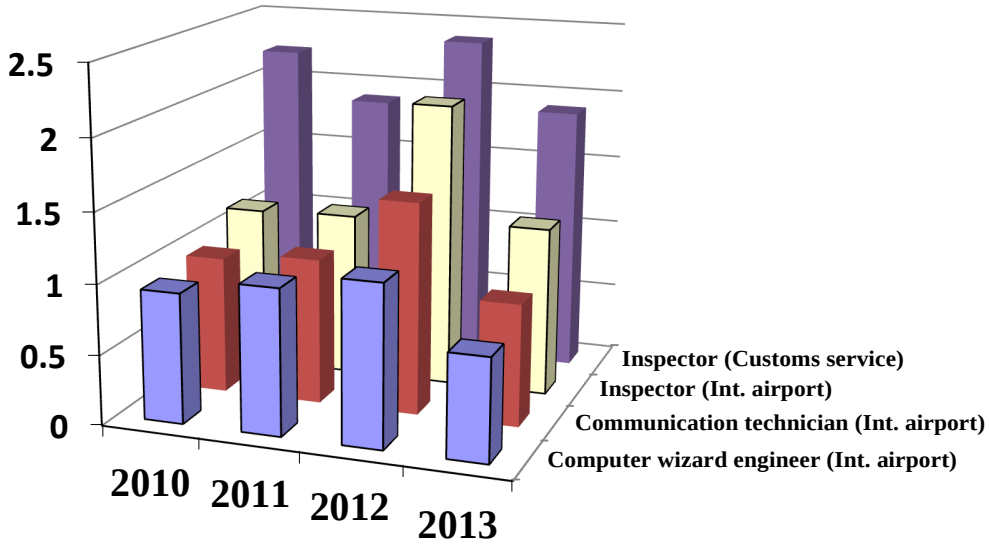

Figure 2. Average annual exposure doses (2010-2013), mSv

As can be find out from Fig. 2, of all indications, the maximum value of the average annual dose (2.38 mSv) was noted in 2012 among inspectors of the Customs Service under the Government of the Republic of Tajikistan. This indicator could be much smaller. One of the inspectors received irradiation with an effective dose of Hp (10) 8.77 mSv working with the RapiscanGaRDS Gantry inspection equipment. Due to the power cutoff, he had to manually close the emitter collimator, which contained a ^{60}Co cobalt source.

Studies have shown that inspectors receive the greatest dose load. This category of employees has the greatest period of contact with devices used IRS. The risk IRSexposure is highly dependent on compliance with the rules and safety regulations during working with devices used IRS.

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ESTABLISHMENT OF CT LOCAL DIAGNOSTIC REFERENCE LEVELS IN SOME TUNISIAN SITES

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Abstract

The main objective of this study is to analyze dose trends in some Tunisian scanners and set local DRLs for most common CT examinations as a first step of optimization. The collected data was performed at five sites in Tunisia of four examinations. Dose data [CT volume index ($CTDI_{vol}$) and dose-length product (DLP)] on a minimum of ten average sized patients in each category were recorded to calculate a median $CTDI_{vol}$ and DLP value. Results are compared with international DRLs. Data were collected for 355 patients. The median $CTDI_{vol}$ value was ranged between 46 and 130, 8.5 and 41, 10.8 and 37 and 4.5 and 24.5 mGy for head, chest, routine abdomen/pelvis and trunk examinations, respectively; the median DLP value was ranged between 675 and 2180, 248 and 1210, 428 and 1608 and 287 and 1633 mGy*cm for head, chest, routine abdomen/pelvis and trunk examinations, respectively. The local DRLs for these CT examinations were set. For CT procedures the comparison between local DRLs and international DRLs shows that one site had very high values for all examinations. There is large potential for optimization ofexaminations.

INTRODUCTION

Computed Tomography (CT) is a valuable medical imaging technique for the diagnosis of wide range of diseases. Due to development of powerful CT machines, new clinical applications continue to emerge in medical fields. Accordingly, the number of CT machines and hence the examinations has significantly increased during the last decade [1]. However, CT is associated with relatively high radiation doses, with a corresponding increased risk of carcinogenesis [2–4].Therefore, application of the international Commission of radiological protection (ICRP) principles of radiation protection--justification, optimisation and minimisation--is essential to reduce unnecessary exposure. At the core of optimisation is the establishment of diagnostic reference levels (DRLs), first proposed by the International Commission on Radiation Protection (ICRP) in 1996 [5]. The DRLs aren't dose limits but is a means to evaluate the practice.
There isn't CT DRLs in Tunisia and like a first step; the purpose of this study was to establish the local DRLS in five sites for the most common CT examinations using two primary dosimetry metrics: dose-length product (DLP) and CT dose volume index ($CTDI_{vol}$).

METHODS AND MATERIALS

A pilot study was conducted in five hospitals to investigate the four most commonly performed CT examinations: head, chest, abdomen and pelvic and trunk (chest and abdomen and pelvic) for adult patients. These sites were represented two university hospitals, two private hospitals and regional one.All the data concerning the parameters of examinations and dose values ($CTDI_{vol}$ and PDL) were collected from the consol for adult patients (> 16 years) had a weight ranged between 50 and 90 kg. For each site and examination the data was collected at least for 10 patients as recommended by the IPEM [6].the five CT machines belong to three different manufactures: Siemens, GE and Hitachi with number of slices from one to 64, see scanner characteristics in table 1.The two first manufactures are the most installed in Tunisia. For all facilities the doses are calculated with used of 16 cm diameter phantom for head and 32 cm for body examinations.

TABLE 1. Characteristic of CT machines at different sites

	Site 1	Site 2	Site 3	Site 4	Site 5
Manufactor	Siemens	Siemens	GE	GE	Hitachi
Model	Somatom Emotion	Somatom Emotion6	LightSpeed 16	LightSpeed VCT XT	Supria
Installation date	2005	2007	2006	2005	2016
Number of slices	1	6	16	64	16
kV	80-110-130	50-80-110-130	80-100-120-140	80-100-120-140	80-100-120-140

To calculate the local DRLs we used the median values as recommended by the ICRP in the published draft in 2016 of "Diagnostic Reference Levelsin Medical Imaging" for public comment.In that document, they say, "The Commission now recommendsthat the median value (not the meanvalue) for the DRL quantity from each of the facilities in the survey should be used".

RESULTS

Table 2 presents the distribution of patient for the examination considered by the study at the five sites. The dose data was collected for 355 patients in all sites of the study for all examinations interested the study. The head and abdomen-pelvic examinations are the most frequent examinations released at Tunisia and represent together 64% of the sample.

TABLE 2. Number of patients by site

	Siemens 1 slice	Siemens 6 slices	GE 16 slices	GE 64 slices	Hitachi 16 slices
Head	54	15	22	19	12
Chest	13	10	25	12	12
Abdomen-pelvic	54	-	16	11	24
Chest-Abdomen-Pelvic	11	10	14	10	11
total	132	35	77	52	59

TABLE 3. Exposure parameters at different CT scanners for Head and Body region

	kV		mAs		pitch	
	Head	Body region	Head	Body region	Head	Body region
Siemens 1 slice	130	130	190	130	1	1.5
Siemens 6 slices	130	130	240	60	0.45	1.5
Hitachi 16 slices	120	120	230	150	0.5625	1.0625
GE 16 slices	120	120	450	175	1	1.375
GE 64 slices	140	120-140	420	350	1	1.375

Table 3 shows the main parameter exposures that have direct influence to the patient dose received through scanner examinations. The higher values of kV and mAs were registered at the sites where the GE machines were installed. For the 64 slices scanner the manipulators used frequently 140 kV with high value of mAs. About the pitch, for head scanner the sequential acquisition was used but the two sites, Siemens 6 slices and Hitachi, the helical technique was used with low pitch (<1). For body region the helical technique was used at all sites with pitch higher than 1, that`s allow to have a faster examination and minimize patient dose.

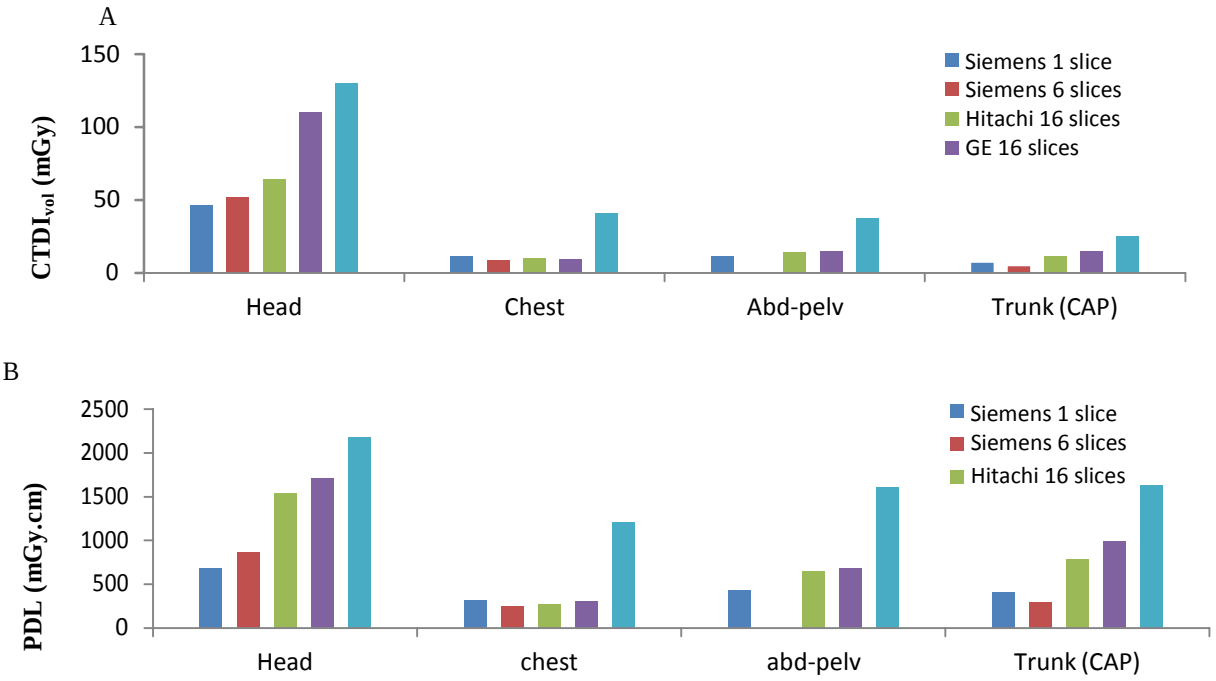

FIG 1.Median values of $CTDI_{vol}$ (mGy) and DLP (mGy.cm) for four typical CT examinations at the five sites of the study

Figure 1 shows the median values of $CTDI_{vol}$ and DLP for each examination in different sites. As can be seen, there isn`t large scales in $CTDI_{vol}$ and DLP values at different sites except the GE 64 slice for all examinations and GE 16 slices for head scanner where the dose values are 2 to 5 higher than others. That was due to the use of high kV (140) and/or high mAs as seen in table 3.

DISCUSSION

The results obtained have been compared with values from other studies which have been recently published in the literature (figures 2 and 3). It can be observed that the majority values of local DRLs ($CTDI_{vol}$ and DLP) were similar and even lower than the values reported by other authors [7-10]. Except for the site where the GE 64 slices was installed for all CT examinations and for Head CT performed at GE 16 slices machine. The reasons for the high values were explained in the last paragraph of the results section. High value of DLP was registered at the Hitachi scanner for head examination, despite the $CTDI_{vol}$ was similar to the international values. This high value was due to the length of region scanned it was about 24 cm, although at the other sites it was around 16 cm. For this reason, it's very important to establish DRLs based on $CTDI_{vol}$ and DLP together, in target for optimisation a correction action must taken where it's possible.

In fact, the establishment of DRLs is first step in the way of the optimisation of patient dose. This work is the first step in the elaboration of National DRLs for adult scanner.

There were some limitations in this study; the clinical indication was not included at the selection of scanner examinations. Also the new CT parameter, the size-specific dose estimate (SSDE), developed by the American Association of Physicists in Medicine (AAPM) was not applied for individual patient dose [11].

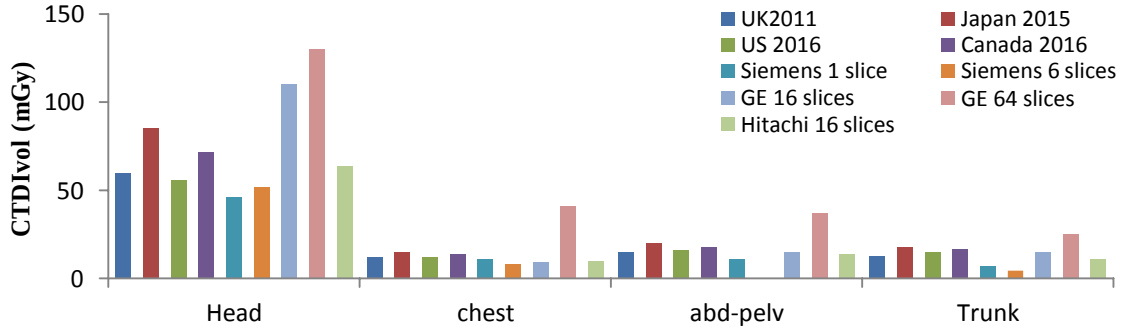

FIG.2. Comparison Local DRLs [$CTDI_{vol}$ (mGy)] for this study with international studies

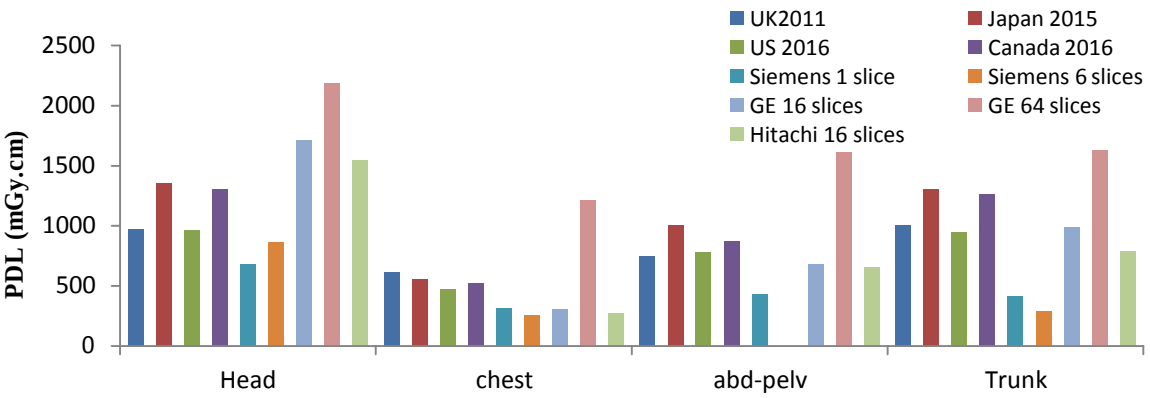

FIG.3. Comparison Local DRLs [DLP (mGy cm)] for this study with international studies

CONCLUSION

The determination of patient dose is the first step in the way of optimisation. Some sites of the study had high dose due to the inadequate practice and certain corrections must be applied. The establishment of Local DRLs is useful but the implementation of national DRLs is essential to know the dose at country level that will be held at the near future with the support of International Agency of Energy Atomic (IAEA).

ACKNOWLEDGEMENTS

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ESTABLISHMENT OF COMPUTED TOMOGRAPHY ANGIOGRAPHY NATIONAL DIAGNOSTIC REFERENCE LEVEL IN IRAN

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Abstract

In recent years, with the presentation of 64-slice CT and dual-source CT technology, coronary CT angiography (CCTA) has emerged as a useful diagnostic imaging modality. CT produces a larger radiation dose than other imaging examinations and cardiac CT involves higher radiation dose with the advances in the spatial and temporal resolution. The purpose of the study are patient dose evaluation and propose national diagnostic reference level for CCTA in Iran. A questionnaire was sent to CCTA centers. Data were collected. The volumetric CT dose index ($CTDI_{vol}$), dose length product (DLP) and total DLP were considered in the 32 cm standard body phantom. Calculation of estimated effective dose (ED) was obtained by multiplying the DLP by a conversion factor. Mean value of $CTDI_{vol}$ and DLP for CCTA was 50 mGy and 825 mGy·cm. The third quartile of the distribution of mean $CTDI_{vol}$ (66.54 mGy) and DLP (1073 mGy·cm) values was expressed as the diagnostic reference level (DRL) for CCTA in Iran. A large variety in $CTDI_{vol}$ and DLP among CT scanner and different sites due to variability in CT parameter is noted. It seems that training could help to reduce patient's dose.

1. INTRODUCTION

Application of CT scan for diagnostic tests has increased in the last two decades as the technology progresses [1]. With the develop of multi-slice and dual source CT, using coronary CT angiography that gives a high radiation dose in comparison with other CT scan examinations has also increased [2]. This study aimed to estimate the radiation dose on the way of creating DRL for CCTA examination in Iranian governmental hospitals.

2. METHODS

The questionnaire were sent to all hospitals with 256 or 64 slice CT scans to collect information on national diagnostic reference levels for CCTA exam. The survey was performed for 10 to 30 patients depending on the number of patients who referred to hospitals. Retrospective Gated Helical (RGH) protocol has been commonly performed in Iran so far, the information collected regarding this protocol. All of the centers machine passed quality control test and had calibration certificate participant in the survey. CTDI and DLP as CT dose descriptors [3,4] were written down after each CTA examination. The effective dose calculated were described the radiosensitivity of the tissue exposed to radiation. Effective dose was calculated by multiplying DLP by a conversion factor of 0.014 [5-7]. The data related to overweight patients (Body Mass Index (BMI) > 35 kg m^{-2}) and duplicated total DLP because of repeated scan were excluded. Organ effective dose was calculated according to ICRP 103 formula. The software version 1 was used to obtain different organ dose for the CT impact. This software is based on the Monte Carlo simulation [8,9]. Statistical analysis were performed using SPSS version 23.

3. RESULTS

According to the assessed data of 281 adult patients, the average BMI for both gender was 27.4 ± 3.8 kg m^{-2} ; mean value of $CTDI_{vol}$ for female and male was 50.9 ± 20 mGy and 49.4 ± 21, respectively; dosimetric values (Range of $CTDI_{vol}$ and DLP) and scan parameters for various scanners are indicated in table 1. Among various centers and in the different scanners, there were many differences between the mas and the scanning time was different. Tube current modulation and electrocardiographically controlled tube current modulation were used for 73.5% and 100% of the of CCTA procedures, respectively. Dosimetric parameters (range, average, SD, 75 percentiles for $CTDI_{vol}$, DLP, Total DLP and effective dose) are presented in table2. The 75th percentile of DLP and $CTDI_{vol}$ for CCTA are considered as national DRL in Iran. Different organ dose in various CCTA scanners are presented in table 3.

TABLE 1. CT parameters and dosimetric values for different CT scanner

Scanner	kVp	mAs range	Ave. mAs	Pitch	Rot. time (seconds)	Scan length (mm)	Slice thick (mm)	CTDI range (mGy)	DLP range (mGy·cm)
Siemens 64	100	196–823	454	0.2, 0.24	0.33, 0.37	98–236	0.6	8.83–37.10	128–610
	120	262–860	587	0.2, 0.024	0.33, 0.37	85–228	0.6	20.44–64.54	275–1392
	140	606–700	653	0.2, 0.24	0.33, 0.37	102–136	0.6	45.52–84.34	572–1299
Philips 64	120	800–1000	—	0.2	0.4	121–299	0.67	51.70–64.70	846–1757
	140	800–1000	—	0.2	0.4	110–234	0.67, 0.9	51.70–70.00	729–1867
GE-64	120	545–762	591	Hidden	0.4, 0.35	91–282	0.625	47.89–103.29	917–2506
Siemens-256	100	220–287	248	<0.31	0.28	124–148	0.6	24.90–45.50	431–694
	120	151–380	245	<0.31	0.28	100–233	0.6	24.88–103.14	258–2396

TABLE 2. Dosimetric parameters (range, average, SD, 75percentiles for $CTDI_{vol}$, DLP, Total DLP, effective dose)

Parameter	Range	Mean	Median	SD	25th	50th	75th	90th
$CTDI_{vol}$ (mGy)	8.83–103.29	50.01	49.81	21.88	34.46	49.81	66.54	73.12
DLP (mGy·cm)	128–2506	826	733	436	506	733	1073	1392
Total DLP	158–3031	924	736	578	503	736	1255	1807
Ca-score (DLP)	13–385	108	46	96	34	46	187	244
Eff. dose (mSv)	1.8–35.0	11.6	10.3	6.0	7.1	10.3	15.0	19.5

TABLE 3. Different organ dose in various CCTA scanners

Organ	W_T	GE 64	Philips64	Siemens sensation 64	Siemens Somatom 64	Siemens Dual source
Gonad	0.08	0	0	0	0	0
Bone marrow	0.12	1.4	1.2	1	1.3	0.47
Large intestine	0.12	0.04	0.04	0.04	0.04	0.02
Lung	0.12	7	5.8	4.9	6.3	2.3
Stomach	0.12	0.83	0.73	0.63	0.78	0.28
Bladder	0.04	0	0	0	0	0
Breast	0.12	7.4	6.6	5.6	6.7	2.7
Liver	0.04	0.42	0.37	0.31	0.39	0.14
Esophagus	0.04	2.3	1.9	1.4	2	0.73
Thyroid	0.04	0.05	0.06	0.04	0.06	0.02
Skin	0.01	0.09	0.07	0.06	0.07	0.03
Bone surface	0.01	0.23	0.19	0.16	0.19	0.08
Brain	0.01	0	0	0	0	0
Salivary glands	0.01	0	0	0	0	0
Remaining tissues	0.12	1.7	1.4	1.2	1.6	0.56
Effective dose	1	21	18	15	19	7.4

4. DISSCUSSIONS AND CONCLUSIONS

The mean value and range of $CTDI_{vol}$ differ in various CT scanner machines; these differences are caused by changes in scan parameters. The great variability in the range of $CTDI_{vol}$ are observed in Siemens 64 slice scanner. The reason could be the more usage of this machine in medical centers and variability to select scan parameters in Simens 64 slice scanner. The higher mean value of CTDIvol was observed in GE scanner which could be due to using 120 Kv tube voltage for CCTA. Calculated 75^{th} $CTDI_{vol}$ was higher than Palorini et al. research in 2013, due to the current application of RGH protocol in the participated centers; while in Palorini et al. research, sequential and RGH protocol were used. In RGH protocol, dose is more than sequential [3]. There was an opposite relationship between $CTDI_{vol}$ and pitch, bivariate coefficient was -0.547 and partial coefficient was -0.616 (pvalue < 0.001). The established DRL for CCTA was incompatible with the most countries [3,10,11].

Breast tissue has the highest absorbed dose followed by lung tissue in all CCTA scanners because they have more volume and on the other hand these tissues are in the direct field of the radiation beam. GE 64 slice machine had the most effective dose among the CT scanners, which is may be due to the high $nCTDI_w$ in this scanner type and applying high mAs.

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Liver	0.04	0.42	0.37	0.31	0.39	0.14
Esophagus	0.04	2.3	1.9	1.4	2	0.73
Thyroid	0.04	0.05	0.06	0.04	0.06	0.02
Skin	0.01	0.09	0.07	0.06	0.07	0.03
Bone surface	0.01	0.23	0.19	0.16	0.19	0.08
Brain	0.01	0	0	0	0	0
Salivary glands	0.01	0	0	0	0	0
Remaining tissues	0.12	1.7	1.4	1.2	1.6	0.56
Effective dose	1	21	18	15	19	7.4

4. DISSCUSSIONS AND CONCLUSIONS

The mean value and range of $CTDI_{vol}$ differ in various CT scanner machines; these differences are caused by changes in scan parameters. The great variability in the range of $CTDI_{vol}$ are observed in Siemens 64 slice scanner. The reason could be the more usage of this machine in medical centers and variability to select scan parameters in Simens 64 slice scanner. The higher mean value of CTDIvol was observed in GE scanner which could be due to using 120 Kv tube voltage for CCTA. Calculated 75^{th} $CTDI_{vol}$ was higher than Palorini et al. research in 2013, due to the current application of RGH protocol in the participated centers; while in Palorini et al. research, sequential and RGH protocol were used. In RGH protocol, dose is more than sequential [3]. There was an opposite relationship between $CTDI_{vol}$ and pitch, bivariate coefficient was -0.547 and partial coefficient was -0.616 (pvalue < 0.001). The established DRL for CCTA was incompatible with the most countries [3,10,11].

Breast tissue has the highest absorbed dose followed by lung tissue in all CCTA scanners because they have more volume and on the other hand these tissues are in the direct field of the radiation beam. GE 64 slice machine had the most effective dose among the CT scanners, which is may be due to the high $nCTDI_w$ in this scanner type and applying high mAs.

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OCCUPATIONAL DOSE ASSESSMENT FOR MEDICAL STAFF IN DUBAI HEALTH AUTHORITY USING DIRECT ION STORAGE SYSTEM

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Abstract

Occupational Dosimetry is essential to verify the compliance of staff radiation doses with international and local standards and insure the safety of staff during work. Dosimerty measurements for the whole body were taken for Medical staff in Dubai Health Authority for the period 2011-2015 using Direct Ion Chamber Dosimeters. Staff badges are read onsite and the dosimetry reports are issued by the Medical Physics Section at Dubai Health Authority. Medical staff from hospitals and clinics were classified to four major groups according to type of work, namely: Doctors, Nurses, Medical Physicists, Radiographers and Nuclear Medicine Technicians. Accumulated doses were calculated for each group from monthly and bi monthly results. All accumulated dose values were below International Dose limit of 20 mSv per year and the dose constraint in Dubai Health Authority of 3 mSv per year. Results were also compared with previous studies and found within acceptable agreement. This shows the good practice at Dubai Health Authority regarding the safe use of ionizing radiation. Further studies can be done to assess eye lens dose and skin dose.

1. INTRODUCTION

The use of ionizing radiation has been increase extensively in medical field and radiation workers accordingly. There are more than 2.3 million radiation workers word wide [1]. There are three types of exposure: medical, public and occupational exposure to radiation workers. Three principles for radiation protection are applied, justification, optimization, and dose limitation. These principles are applied for public and occupational exposures, while guidance levels and dose constraints are applied to medical exposure instead of dose limits [2]. Occupational dose limits for the whole body is 20 mSv/year averaged over a period of five years, 20 mSv/year for the lens of the eye, and 500 mSv/year for skin and extremities [3] All individuals occupationally exposed to external radiation shall be monitored with personal radiation dosimeters. Through Occupational dosimetry, actual doses to each staff can be measure to comply with international dose limits and local dose constraints. Therefore, radiation safety conditions can be assist during working with ionizing radiation, and determining new exposure pathways or risks [4]. Dubai Health Authority (DHA) initiated occupational dosimetry in 2005 using Direct Ion Storage Dosimters (DIS). It is the first DIS system used in the Middle East. DIS badges are read onsite for hospitals and clinics in DHA, the DIS badges and the reports are issued by the Medical Physics section at Dubai Hospital. DHA dose constraints are 3 mSv per year for the effective dose in DHA, and 120 mSv per year for the skin dose. This study is focusing on the effective whole body dose and its compliance with the international standards.

2. MATERIALS AND METHODS

The study was conducted using DIS (Direct Ion Storage). DIS dosimeters are used to measure the amount of energy deposited by ionizing radiation. DIS technology has high sensitivity, excellent linearity of response to personal dose with respect to radiation energy or dose. One important technical feature of the dosimeter is that its "instant reader capability". The Medical Physicist evaluate the measured personal dose on specific reader situations. This measurement used to estimate the effective dose received by the human body through exposure to external ionizing radiation (5).

Staff dosimetry measurement were performed from year of 2011 to 2015 for all Radiation workers in radiology, interventional radiology and nuclear medicine departments in 4 government hospitals and 28 primary health center in Dubai, United Arab Emirates.

All the radiation workers are monitored using personnel monitoring services as per statutory conditions. Radiation workers classified into four major groups and sub groups as following:

1- Doctors group: Radiology Doctors (Radiologists, OT doctors, Anaesthesia doctors, Vascular doctors) ,Cath lab Doctors, Nuclear Medicine Doctors
2- Nurses group: Radiology Nurses, Cath lab Nurses, Nuclear Medicine Nurses
3- Medical Physicists group
4- Radiographers and Nuclear Medicine Technicians

Table 1 shows the detailed classification and number of radiation workers working in different departments.

TABLE 1.Number of radiation workers monitored according to their speciality

No. of Staff	Doctor (Rad, OT, Anes, Vasc)	Doctor (Cath lab)	Doctor (NM)	Nurse (Rad)	Nurse (Cath lab)	Nurse (NM)	Medical Physicist	Radiographer	NM Technicians
2011	35	9	3	19	9	3	9	188	6
2012	35	10	3	15	9	3	9	191	5
2013	29	9	4	15	11	3	9	187	4
2014	21	8	3	19	8	3	4	193	6
2015	30	5	3	35	8	3	6	179	5

Occupational dosimetry readings taken every one-month for interventional radiology departments ,and every two months for all hospitals and PHCs (Primary Health Center) according to International and Federal regulations, the readings done onsite .Accumulated dose for each staff were calculated. Average doses for each group compared with international dose limit and DHA dose constraint.

3. RESULTS AND DISCUSSIONS

Occupational dosimetry results taken for radiation workers in Dubai health Authority for four major hospitals and twenty clinics in Dubai during 2011 to 2015. For the presentation and comparison of results, radiation workers classified into groups and sub groups as been explain in the previous paragraph.

The results of average accumulated dose for these groups from 2011 to 2015 are presented. As shown in Fig1, the accumulated dose range from 0.50 mSv to 0.57 mSv for radiology doctors, 0.59 mSv to 0.77 mSv for Cath lab doctors, 0.54 mSv to 0.66 mSv for Nuclear Medicine doctors. The maximum accumulated dose on 2015 for Cath lab doctors was 3.87% of dose limit for occupational exposure (20 mSv/year) and 25.8% of DHA dose constraint (3mSv/year). A decrease in the accumulated dose during 2011-2015 was observed.

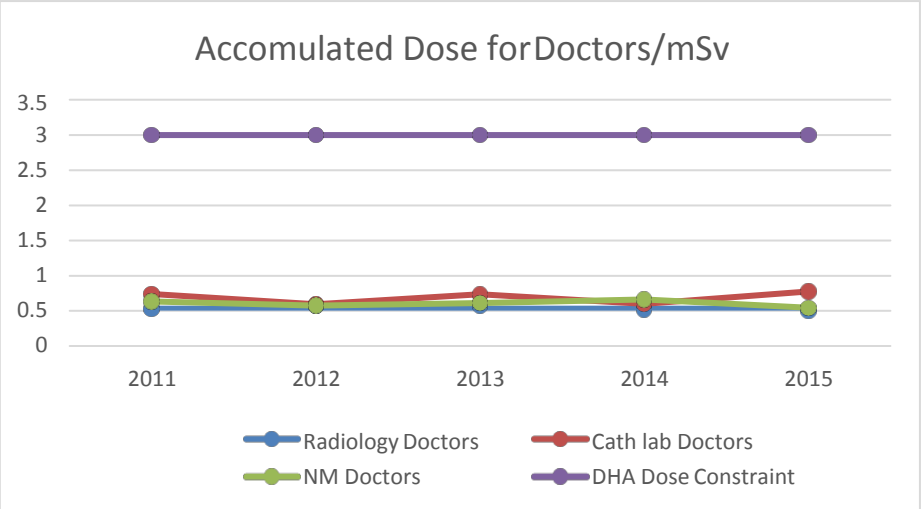

FIG 1: Accumulated dose for doctors

As shown on Fig2, the accumulated dose ranged from 0.55 mSv to 0.70 mSv for radiology nurses, 0.66 mSv to 1.15 mSv for Cath lab nurses. From Fig2, the accumulated dose for the Nuclear Medicine nurses shows a higher reading than the other groups, due to the handling of radioactive sources. The maximum accumulated dose on 2012 for Nuclear Medicine Nurses was 8.82% of dose limit for occupational exposure and 58.83% of DHA dose constraint.

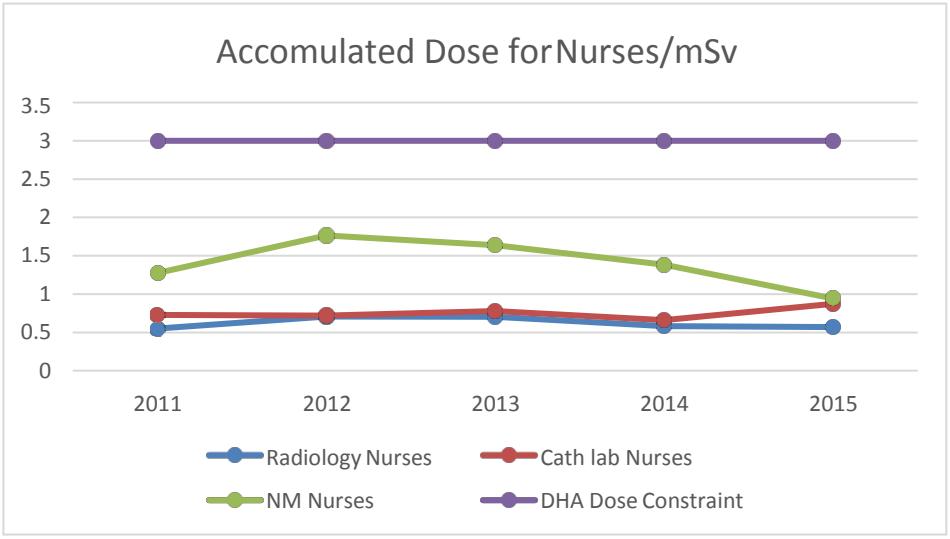

FIG2. Accumulated dose for Nurses

As shown in Fig3, the accumulated dose for Medical Physicists was range from 0.64 mSv to 0.83 mSv for the yyear of 2011 to 2015. Dose values reached the maximum on 2013 where the accumulated dose was 4.15% of dose limit for occupational exposure and 27.7% of DHA dose constraint.

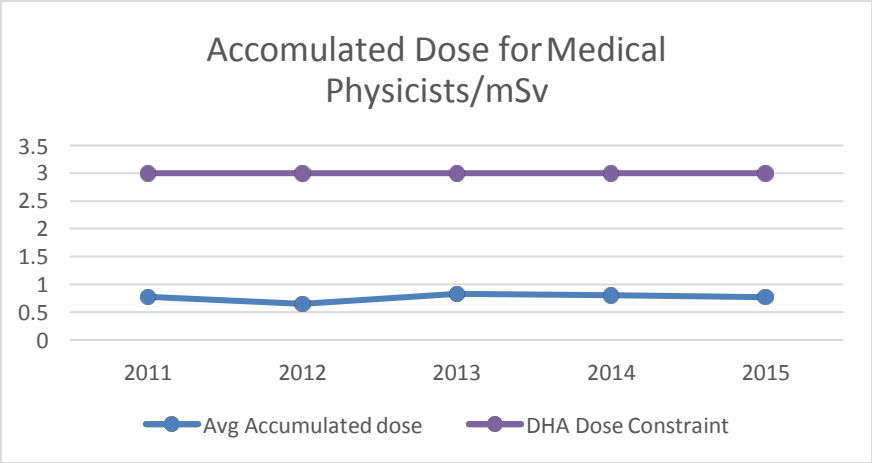

FIG3. Accumulated dose for Medical Physicists

As shown on Fig 4, the accumulated dose ranged from 0.55 mSv to 0.65 mSv and from 0.81 mSv to 1.16 mSv for radiographers and Nuclear Medicine Technologists respectively. Maximum dose values for radiographers was on 2011 was 3.28% of the dose limit and 21.9% of DHA dose constraint. Maximum accumulated dose for Nuclear Medicine Technicians was on 2013 with a value of 5.84% of the dose limit and 38.96% of DHA dose constraint.

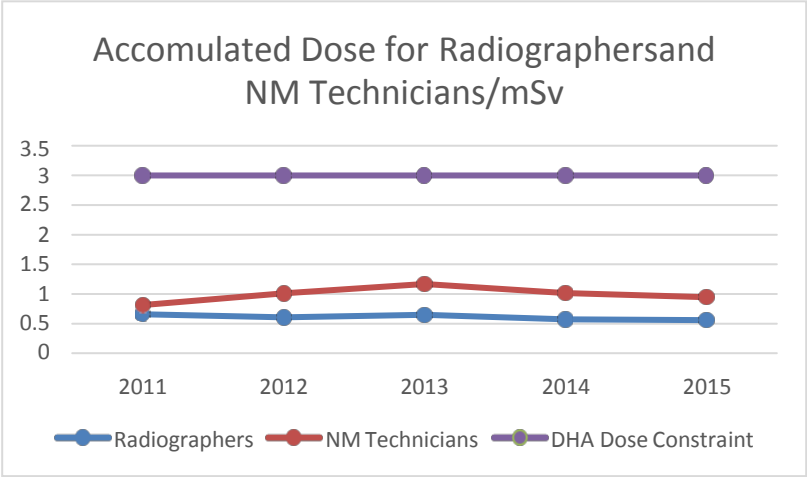

FIG4. Accumulated dose for Radiographers and Nuclear Medicine Technicians

Conclusions

Occupational dosimetry is important to assess the compliance with regulatory dose limits. Dosimetry results for medical staff in Dubai Health Authority been measured from 2011 to 2015. Values of accumulated doses calculated from monthly and bi monthly dosimetry results. Nuclear medicine staff received higher doses than Radiology staff by 43.02% due to handling radioactive sources and dealing with patients, but for both specialties, the values of accumulated doses were far below thank the international dose limits and local DHA dose constraints. This shows the good practice in DHA regarding radiation protection for staff, which is regulated by the Medical Physics section and local RPOs in the hospitals and clinics. Radiation protection practice enhanced by International and local training courses, educational program by Medical Physicists for doctors, radiographers, NM technicians and nurses. Further studies will carried for assessing occupation radiation doses to the skin and the lens of the eye, evaluating, and comparing doses from different procedures.

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ASSESSMENT OF OCCUPATIONAL EXPOSURE IN MEDICAL FACILITIES IN GHANA

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Abstract.

This study was undertaken at the Radiation Protection Institute of the Ghana Atomic Energy Commission. The study assesses the occupational radiation exposure for workers in medical facilities in Ghana for 10-year (2000-2009). RPI employs Harshaw 6600 Plus Automated TLD Reader system for monitoring whole-body by determine personal dose equivalent values Hp(0.07) and Hp(10). The study covers diagnostic radiology, radiotherapy and nuclear medicine facilities. Over the study period, number of medical facilities increased by 18.8 %, while the exposed workers decreased by 23.0 %. Average exposed worker per medical facility for the study was 4.3. Average dose per exposed worker was least in radiotherapy and highest in diagnostic radiology with values 0.14 mSv and 1.05 mSv respectively. Nuclear medicine however recorded average dose per worker of 0.72 mSv. Annual collective dose received by all the exposed workers reduced by a factor of 4 between 2000 and 2009. The highest and lowest annual collective dose of 601.2 and 142 man Sv were recorded in 2002 and 2009 respectively. Annual average values for dose per institution and exposed worker decreased by 79 % and 67.6 % between 2000 and 2009. Exposed workers in diagnostic radiology received the highest individual doses, with corresponding collective dose representing 96% of the total dose during the 10 years study period.

1.0 Introduction

The Radiation Protection Institute (RPI) of Ghana Atomic Energy Commission (GAEC) served as the agency responsible for operational functions of the Radiation Protection Board (now Nuclear Regulatory Authority). The RPB, was until January 2016 the body mandated by law as the national competent authority in the country with regulatory, monitoring and advisory responsibilities in matters pertaining to ionizing radiation [1, 2, 3, 4]. The RPI through the occupational radiation protection section monitors occupationally exposed workers (OEWs) in medical facilities in Ghana.

The RPI of GAEC has adopted, tried and tested, and is successfully using the IAEA's developed Dose Management System (DMS) as a tool to improve personnel and area monitoring in Ghana [6, 7, 8, 9]. For all justified practices that could involve occupational exposure, dose limits are imposed so that no exposed worker will be subject to an unacceptable risk attributable to the radiation exposure in medical facilities [10]. The dose limits were set and specified by the RPB with the backing of the LI 1559 to prevent the occurrence of deterministic effects and limit the probability of stochastic effects [11]. However, by international standards, the RPB was not effectively independent as required. Because of this, the Nuclear Regulatory Authority was established by Act 895 of 2015 through the country's radiation safety legislation to form an effective independent regulatory body and leading to a repeal of the LI 1559 of 1993 [4, 12]. This study assesses the occupational radiation exposure for workers in medical facilities in Ghana for a 10-year period(2000-2009).

2.0 Materials and Methods

The RPI employs an automated TLD processing service with manual data transfer system. Harshaw 6600 Plus Automated TLD Reader system [13] was used by RPI for whole body, extremity and environmental monitoring. The system offers 'one dosimetry solution' by its ability to monitor whole body (beta, photon and neutron), extremity and environmental exposure, with a single dosemeter. It is connected to an external personal computer (PC), and is operated through installed menu-driven WinREMS software. LiF-100 TLDs were used in monitoring whole-body occupational exposure by RPI. The TLDs were calibrated against ^{137}Cs source. Skin and deep exposure values (R_{skin} and R_{deep}) were generated by the TLD reader and manually entered into a Microsoft Excel spreadsheet to estimate the corresponding personal dose equivalent values Hp(0.07) and Hp(10) [6, 13, 14]. The estimated dose data were then transferred manually into the DMS, where they are stored.

The skin and deep doses are calculated from the personal dose equivalent expressions (1) and (2) [15].

$$\text{Skin dose: } Hp(0.07) = \left[\left(1.2958 \cdot R_{skin}\right) + 0.0097\right] \text{ mSv} \quad (1)$$

$$\text{Deep dose: } Hp(10) = \left[\left(1.3772 \cdot R_{deep}\right) + 0.0566\right] \text{ mSv} \quad (2)$$

4.0 Results and Discussions

4.1 Distribution of medical facilities monitored in Ghana

Medical facilities which employ the use of ionizing radiation for diagnostic and therapeutic purposes are widely circulated throughout the country. Each of the ten regions of Ghana has at least 4 medical facilities monitored by the RPI of the GAEC. Distribution of medical facilities monitored by the RPI on regional basis for the 10-year study period is shown in Table 1. Facilities in the Greater Accra Region alone make up ~ 32 % of monitored facilities countrywide. Out of the 58 monitored facilities in the Greater Accra Region, 52 are located in Accra, the capital city of Ghana. Two radiotherapy facilities are operational in the country and these are located in Kumasi and Accra, the regional capitals of the Ashanti and Greater Accra Regions respectively. A third radiotherapy facility is currently under construction in the Northern Region of the country. Only one nuclear medicine facility is operational and is located in the capital city on Ghana. A total of 180 medical facilities were monitored by the RPI in the 10-year period, and out of this ~ 98 % are diagnostic radiology facilities.

Table 1. Number of medical facilities monitored in Ghana on regional basis (2000 – 2009)

Region	Ashanti	Brong Ahafo	Central	Eastern	Greater Accra	Northern	Upper East	Upper West	Volta	Western
Diagnostic Radiology	23	11	12	19	56	8	4	4	21	19
Radiotherapy	1	0	0	0	1	0	0	0	0	0
Nuclear Medicine	0	0	0	0	1	0	0	0	0	0
Total	24	11	12	19	58	8	4	4	21	19

4.2 Monitoring of occupational exposure workers in medical facilities

The trend of monitored medical facilities and their corresponding OEWs is shown in Figure 1. The monitored medical facilities increased by 18.8 % while the exposed workers decreased by 23.0 % between 2000 and 2009. The average exposed worker per entire medical facility for the 10-year study period was 4.3. The highest 'exposed worker per institution' of 5.6 was recorded in 2000 and the least of 3.6 was recorded in 2009.

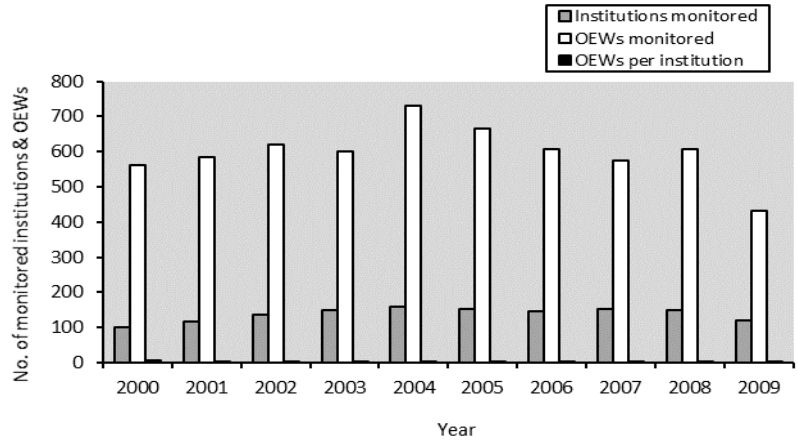

Figure 1. Number of monitored medical facilities and corresponding OEWs

This is a result of an observable increase in the number of monitored medical facilities as against a corresponding decrease in the number of exposed workers for the 10-year period. Although monitored diagnostic facilities increased in number over the 10-year period from 98 to 117, the number of exposed workers reduced by a factor of 1.5 in the same period. Diagnostic radiology facilities monitored by the RPI have consistently dominated over the radiotherapy and nuclear medicine facilities since 2000. Average 'exposed worker per facility' is however least in the diagnostic radiology subsector. Average 'exposed worker per facility' in the diagnostic radiology, radiotherapy and nuclear medicine facilities were 3.8, 37.4 and 8.7 respectively. This observation is indicative of the workloads in the three subsectors of the medical sector. Clearly, the workload in the radiotherapy facility far outweighs that of the diagnostic radiology facility and hence this observation. A plot of 'exposed worker per facility' for the three subsectors is shown in Figure 2. In the radiotherapy subsector

'exposed worker per facility' increased by 108 % from 2000 to 2009, while a decrease of 45 % and 46 % was recorded in the diagnostic radiology and nuclear medicine subsectors respectively.

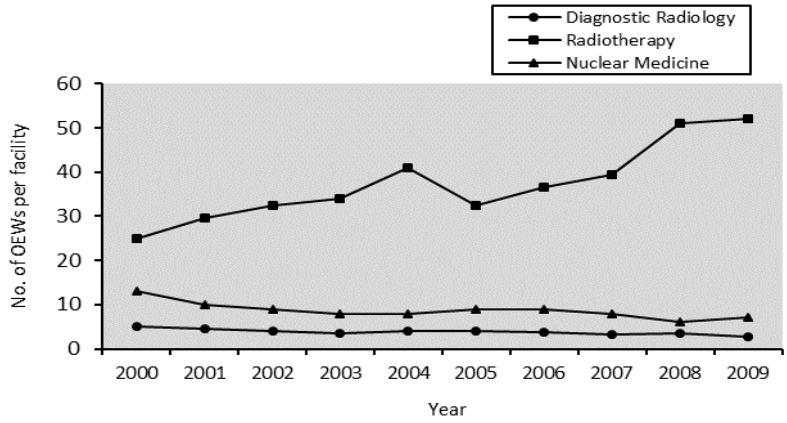

Figure 2. Exposed worker per medical facility (2000 – 2009)

4.3 Occupational dosimetry in medical practice

The annual collective dose received by exposed workers in the medical institution in Ghana reduced by a factor of 4 between 2000 and 2009. Maximum annual collective dose of 601.2 man mSv for the 10-y study period was recorded in 2002 and a minimum of 142.6 man mSv was recorded in 2009. Annual average dose per medical institution decreased by 79 % from a value of 5.7 in 2000 to 1.19 in 2009. The annual average dose per exposed worker in the medical institution also followed a similar trend with a 67.6 % reduction in value from 2000 to 2009. The dose per exposed worker and dose per facility for the three categories are shown in Figures 2 and 3, respectively.

Annual collective dose in the diagnostic radiology decreased from 546.2 man mSv in 2000 to 132.4 man mSv in 2009, which shows ~76 % fall in annual collective dose during the 10-y study period. The highest dose of 580.9 man mSv was recorded in 2002. The radiotherapy and nuclear medicine facilities also showed reduction in collective doses by ~72 and ~55 %, respectively from 2000 to 2009. Highest annual collective dose in the two categories were however recorded in the year 2000.

Average dose per exposed worker in all medical facilities showed reduction over the study period. This observation may be the result of decreased workload or observation of proper radiation protection protocols [15]. Figure 2 shows that the average dose per exposed worker was consistently low in radiotherapy when compared with the other facilities in each year. This observation is confirmed in Table 1, which shows average dose per worker values (for the 10-y period) of 1.05, 0.14 and 0.72 mSv in the diagnostic radiology, radiotherapy and nuclear medicine facilities, respectively. Average effective dose within the diagnostic radiology, radiotherapy and nuclear medicine facilities varied in the range 0.328–2.614, 0.383–0.728 and 0.448–0.695 mSv, respectively.

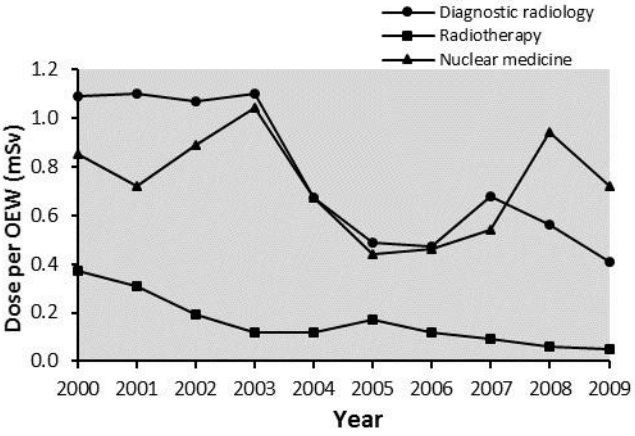

Fig. 2: Average dose per exposed worker in medical sector

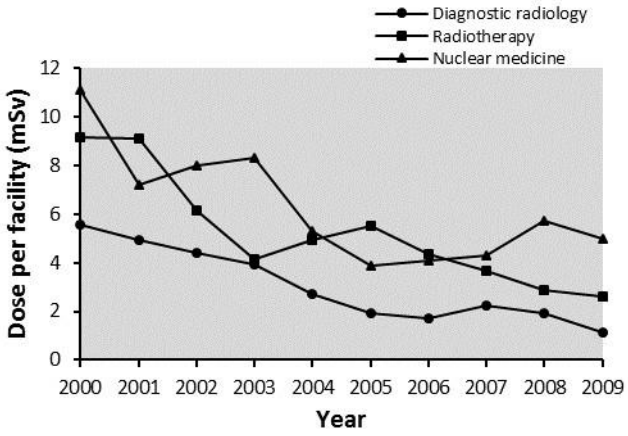

Fig. 3: Average dose per medical facility

Nuclear medicine recorded the highest 'dose per facility' throughout the study period, except for the years 2001, 2005 and 2006, whilst diagnostic radiology consistently recorded the least in the study period. In the first year, 'dose per facility' value of 11.1 mSv was recorded in nuclear medicine as against 5.57 mSv in diagnostic

radiology, while the last year of the study period recorded 'dose per facility' value of 5.0 mSv in nuclear medicine as against 1.13 mSv in the diagnostic radiology.

Diagnostic radiology practice recorded most of the individual doses > 1 mSv. For all individual doses > 1 mSv, ~97 % were in diagnostic radiology. The highest individual dose in radiology was 31.76 mSv, recorded in a period of 17 months. In radiotherapy, an individual dose of 59.5 mSv was also recorded in a period of 5 months in the year 2001. No reasons were given for this observation but it is believed the TLD of the personnel might have been left in a treatment room for a long period. Subsequently, monthly dose records of the personnel were observed to have shown continuous reduction to levels below 1 mSv.

Table 1: Summary of dose data for occupational radiation exposure in medical practice (2000-09)

Medical facility	Average effective dose (mSv)		Total collective dose (man mSv)	Monitored medical facilities	Workers receiving doses	Average dose per medical institution (mSv)	Average dose per exposed worker (mSv)
	Min	Max					
Diagnostic radiology	0.328	2.614	3981.0	1353	5152	2.94	1.05
Radiotherapy	0.383	0.728	105.0	20	747	5.24	0.14
Nuclear medicine	0.448	0.695	62.9	10	87	6.30	0.72
All categories	0.328	2.614	4148.9	1383	5986	3.00	0.69

5.0 Conclusion

The overall collective dose of occupational exposure in medical facilities for the study period was estimated to be 4148.9 man mSv, with corresponding average dose per exposed worker of 0.69 mSv. Collective doses in each of diagnostic radiology, radiotherapy and nuclear medicine facilities reduced between 2000 and 2009, an indication that there could be further reduction in subsequent years. This observation could be a result of improvement in radiation protection protocols in the respective facilities. Exposed workers in diagnostic radiology received the highest individual doses. Correspondingly, collective dose in diagnostic radiology represented ~ 96 % of the total collective dose during the period. Approximately 12 % of all annual doses were individual doses > 1 mSv. Average doses per the medical institution and exposed workers were 3 and 0.69 mSv respectively in the entire survey period. Generally, the individual doses also showed reduction with time.

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CHALLENGES IN THE RADIATION DOSE MANAGEMENT OF THE MEDICAL STAFF:
5 years (2012-2016) using a new software tool for the control of doses above the investigation level

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Abstract

The present study attempts a first analysis of the results of the investigation procedure that is performed within EEAE's dose management programme. More specifically, the paper is focused on the investigation of the doses received by the medical staff who is the vast majority of the occupationally exposed workers in Greece. The national dose registry –being part of the radiation protection database developed in EEAE - has been proved a powerful tool that enabled such a procedure. Since 2012 specific queries have been designed for this objective and the investigation is carried out on monthly basis. From the analysis, it is shown that during the last five years, there has been a significant decrease in the number of the cases exceeding the investigation level of 6 mSv. The decreasing trend is attributed to the persistent and immediate interaction of EEAE with the staff of the facilities through the investigation procedure.

1. INTRODUCTION

Greek Atomic Energy Commission, EEAE, is the national regulatory authority for radiation safety having as one of its mandates to keep the National Radiation Protection Database (NRPD), where all information related to radiation sources, facilities and personnel is kept. Part of the NRPD is the National Dose Registry (NDR) for the workers occupationally exposed to ionising radiation. The NDR has been designed in the 90's and then amended according to the requirements of the Technical Recommendations for Monitoring Individuals Occupationally Exposed Workers [1].

The NDR contains all the relevant data in electronic form since 1989 about the occupationally exposed personnel. The registry uses a two-level classification for the workers – occupational category and working category and two-level classification for the employer – establishment characterization and laboratory categorization. A number of 11500 workers are monitored using TL dosimeters in 1400 facilities. The 95% of those workers belong to the medical staff. From these a small percent (almost 12%) receive doses higher than the reporting level.

According to the Greek radiation protection regulations [2] an investigation shall be carried out if the effective dose received by the exposed worker exceeds the level of 6 mSv. A relevant report is drafted with the results of the investigation. EEAE has set up a systematic procedure of this investigation since 2012. In the present study an analysis of the results of these investigations in national level is performed.

2. DESCRIPTION OF DOSE MANAGEMENT PROCEDURE

The NDR information system features multiple security levels and is based on a double redundant INGRES relational database system. It is accessible via the intranet from secured internet. Only the personnel responsible from the IT department and the personnel responsible for the NDR have access to the NDR in different levels. Backup of the database is performed on a daily, weekly and monthlybasis.

Within the NDR there is a connection of the exposed worker, the facility he/she works in and the local Radiation Protection Officer (RPO), the indication of the personal dosimeter and the corresponding monitoring period, the occupational category and the working category. Special queries have been designed that combine data from different levels from NDR and NRPR. These queries are able to check the overexposures of workers who have reached or surpassed the investigation level (6 mSv) for whole body doses. Moreover, using the data from

the national dose registry the number of workers who have reached the dose limit of 20 and 50 mSv per year, as well as the 100 mSv for 5 consecutive years are investigated. The same procedure is performed for workers who have reached the limit for the extremities. The procedure is performed every month after NDR is updated with the latest results of individual monitoring.

After identifying the above mentioned cases investigations letters are drafted and sent to the RPOs of the facilities. The letters include questionnaires according to the situation and are related to: changes of the type of work with ionizing radiation, changes in the workload, use of radiation protection measures, position where the personal dosimeters are worn, indications of the active personal dosimeter –if used- management of the personal dosimeters. When no answer is received to the above questionnaires EEAE keeps on sending reminders and an unexpected inspection can be performed to the specific facility. Otherwise, the results of the questionnaires are registered and possible consultation with the RPO, or the worker, is foreseen in the management procedure.

3. RESULTS OF 5 YEARS (2012-2016) INVESTIGATION PROCEDURE

In Figure 1 the total number of cases that were investigated is shown for the whole body dosimeters as well as for the extremities. From the figure it is shown that there is a decreasing trend of the cases that have been investigated over the last five years. This trend can be explained by the persistent and immediate interaction of EEAE with the RPOs and the staff of the radiation facilities.

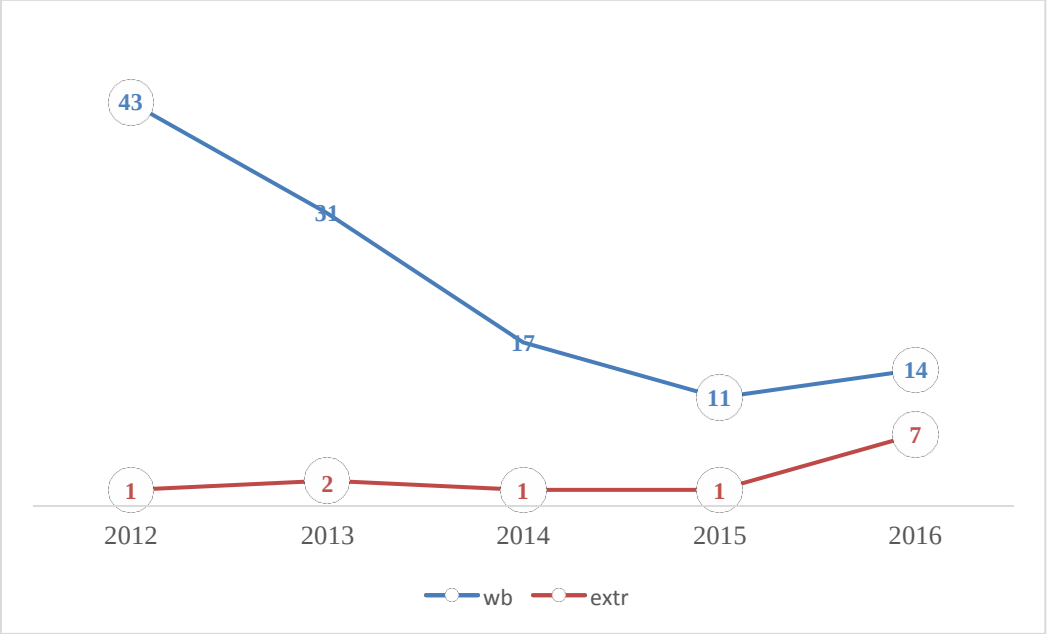

FIG.1. Number of investigation cases for the five year period 2012-2016

In figure 2 the total number of investigation cases for the whole body and extremity dosimeters per occupational category is shown. From the figure it is shown that the technologists and physicians are the categories with the majority of the investigation cases which is due to the higher workload, their proximity to the primary beam and the scattered radiation received by the patient.

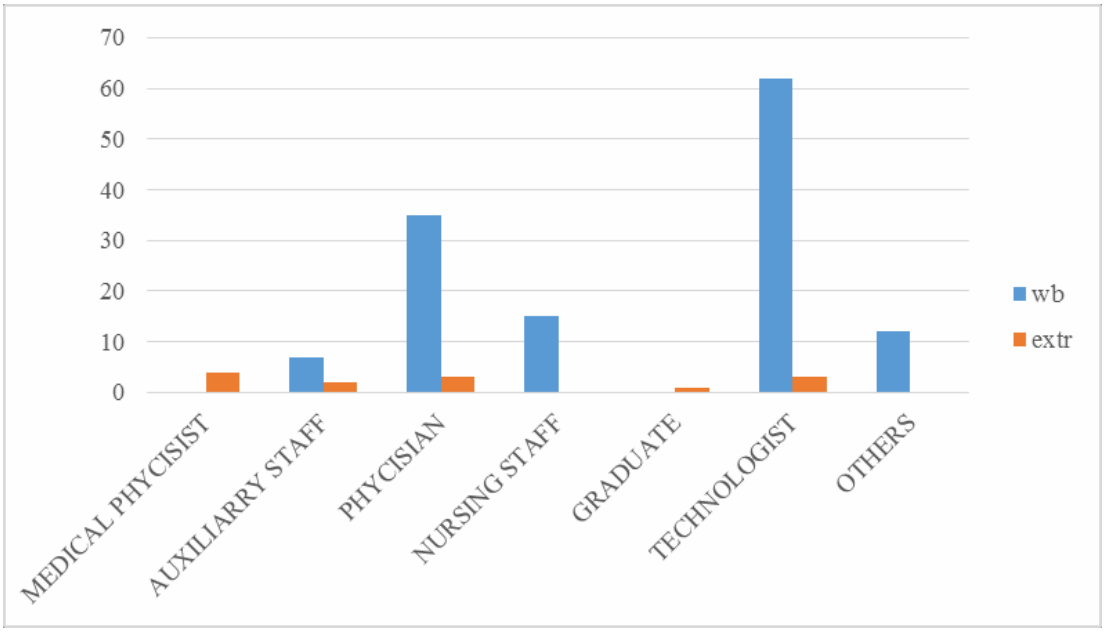

FIG. 2 Number of investigation cases for five years (2012-2016) per occupational category

Finally in figure 3 the total number of investigation cases is shown for the whole body and extremity cases per working category. In this figure it is shown that the majority of cases belong to the general radiology. It should be noticed within this term some interventional procedures performed outside the radiology departments which explains the increased number of investigations. Moreover, in the same graph it is shown that the workplaces of nuclear medicine, interventional cardiology and radiology are associated with possible overexposures. Finally, it is noted that the investigation cases related to overexposure belong to the nuclear medicine sector.

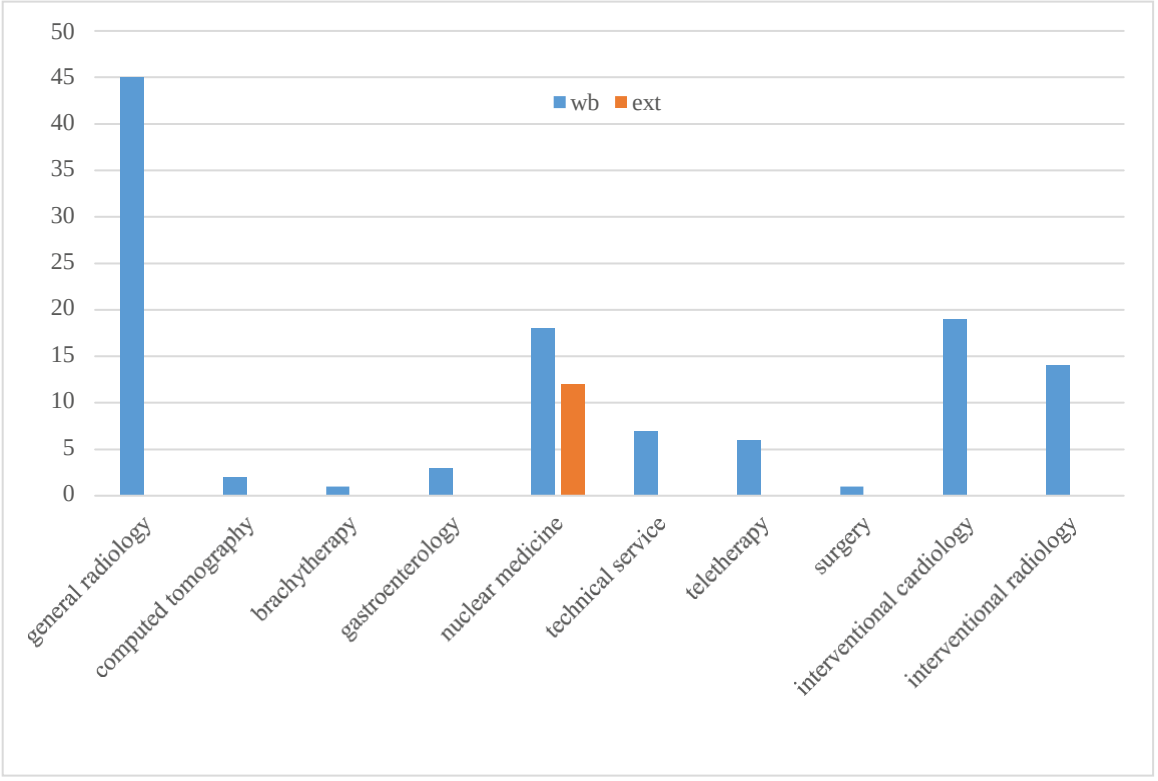

FIG. 3 Number of investigation cases for five years (2012-2016) per working category

4. DISCUSSION

The national central register is a powerful tool for continuously monitoring and evaluation the implementation of the national radiation protection programme. Such situations were identified by EEAE using special designed queries in the medical sector and treated accordingly. The result of this management procedure is the decreasing number of investigated cases related to the persistent and immediate interaction of EEAE with the RPOs and the staff of the radiation facilities.

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JUSTIFICATION AND OPTIMIZATION IN DIAGNOSTIC RADIOLOGY. OVERVIEW OF ROMANIAN ISSUES

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Abstract

The development of telemedicine has changed the way justification of individual medical exposures is being done. Often the direct interference between the practitioner (radiologist) and the patient, the benefit/risk – dialogue with patients, are missing. Also the evaluation and traceability of the referrals are difficult to achieve. In the last years, most of young medical physicists have chosen radiotherapy or nuclear medicine departments. The small number of medical physicists working in diagnostic radiology makes it difficult to ensure QA-system and QC. So optimization process can't be effective. The medical staff only can't implement DRL's and to use them as optimization tool. Based on these facts, Regulatory Body faces a lot of challenges.

1.JUSTIFICATION

In the last few years, the number of diagnostic radiology laboratories in Romania has increased. It has been a tremendous development but in the same time we have seen growth in high-dose radiation procedures and increase of individual patient doses from diagnostic examinations.

Most of the new laboratories are outpatient clinics and many are equipped with high-dose radiological equipment (CT). But there aren't enough radiologists in the country so they frequently use telemedicine. That means the radiologist could be at hundreds kilometers away. He can't see the patient, he can't evaluate the request, he can't decide the procedure, etc. He would only see the images and give the result.

The patient-related activities are done by a radiographer or a technologist. This person is not in position to discuss the correctness of the referrals, besides the fact that there aren't any national referral guidelines in place. Just a few hospitals have implemented algorithms for their prescriptions and referrals, but only as local rules.

Even though generic justification exists, justification of individual exposure can't really be performed. The justification process should be completed prior to the exposure taking place. But if there is no interaction between the radiologist and the patient, the following aspects can't be achieved:

The benefit/risk – dialogue with the patient (pre-examination interview);

Individual characteristics of the patient and evaluation of previous diagnostic information (pre-examination interview);

Change of information with the referring practitioner in order to clarify or change the investigation;

Request evaluation and final decision of the appropriate imaging procedure, changing the referred examination or refusing it.

As regulatory body, we need to improve the regulatory framework, including more specified requirements for the justification process. It is also necessary to define clear responsibilities for the justification process. If the practitioner (radiologist) may not be able to evaluate each patient or procedure, the tasks (not the responsibility) could be delegated but only under certain legal conditions.

2.OPTIMIZATION

Another problem we are facing is the absence of medical physicists in diagnostic radiology. In the last years, most graduates chose to work in radiotherapy or nuclear medicine departments. They consider these areas more

"spectacular" and more "important". Moreover, their presence in these domains is mandatory for the authorization process, contrary to diagnostic radiology. For example, at the end of 2016 there were 95 medical physicists in radiotherapy and nuclear medicine, but only 38 medical physicists in diagnostic radiology. On the other hand, the number of diagnostic radiology departments is several times greater than the former ones.

Their absence in diagnostic radiology means lack of quality control and quality assurance, so the optimization, as requested by BSS Req.38, can't be fulfilled. The dosimetry of the patients must be performed by or under supervision of medical physicist. Dosimetry is performed for guidance levels – optimization (including DRLs) and also for equipment performance testing. The medical staff only can't implement DRL's and use them as an optimization tool and does not have the necessary knowledge for performing patient dosimetry or equipment performance assessment.

3. CONCLUSION

Based on these facts, Regulatory Body faces a lot of challenges in the near future:

To develop the requirements for the justification process (including for individual justification), keeping in mind the current situation of Romania:

- To inspect the justification process in order to ensure compliance with legal provisions;
- To coordinate the issuing of the national referral guidelines;
- To encourage and support, by regulatory requirements, the hiring of medical physicists in all diagnostic radiology departments.

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THE EVALUATION OF MEDICAL EXPOSURES IN THE CZECH REPUBLIC

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Abstract

The paper is giving an overview of the evolution of medical exposures assessment in the Czech Republic during last decades. The collection and evaluation of data is based on the co-operation with health insurance companies, the Institute of Health Information and Statistics under the Ministry of Health, National Radiation Protection Institute, professional medical societies and selected medical facilities or experts in the field. The description of data collection, their structure and validity is described. The basic results of data evaluation are presented including the trends in number of examinations and age and sex distribution.

Although the numbers of examinations are growing it is also necessary to take into account in their evaluation such aspects as the changes of population curves. This could be illustrated by relationship of number of examination performed in specified age groups and number of persons in these age groups for certain year. Presented data clearly shows that the structure of examinations and treatments carried out is changing and the number of examinations and treatments associated with higher patients' doses is growing. But it cannot be considered as definitely negative phenomenon. Increasing number of sources and procedures with ionizing radiation is undoubtedly associated also with increasing quality of medical care where obtaining of better diagnostic information or possibility of performing some therapy has positive benefits for the patient. This must be also taken into account when evaluating data and all related aspects should be taken into account. The central registration system created by State Office for Nuclear Safety which includes also register of radiation sources and doses of workers enable to perform very sophisticated and detailed analyses leading to valid and interesting results.

1. INTRODUCTION

The beginning of assessment of population exposure from medical examination in the Czech Republic falls into 1980s when the first results of medical exposure evaluation in the Czechoslovakia were presented [1].

In the 1990s, further evaluations were conducted in this area and efforts have been made to develop a complex system of national records of numbers, sex and age distribution and doses of persons undergoing X-ray diagnostic and nuclear medicine examinations with the aim to ensure regular and consistent monitoring and evaluation of medical exposures on the national level. The State Office for Nuclear Safety (SÚJB) initiated a co-operation with the General Health Insurance Company (VZP) and based on the data provided the Central Database of Medical Exposures (CDME) has been created. VZP is major health insurance company in the Czech Republic covering about 60% of insured persons. Data provided by VZP enable to determine sex and age distribution of individual types of examinations performed in X-ray diagnostics and nuclear medicine. In addition, for nuclear medicine, an amount of administered radiopharmaceuticals is registered for each examination. Data in relation to persons and workplaces are anonymous. These activities have been followed up in the next decade by other projects focused mainly to investigations of doses for X-ray diagnostics, nuclear medicine and radiotherapy and further refine the processing of the collected data. Some data were verified directly at selected medical facilities and correlated also to data held by the Institute of Health Information and Statistics under the Ministry of Health (ÚZIS) with the aim to obtain more accurate data for estimation of patient doses.

In recent years several population dose surveys were performed in specific imaging modalities and results were used for reporting to DOSE DATAMED project and UNSCEAR.

Currently, the possibility of data collection is expanding and, based on the new Atomic Law [2], health insurance companies (Table 1) shall provide SÚJB upon the request with information related to medical exposure in the content and format specified in new Decree on Radiation Protection [3].

TABLE 1 THE LIST OF HEALTH INSURANCE COMPANIES

Health Insurance Company	Number of insured persons (2014)
General Health Insurance Company	5 946 000 (57%)
Health Insurance Company of the Ministry of the Interior	1 242 000 (12%)
Czech Industrial Health Insurance Company	1 208 000
Branch Health Insurance Company for Employees of Banks, Insurance and Construction	736 000

Military Health Insurance Company of the Czech Republic	709 000
The Fraternal Brotherhood Cashier	431 000
Škoda Employee Insurance Company	140 000
TOTAL	10 412 000

TABLE 2 FORMAT OF DATA REQUESTED [3]

X- Ray Radiology, Radiotherapy	Nuclear Medicine – with IVLP
Coded number of medical provider	Pointer to performance table
District in which the medical provider is located	Coded number of medical provider
Coded (parent) number of examined person	District in which the medical provider is located
Year of birth of examined person	Coded (parent) number of examined person
Month of birth of examined person	Year of birth of examined person
Sex of examined person	Month of birth of examined person
Code of medical specialization	Sex of examined person
Performance code	Code of medical specialization
Diagnosis	Drug Code (IVLP)
Date of examination	Date of examination
Number of examinations carried out	The amount of radiopharmaceuticals administered

2. METHODS

The data from the VZP for the period 2009-2015 were processed and particular trends were estimated for X-ray diagnostics, nuclear medicine and radiotherapy. Specific examination groups with subgroups were created in order to assess trends in the frequency in particular categories of examination (Table 3).

TABLE 3 EXAMINATION CATEGORIES

Examination category	Subgroup
Radiography (without contrast)	Head, Neck, Chest/Thorax, Thoracic Spine, Shoulder, Lumbar Spine, Lumbo-Sacral Joint, Abdomen, Pelvis and Hips, Limbs and Joints, Whole Spine
Mammography	Mammography, Mammography Screening
Dental	Intraoral, Panoramic
Radiography (with contrast)+ Fluoroscopy	Gastrointestinal Tract, Biliary Tract, Uro-genital tract, Myelography, Arthrography, Fluoroscopy
Angiography	Cerebral, Cardiac, Thoracic, Abdominal, Pelvic, Peripheral; Lymphangiography
CT examination	Head, Neck, Chest, Lumbar Spine, Abdomen, Liver, Pancreas, Kidneys, Pelvis Full spine, Trunk, Limbs
PTCA	PTCA
Image guided interventions	Cerebral, Chest, Thoracic, Abdomen Intervention, PTA, Stenting, Dilatation, Fibrinolysis, Biopsy, Drainage, Embolization, Vertebroplasty

The data are absolute number of examinations/procedures performed in a year and consequently they were correlated to 1000 examined patients in each age category.

3. DATA ANALYSIS

The relationship between the population curve and the increase of the examinations in the relevant age category is interesting. This manifests two significant population booms - shortly after the Second World War, and at the beginning of the 1970s. The increase in numbers in these age categories is evident and it is also projected in the increase of absolute number of examinations while the relative number of examinations does not change so much.

X ray radiology

Total number of X-ray examinations is increasing. An illustration of the trend can be seen on Fig.1.

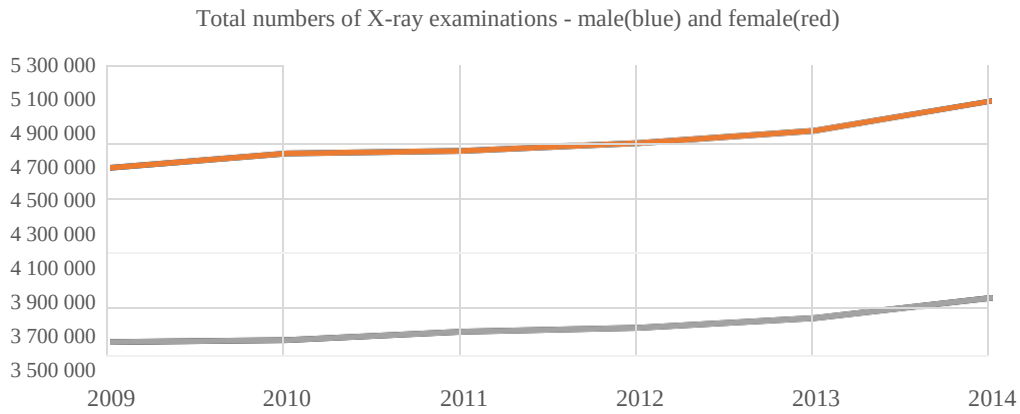

FIG. 1. Graphs showing the tendency in X-ray examination numbers for years 2009-2014

A significant increase is evident in **mammography screening examinations -** an increase about 48% (Fig.2.), while a decrease 47% has been observed for non-screening mammography examinations (Fig.3.). This is mainly due to established and well-organized mammography screening program which was fully implemented towards the end of the first decade of the 21st century.

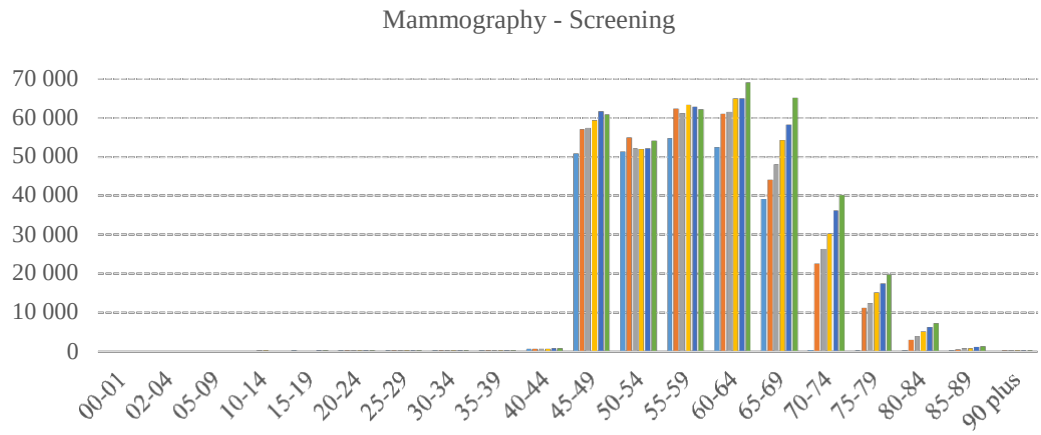

FIG.2. Bar chart presenting an increase of mammography screening examinations for age groups in the years 2009-2014

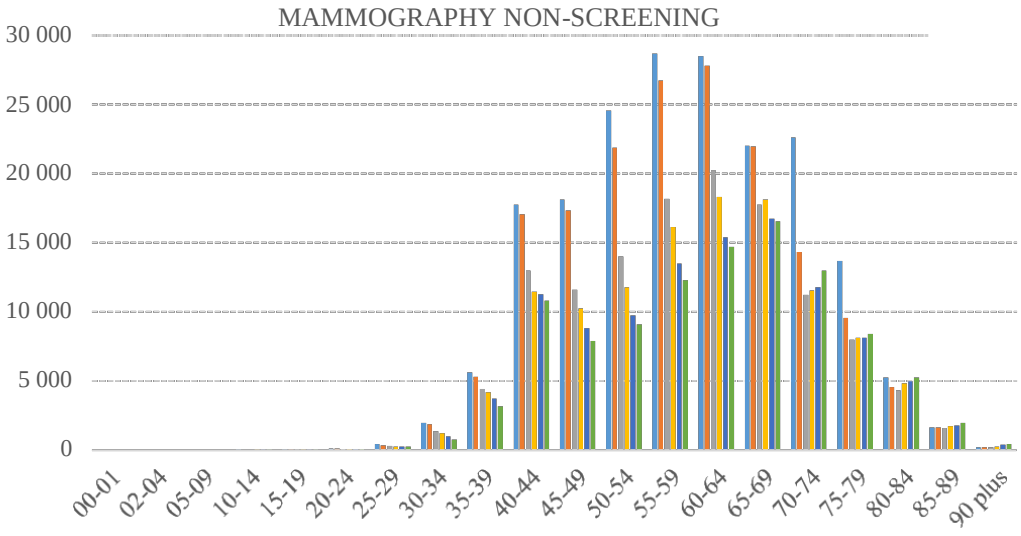

FIG. 3. Bar chart presenting a decrease of mammography non-screening examinations for age groups in the years 2009-2014

CT examinations are increasing constantly, about 17% more examinations were performed in 2015 compared to 2009. However if we compare an increase of examinations for one age category (65-69 men, years 2009-2015) which is 44% to the data related to 1000 of members of population in this groups, the increase is much more lower, only 8%. This is well illustrated in the poster.

The number of radiography examinations without contrast media remained approximately the same. Number of fluoroscopy and radiography examinations with contrast media is growing similarly to CT examinations, but the absolute number of these examinations represents only about quarter of CT examinations and about 3% of all X- ray examinations.

PTCA procedures fluctuates ± 2.5% (men) and are decreasing about 15% (women); similar trend is observed in angiography procedures, fluctuation ± 2.8% (men) and decrease about 10% (women). Number of image guided procedures for both categories does not show any significant trend.

Dental examinations are growing continuously and in 2015 there was about 40% more examinations compared to 2009.

3.1. Radiotherapy

In the external radiotherapy, the trends are similar for both categories (men/women) and the total number of procedures increased during 6 years about 10% compared to the year 2009.

In brachytherapy, the number of procedures fluctuated a lot. The maximum was in 2011-2012 (men) - an increase compared to year 2009 was almost triple and since that time the number of procedures decreases. Interesting is the tendency in category women - the decrease is obvious. In the year 2015 the number of procedures was about 25% lower than 6 years ago.

3.2. Nuclear medicine

In the diagnostic area it is observed a significant decrease in SPECT examinations - almost 10% for all age groups except the 65-69 and 70-74 age categories. On the other hand a dramatic jump was in PET examinations, whose number increased nearly 3 times. If we look at the absolute number of examinations/procedures for both categories we can say that the increase in PET examinations does not compensate the decrease in SPECT examinations. In radiotherapy, number of nuclear medicine treatments fluctuates with a rising trend.

Radiotherapy procedures in nuclear medicine show increasing trend in both categories about 23% in total.

4. FURTHER INFORMATION

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COMPARISON OF EFFECTIVE DOSE RECEIVED BY ADULT PATIENTS WHO UNDERWENT CHEST CT SCAN USING EITHER 64- OR 256-MULTISLICE CT (MSCT) IN ST. LUKE'S MEDICAL CENTER - QC

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Abstract

OBJECTIVE: To compare the effective dose received by patients who underwent Chest CT scan using either 64-or 256- MSCT METHODOLOGY: A cross-sectional study of patients who underwent 64- or 256-MSCT chest from January 1, 2014- May 31, 2017 was done. The age, sex, BMI, chest scan procedure, $CTDI_{vol}$ and DLP were collected. Primary outcome is mean effective dose. RESULT: There is significant difference between the mean effective dose received from plain and contrast CT using the 64-MSCT (349.750±177.686, p=0.03) and 256-MSCT (262.078±102.702, p=0.03). A significant difference is seen between the mean effective dose from plain and contrast HRCT using 64-MSCT (582.277±180.20, p <0.0001) and 256-MSCT (299.600±171.33, <0.0001) CONCLUSION: Lower mean effective dose was received from plain and contrast chest CT; and HRCT with contrast procedures using the 256-MSCT as compared to 64-MSCT.

1. INTRODUCTION

Over the past few years, the use of radiation in the medical field has become more common. In the United States alone, in 2007, >70 million CT scans were performed [1]. Through these chest CT scans, the diagnosis of pulmonary chest disease, coronary artery disease, infectious diseases and mediastinal tumors, to name a few are identified and proper management can be given. We are aware however that medical exposure to ionizing radiation from CT scans likewise have its adverse effects that may lead to DNA damage and eventually to cellular loss of function, necrosis or malignancy [1]. There is therefore a need to be able to quantify the amount of radiation received by patients who undergo chest CT scans in accordance to the principle of As Low As Reasonably Achievable (ALARA).

For this study, Effective dose, which is an estimate of the amount of whole-body radiation equivalent to a partial body exposure, will be computed and compared among the multislice chest scans. Effective dose is used because it allows comparison across the different types of CT studies as well as between CT and other imaging tests. It accounts for the amount of radiation to the exposed organs and each organ's sensitivity to developing cancer from radiation exposure [2]. This study will determine the amount of effective dose that is absorbed in the lungs, thyroid, breast and bone marrow, as these are organs exposed when one takes a chest CT scan.Currently, there are relatively few data describing how much radiation is received by each patient when they are exposed through the most common types of chest CT exams used in clinical practice. Computed tomographic coronary angiography is the only exam that has been studied in detail. [2]. Our study aims to estimate how much radiation is received by a patient who undergoes a chest CT scan (plain, plain and contrast and high resolution CT plain and contrast).

2. METHODS

This is a hospital based cross-sectional study conducted at St. Luke's Medical Center Quezon City among adult patients who underwent the different chest CT scans (plain, plain and contrast, and HRCT plain

and contrast) from January 1, 2014 to May 31, 2017. Systematic random sampling was used for this study. Inclusion criteria included all patients who underwent the abovementioned chest CT scans in the said period. Exclusion criteria included were chest CT scans that had no dose information (missing dose parameter) and chest CT scan combined with other CT scan examination (another part of the body except the chest). Two scanners were included in the study, namely the Philips Brilliance 64-multislice and Philips iCT 256-multislice CT scanner, manufactured in Cleveland, Ohio, USA and in 2005 and 2009, respectively.

The patient's data regarding the age, sex, BMI, type of chest CT scan procedure, $CTDI_{vol}$ and DLP were taken from the patient's records as well as the dose summary from each scan included.

2.1 Outcome Measure, Sample Size and Data Analysis

The Mean Effective Dose for different chest CT scan procedures was determined. According to the study of Christner et al, 2010, the following formula will be used to compute for effective dose. Using DLP and k Coefficients From the European Guidelines, DLP is defined as the product of the volume CTDI and the irradiated scan length. DLP = $CTDI_{vol}$ × irradiated length, where $CTDI_{vol}$ is the volume CTDI. The shortcut method for effective dose is calculated as follows: E = k × DLP, where the k coefficient is specific only to the anatomic region scanned.For the study, the shortcut method was used. DLP was added for each study to obtain the total DLP and the k coefficient was multiplied to the anatomic region involved (thyroid, breast, lung and bone marrow). Using the study of Sabarudin, et al, as reference [3], atleast 20 subjects who underwent each type of chest CT scan procedure (plain, plain and contrast and plain and contrast HRCT) for each type of multislice CT scanner (64 slice and 256 slice) is needed. Therefore, 120 Chest CT scan is the minimum computed sample size.

Data were encoded and tallied in SPSS version 10 for windows. Descriptive statistics were generated for all variables. For nominal data frequencies and percentages were computed. For numerical data, mean ± SD were generated. Analysis of the different variables was done using the following test statistics: T-test – used to compare two groups with numerical data, Mann Whitney U test – non-parametric equivalent of t-test and Chi-square test - used to compare/associate nominal (categorical)data

3. RESULTS

A total of 211 subjects were included in the study, 112 underwent the 64 slice CT scan while 99 underwent 256 slice CT scan. Table 1 shows that there is no significant difference between the age, sex and BMI of the patients who underwent plain chest CT scan using the 64 slice and 256 slice scanner. It also shows there is no significant difference between the CT parameters of 64 slice CT and 256 slice CT scan except for the CTDI of surview and CTDI plain and DLP surview. Table 1 shows the comparison of the demographic characteristics, CTDI and DLP between the 64-MSCT plain chest CT scan and 256-MSCT plain chest CT scan.

TABLE 1. COMPARISON OF DEMOGRAPHIC CHARACTERISTICS, CTDI AND DLP BETWEEN 64-MSCT PLAIN CHEST CT SCAN AND 256- MSCT PLAIN CHEST CT SCAN

	64 Plain (n=36)	**256 Plain** (n=36)	***p-value**
Age (in years) Mean ± SD	52.19 ± 11.63	50.33 ± 11.25	0.49 (NS)
Sex			
Male	20 (55.6%)	16 (44.4%)	0.35 (NS)
Female	16 (44.4%)	20 (55.6%)	
BMI			
Normal	20 (55.6%)	20 (55.6%)	1.00 (NS)
Obese	16 (44.4%)	16 (44.4%)	
CTDI Surview	0.076 ± 0.016	0.044 ± 0.021	<0.0001 (S)
CTDI Plain	8.375 ± 5.237	6.209 ± 2.621	0.02 (S)
CTDI Total	8.176 ± 5.405	6.526 ± 2.465	0.45 (NS)
DLP Surview	2.467 ± 0.489	1.561 ± 0.696	<0.0001 (S)
DLP Plain	324.642 ± 207.008 (246)	244.172 ± 95.408 (223)	0.22 (NS)
DLP Total	326.722 ± 206.938 (246)	256.00 ± 87.455 (226)	0.36 (NS)

** p>0.05- Not significant; p ≤0.05-Significant*

Table 2 shows that there is no significant difference in the amount of effective dose received by patients (thyroid, breast, lung and bone marrow) who underwent chest CT scan using 64 and 256 slice CT scan.

TABLE 2. COMPARISON OF THYROID, BREAST, LUNG AND RED BONE MARROW BETWEEN 64-MSCT PLAIN CHEST CT SCAN AND 256- MSCT PLAIN CHEST CT SCAN

	64 Plain (n=36)	**256 Plain** (n=36)	***p-value**
Thyroid	13.069 ± 8.278 (9.828)	10.240 ± 3.498 (9.054)	0.36 (NS)
Breast	39.207 ± 24.833 (29.484)	30.718 ± 10.496 (27.114)	0.35 (NS)
Lung	39.207 ± 24.833 (29.484)	30.718 ± 10.496 (27.114)	0.35 (NS)
Red Bone Marrow	39.207 ± 24.833 (29.484)	30.718 ± 10.496 (27.114)	0.35 (NS)

** p>0.05- Not significant; p ≤0.05-Significant*

Table 3 shows the comparison of 64 and 256 plain and contrast chest CT scan and shows statistically significant difference in the DLP parameters with p value of 0.05.

TABLE 3. COMPARISON OF DEMOGRAPHIC CHARACTERISTICS, CTDI AND DLP BETWEEN 64-MSCT PLAIN AND CONTRAST CHEST CT SCAN AND 256- MSCT PLAIN AND CONTRAST CHEST CT SCAN

	64 Plain (n=36)	**256 Plain** (n=36)	***p-value**
Age (in years) Mean ± SD	50.06 ± 13.23	47.62 ± 12.40	0.45 (NS)
Sex			
Male	16 (50.0%)	17 (53.1%)	0.80 (NS)
Female	16 (50.0%)	15 (46.9%)	
BMI			
Normal	20 (62.5%)	20 (62.5%)	
Obese	12 (37.5%)	12 (37.5%)	0.02(NS)
CTDI Surview	0.078 ± 0.023	0.046 ± 0.021	<0.0001 (S)
CTDI Plain	8.951 ± 4.861 (8.275)	6.934 ± 3.266 (6.05)	0.04 (S)
CTDI Total	18.705 ± 10.195	14.774 ± 9.326	0.11 (NS)
DLP Surview	2.594 ± 0.721 (2.60)	10.772 ± 51.889 (1.80)	<0.0001 (S)
DLP Plain	349.750 ± 177.686 (329.45)	262.078 ± 102.702 (236.90)	0.03 (S)
DLP Total	730.947 ± 392.024 (642.85)	537.784 ± 214.70 (480.80)	0.03 (S)
DLP Contrast	361.956 ± 249.403 (310.950)	264.428 ± 100.883 (234.100)	0.08 (NS)
CTDI Contrast	9.70 ± 6.11 (7.91)	6.52 ± 2.51 (6.05)	0.002 (S)

** p>0.05- Not significant; p ≤0.05-Significant*

Table 4 shows that there is statistically significant difference in the amount of effective dose received by patients (thyroid, breast, lung and bone marrow) who underwent plain and contrast chest CT scan using 64 and 256 slice CT scan.

TABLE 4. COMPARISON OF THYROID, BREAST, LUNG AND RED BONE MARROW BETWEEN 64-MSCT PLAIN AND CONTRAST CHEST CT SCAN AND 256- MSCT PLAIN AND CONTRAST CHEST CT SCAN

	64 Plain (n=32)	**256 Plain** (n=32)	***p-value**
Thyroid	29.238 ± 15.681 (25.714)	21.511 ± 8.592 (19.232)	0.03 (S)
Breast	8771.36 ± 4704.289 (7714)	64.53 ± 25.78 (57.70)	<0.0001 (S)
Lung	8771.36 ± 4704.289 (7714)	64.53 ± 25.78 (57.70)	<0.0001 (S)
Red Bone Marrow	8771.36 ± 4704.289 (7714)	64.53 ± 25.78 (57.70)	<0.0001 (S)

Table 5 shows the comparison of 64 and 256 High Resolution Chest CT scan (plain and contrast) showing statistically significant difference in the DLP and CTDI parameters with p value of 0.05.

TABLE 5. COMPARISON OF DEMOGRAPHIC CHARACTERISTICS, CTDI AND DLP BETWEEN 64-MSCT PLAIN AND CONTRAST HIGH RESOLUTION CHEST CT SCAN AND 256- MSCT PLAIN AND CONTRAST HIGH RESOLUTION CHEST CT SCAN

	64 HRCT Plain and Contrast (n=40)	**256 HRCT Plain and Contrast** (n=31)	***p-value**
Age (in years)			
Mean ± SD	52.45 ± 10.82	55.84 ± 8.16	0.15 (NS)
Sex			
Male	20 (50.0%)	11 (35.5%)	0.22 (NS)

Female	20 (50.0%)	20 (64.5%)	
BMI			
Normal	20 (50.0%)	16 (51.6%)	
Obese-OW	7 (17.5%)	2 (6.5%)	0.35 (NS)
Obese	13 (32.5%)	13 (41.9%)	
CTDI Surview	0.070 ± 0.026	0.057 ± 0.024	0.04 (S)
CTDI Plain	16.165 ± 4.261	8.571 ± 5.160	<0.0001 (S)
CTDI Total	27.443 ± 7.697	16.601 ± 8.060	<0.0001 (S)
DLP Surview	2.037 ± 0.766 (2.300)	2.274 ± 2.644 (1.600)	0.05 (S)
DLP Plain	582.277 ± 180.20	299.600 ± 171.33	<0.0001 (S)
DLP Total	1035.559 ± 271.598	613.113 ± 282.387	<0.0001 (S)
DLP Contrast	416.448 ± 199.383	308.506 ± 128.970	0.003(S)
CTDI Contrast	11.744 ± 4.468	8.295 ± 3.404	<0.001 (S)

** p>0.05- Not significant; p ≤0.05-Significant*

Table 6 shows that there statistically significant difference in the amount of effective dose received by patients (thyroid, breast, lung and bone marrow) who underwent chest HRCT scan using 64 and 256 slice CT scan with p value of <0.0001.

TABLE 6. COMPARISON OF THYROID, BREAST, LUNG AND RED BONE MARROW BETWEEN 64-MSCT PLAIN AND CONTRAST CHEST HIGH RESOLUTION CT SCAN AND 256- MSCT PLAIN AND CONTRAST HIGH RESOLUTION CHEST CT SCAN

	64 HRCT Plain and Contrast (n=40)	**256 HRCT Plain and Contrast** (n=31)	***p-value**
Thyroid	0.647 ± 0.170 (0.728)	24.524 ± 11.292 (22.444)	<0.0001 (S)
Breast	124.267 ± 32.592	73.573 ± 33.886	<0.0001 (S)
Lung	124.267 ± 32.592	73.573 ± 32.592	<0.0001 (S)
Red Bone Marrow	124.267 ± 32.592	73.573 ± 33.886	<0.0001 (S)

4. DISCUSSION

In the advent of increase in the use of multislice CT scanners to help in the proper diagnosis of patients, the knowledge of the effective dose received by the patient is essential.

This study included the different types of chest CT scan available in St. Luke's Medical Center namely - plain chest CT scan, plain and contrast chest CT scan and the plain and contrast high resolution CT scan.

This study used the Tissue-Weighting Factors for International Commission on Radiological Protection (ICRP) Publications 26, 60, and 103[4] to compute for the organ specific radiation dose, specifically the organs that received radiation in the chest CT scan study (thyroid, breast, lung and bone marrow).

Our study shows that in patients who underwent plain chest CT scan using the 64 slice and 256 slice CT scan, they received the same amount of effective dose. In patients who underwent plain and contrast chest CT scan as well as HRCT plain and contrast CT scan, the patients who underwent the scan using 256 slice scanner received a lesser effective dose than the patients who used the 64 slice scanner. This finding is comparable with the study of Khan et al, 2011 [5] from the American Journal of Radiology entitled - Comparison of Radiation Dose and Image Quality: 320-MDCT versus 64-MDCT Coronary Angiography, wherein results also showed lower effective dose in patients who underwent 320-MDCT than those who underwent 64-MDCT coronary angiography.

The decreased effective dose received by patients who underwent 256 slice CT scan (plain and contrast, HRCT plain and contrast) may be attributed to a dose reduction method that is applied by the Multi-detector 256 slice scanner (Phillips, iDose^4) [7]. According to the study by Hausleiter et al, [6] another approach for reducing radiation dose is reduction in the tube voltage, because the radiation dose varies with the square of the tube voltage.The limitation of this study is that this study is not age and sex matched. Despite of this limitation, both age and sex of the two populations were homogeneous.

5. CONCLUSIONS

In this study, we found that patients who underwent plain and contrast chest CT scan as well as the HRCT plain and contrast studies using the 256 slice scanner received lesser mean effective dose compared to those who underwent the same study protocols using the 64-slice scanner.

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ESTIMATION OF ABSORBED RADIATION DOSE BY TLD ON PATIENTS DURING PROCEDURES OF DIGITAL RADIOGRAPHY AT FUNDACIÓN VALLE DEL LILI

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Abstract

In the research it has been measured absorbed dose, equivalent dose, and entrance surface dose (ESD) to calculate the effective dose in agreement with the weighting indices reported by ICRP for the 16 most common digital radiographic (DR) examinations. To do that, it has been used thermoluminescent dosimeters TLD-100, which were inserted in an anthropomorphic phantom (Alderson Rando) in the radiosensitive tissues, and also located in the entrance surface of the primary beam of radiation. After irradiation, the TLD crystals were subjected to a measurement process to obtain the response in charge units (Coulombs), and through a calibration process, in dose units (Gy). The DR parameters used for the radiographic research on the Phantom, were the same parameters used during the daily clinical practice with real patients. 15 of 16 studied examinations were below of the reference level for the effective dose (*E*), but it is necessary take in account that during the experimental measurements it has been not used lead shielding for any examination. For the research it has been used the equipment and facilities of the *Fundación Valle del Lili* (FVL), Cali, Colombia; and the academic support of the *Universidad del Cauca*, Popayán, Colombia.

1. INTRODUCTION

In the diagnostic evolution and the clinical procedures are generated novel research and new alternatives to benefit humanity. In this case, the use of ionizing radiation is mentioned, becoming more frequent in clinical practice, generating expositions for the patients as well as for the medical assistance personnel who are present in the interventions or the generation of diagnostic images.

Radiation doses resulting from X-ray examinations depend on the X-ray imaging technology and the exposure setting employed for recording the images on these imaging devices. The X-ray imaging is the largest contributor to population dose because a large number of X-ray examinations are conducted every year globally [1]. International Basic Safety Standards (BSS) for Protection against Ionizing Radiation and for the Safety of Radiation Sources published by the International Atomic Energy Agency (IAEA) in 1996 recommended the establishment of Dose Guidance Levels (DGLs) for medical exposures [2]. Recording of patient doses in medical X-ray examinations is not a routine procedure in Colombia, and with this work we expect to contribute to the implementation of this kind of procedures in our country.

This paper reports the measurements of absorbed radiation dose on patients during 16 different procedures of digital radiography used at *Fundación Valle del Lili* (FVL) by means of thermoluminescence dosimetry (TLD) technique.

2. THEORETICAL FRAMEWORK

2.1. Dosimetry in patients

The dosimetry allows to determine the absorbed dose in certain points of interest of the organism. These usually include:

- Dose in organs: is the estimated dose that is received in each organ by means of a given examination; the organs considered are those included in the irradiation field and in the neighboringareas.
- ESD: is the estimated dose that produces a scan in the entrance area of the x-rays (Entrance Surface Dose).
- *E*: Weighted sum of equivalent doses in different organs (Effective dose)[3].

2.2. Thermoluminescent dosimetry

Thermoluminescent dosimeters (TLDs) are generated naturally or by the doping of materials such as LiF with a very small percentage of activators. LiF:Mg,Ti is lithium fluoride doped with magnesium and titanium. For photon beams, a material whose effective atomic number is comparable to the tissue to be studied should be chosen. In the case of LiF:Mg,Ti this value is 8.14 which is similar to that of water: Z = 7.42, Fat: Z = 5.92 and Muscle: Z = 7.42. Therefore this would be a good TL material for estimating absorbed dose in patients [4].

3. MATERIALS AND METHODOLOGY

An investigative work was carried out in which 16 digital radiographic (DR) protocols were analyzed. 120 thermoluminescent crystals were placed in a crystal holder of 12 columns and 10 rows so that they were easily distinguishable and calibrated in a Siemens Artiste linear accelerator in solid water medium, with 1.5 cm above them and 5 cm below. Additionally, with a focus-film distance (FFD) of 100 cm and a field aperture of 10×10 cm^2.

The determination of the calibration coefficient was performed using the linear response of the TLD-100, which were irradiated column by column at different known doses of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 and 55 cGy, leaving the last one without irradiating in order to obtain the reading of the background values. We have plotted Charge (nC) as function of Dose (mGy) in order to obtain the calibration factor F_c of crystals. This procedure described above was done three times in order to compare the response of the crystals and to discard those with significant deviations using the Grubbs test. To simulate the human body, we have used a male anthropomorphic Alderson Radiation Therapy (ART) phantom. The organs in which the TLDs were placed are shown in Table 1. These 15 organs/tissues are recommended by ICRP [5].

TABLE 1. ORGANS WHERE IT HAS BEEN LOCATED THE TLD CRYSTALS

Organ	Location	Quantity
Brain	Center	5
Gonads	Center	6
Bone Marrow	Thorax	4
	Abdomen	4
Colon	Transverse	2
	Ascending	2
	Descending	2
Right and left lung	Upper third	6
	Middle third	4
	Bottom third	6
Stomach	Center	5
Bladder	Center	5
Breast	Center	6
Liver	Center	5
Esophagus	Upper	2
	Center	2
	Lower	2
Thyroid	Center	4
Osseous surfaces	Whole body	10
Skin	Whole body	14
Salivary glands	Heterogeneously	4

Kidneys	Center	4
	Background radiation	4
	Beam entrance	4
	Beam output	4
	Total of Dosimeters	120

The phantom, with the crystals inside, was taken to the X-ray room and irradiated 50 times with the same protocol, in order to increase the thermoluminescent signal and thus obtain a truthful dose measurement. Then, the crystals were removed from the phantom and read one by one in a Harshaw TLD System 3500, averaging the measurements for each organ and dividing by 50 to obtain the doses in a single protocol. After being read, the TLD crystals were erased using the PTW-TLDO programmable furnace. The steps described above were performed for each of the protocols shown in Fig. 1.

4. ANALYSIS AND RESULTS

From the calibration process carried out on the 120 crystals, after plotting Dose [mGy] as function of Thermoluminescent reading [nC], we obtained the calibration factor from the slope of the line:

Thus, in order to obtain the dose received by each crystal, its response thrown by the reading equipment in nC is multiplied with the calibration factor.

After reading all TLDs for the 16 RD protocols, and calculating the absorbed dose for each organ, we calculated the effective dose, *E*. The effective dose found for the protocols: Cranium LT, Cranium PA, Cranium AP, Abdomen AP-standing, Abdomen LT-standing, Pelvis AP, Hip AP-standing, Thorax PA, Thorax AP, Thorax LT, Cervical spine AP, Cervical spine LT, Lumbar spine AP, Lumbar spine LT, Thoracic spine AP, and Thoracic spine LT are shown in Fig. 1, where the sky blue bar is the *E* estimated and the purple bar the international reference *E* [6] for each of the protocols.

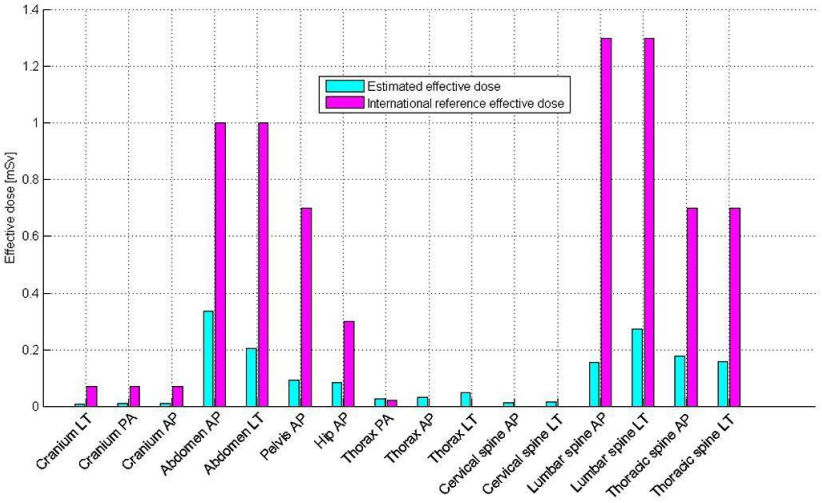

FIG. 1. Comparison between the reference effective dose (purple bars) and the estimated effective dose (sky blue bars).

In all protocols we have performed, the value for the calculated effective dose is always below the representative reference level for each type of examination, except for the Thorax PA protocol. It should be noted that we have not used leaded protectors on the phantom for any protocol during the measurements of the study, but when the protocol is performed on patients, they use leaded protectors. The value of the estimated effective dose for the Thorax PA protocol is above the reference level by 0.0058 mSv, which is a value below the uncertainty that was obtained for the calibration factor. Additionally, an effective dose value below the reference level can be obtained if lead protection is placed for this type of study.

Another purpose of this research was to find the ESD. The results are shown in figure 2. The purple bar indicates the international reference level [7] and the sky blue bar represents the measured value.

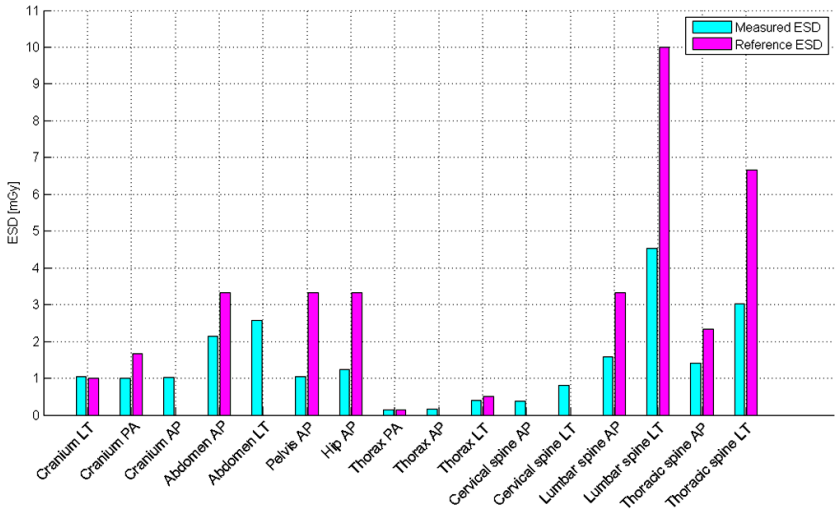

FIG. 2. Comparison between the reference and measured value of the ESD for the different studied protocols.

The results for all protocols under study are below the reference dose levels, except for the Cranium LT protocol. This implies that the radiographic technique being used in FVL for average adult patients is adequate with respect to the radiological protection of the patient. The value measured for Cranium LT is above the international reference level in 0.053 mGy. In this case it is recommended to decrease the value of mAs when this type of examination is performed.

5. CONCLUSIONS

An uncertainty in the calibration factor of 1.027% allows to deduce that this measurement system is very precise and that the deviation in the linear response of the TLDs is negligible. In all DR procedures in which it can be compared, it is easy to see that the calculated effective dose is always below the established reference level. The value for the Thorax PA gives a small amount higher, but this difference is within the uncertainty of the calibration. For the ESD values, all protocols are below the international reference, except (in a small amount) for the Cranium LT, where it was recommended to decrease the value of mAs for these type of examinations. The parameters used in the *Fundación Valle del Lili* for the performance of radiographs in the clinical setting with real patients are safe and fulfill with the international regulations.

We have successfully obtained in-situ experimental measurements on each of the organs for the calculation of the effective dose using anthropomorphic phantom, and TLD technique, which is a pioneer work in Colombian institutions and it will contribute to the implementation of recording of patient doses in medical X-ray examinations in Colombia and other Latin American countries.

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IMPLEMENTATION OF INDONESIAN REGULATION OF COMPLIANCE TESTING FOR INTERVENTIONAL AND DIAGNOSTIC X-RAY EQUIPMENT TO ENHANCE RADIATION PROTECTION OF PATIENTS AND WORKER

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Abstract

Radiation protection of patients and worker can be obtain if the X-ray equipment is in compliance with the regulation. The obligation to perform compliance testing for interventional and diagnostic X-ray in Indonesia is a mandatory of Government Regulation (GR) no. 33 of 2007. This GR has been elaborated in BAPETEN Chairman Regulation (BCR) no. 9 of 2011 on the compliance testing on Interventional and Diagnostic X-Ray equipment. Difficulties appear during the implementation of BCR. Some of the difficulties are huge number of X ray, meanwhile only a few qualified testers to do the compliance testing. Another problem is very few experts to evaluate the result. There are 7163 X-ray equipments, and there are less than 30 qualified experts to do the X-ray compliance test and there are only 14 experts to evaluate the result. Until now (June 2017), the number of X ray that have done compliance testing is about 4532 X-ray (63%). The BCR does not implement well and need to be revised. The revisions of BCR was expected to be implemented better in the facility so patients, workers and all other persons are not unnecessarily exposed to X-ray radiation in facility.

1. INTRODUCTION

Radiation protection of patients and worker can be obtain if the X-ray equipment is in compliance with the regulation. The obligation to perform compliance testing for interventional and diagnostic X-ray in Indonesia is a mandatory requirement of Article 40 of Government Regulation (GR) no. 33 of 2007 on the Safety of Ionizing Radiation and Security of Radioactive Sources [1].

The compliance testing was performed to ensure that the equipment used in the interventional and diagnostic radiology procedure is functioning correctly so that the patient does not get unnecessary exposure and the radiation worker does not get excessive personal dose. This government regulation has been elaborated to a more detail requirement in BAPETEN Chairman Regulation (BCR) no. 9 of 2011 on the compliance testing on Interventional and Diagnostic X-Ray equipment [3], [5].

2. METHODS

The method of the paper is guided by literature review. The paper examine the existing national legal frameworks of Indonesia in the context of the compliance testing on Interventional and Diagnostic X-Ray equipment, BCR No. 9/2011 to enhance the radiation protection of patients and worker. It described some data of personnels that involved in the compliance testing of X-ray equipment, they are qualified testers and experts. The paper also provide the number of existing X-ray equipment and the X-ray equipment that have done the compliance test.

3. RESULTS

The compliance testing on interventional and diagnostic X-ray was implemented since 2012, since that time Indonesian governement has recruited the qualified testers to perform the X ray equipment compliance test in the facility and also recruit the experts to evaluate all the result from compliance testing done by qualified testers and issued the compliance certificate. Some difficulties appear during the implementation of the BCR No. 9/2011. Some of the difficulties are there are huge number of X ray equipment in Indonesia, meanwhile

only a few qualified testers to do the compliance testing. Another problem when implementing the X ray compliance testing regulation in Indonesia is very few experts to evaluate the result of compliance testing and issued the compliance certificate.

There are about 7163 X-ray equipments in Indonesia, and there are less than 30 qualified experts to do the X-ray compliance test and there are only 14 experts to evaluate the result of X-ray compliance testing. Until now (June 2017), the number of X ray that have done compliance testing is about 4532 X-ray (63% of X-ray equipment in Indonesia) [2], as seen in table 1.

TABLE 1. Number of X-ray equipments in Indonesia

Number of X-ray equipments	X-ray equipments that have done compliance testing
7163	4532

The X-ray was testing by the qualified testers and the result of this test was evaluate by the experts from different institution, and expert is the one that have right to issue the compliance certificate of X-rays equipment. The very few of experts that doing the evaluation of the compliance testing is one of the main problem that cause this regulation doesn't implement well in the facility. All of the process was stuck in the experts, so many X-ray compliance test results were waiting to be evaluate by the experts[3].

From the data describe in table 1, the number of X-ray equipment that have done compliance testing is 4532 X-ray equipments, from that data there are only 289 X-ray equipments that have been evaluated by the experts, and the result is not all of the X-ray was comply with regulation, there are only178 (61%) X-ray equipments were in compliance with regulation, 48 (17%) X-ray equipments were conditional compliance (need some repairement), and 63 (22%) X-ray equipments were not in compliance with regulation (failed the test) as describe in figure 1.

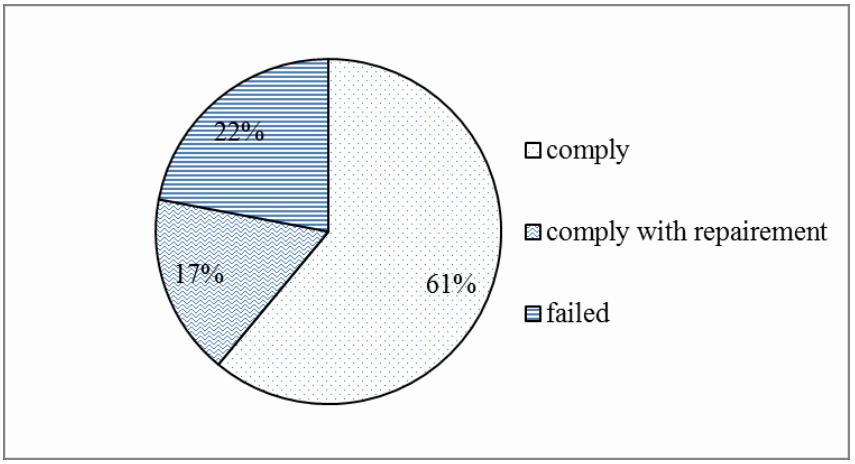

FIG. 1. Chart showing the result of X-ray equipment compliance test

In Indonesia the compliance testing was one of the requirement to get the license of X-ray. If there is no compliance test certificate from the experts so there will be no license for the X-ray equipment, if there is no license, the facility cannot use the X-ray equipment for patients.

Another problem is the number of qualified testers also not enough to do the compliance test to all X-ray equipment in the country, some facility have to wait for a long time to get the compliance testing for their X-ray. During the time of waiting for compliance testing to be done, the facility keep using the X-ray equipment to patients.

The use of X-ray equipments without compliance testing has a radiation risk to patients and workers, and public, so the government consider to revise the regulation. Some revisions have been made to the BCR No. 9/2011. There are few issues that need to be revised in the BCR No. 9/2011. Indonesian government have an

expectation that the revision of this regulation can help to enhance the radiation protection of patients and workers. That's very important to make sure that the X-ray equipments to expose the patients are comply with the regulation.

Some of the main issue of revision is cutting the process of compliance testing, in this case the experts and the qualified testers are from the same institution, and the institution will issued the certificate. In the existing regulation, BCR No. 9/2011 the qualified testers and the experts are from different institution.

4. DICUSSION

Studies in Indonesia and elsewhere demonstrating that poor X-ray equipment performance is a significant contributor to unnecessary patient radiation exposure. Patients need to be reassured about their safety when using the X-ray equipment, by showing them that the X-ray equipments is in compliance with the regulation by implementing the regulation of Compliance Testing for Interventional and Diagnostic X-Ray Equipment, BCR No. 9/2011.

After few years implementing the BCR No. 9/2011, it show that the regulation does not implement well and need to be revised. Some revisions have been made to the BCR No. 9/2011. It mention in the pharagraph above that the compliance certificate of X-ray equipment was one of the requirement to get the license of X-ray. If there is no compliance certificate issued by the experts so there will be no license for the X-ray equipment. And the facility cannot use the X-ray equipment without license from regulatory body. It show that the implementation of the regulation have an effect to the licensing process.

The problem with the implementation of BCR No. 9/2011 has been discussed in forum between the qualified testers, experts, and regulatory body. As mention before there are so many X-ray equipments to be tested and only few human resources to do the test, it shows in table 2 [2].

The data describe in table 2 shows that there are too many X-ray equipments that need compliance testing, and there are only few qualified testers and experts. It explain where all the problem come from when implementing this regulation.

TABLE 2. Number of X-ray qualified testers and experts

The number of X-ray equipments	The number of qualified testers	The number of experts
7163	Less than 30	14

It clear that in order to implement the BCR No. 9/2011, the first thing to do is recruiting more qualified testers and experts as describe in table 2. It doesn't guarantee that by having more human resources can solve all the problem of implementing this regulation but at least reduce the main cause of difficulty when implementing it in the facility, and more X-ray equipment have compliance testing done, and more patients and worker work with comply X-ray equipment

Some other issue of revision also has been mentioned in the previous pharagraph that government try to cut the process of compliance testing result evaluation. Because the other problem is the slow evaluation by experts, due to many reason, such as incomplete data submitted by the qualified testers, unclear image of the test result so it is cause difficulties for the experts to evaluate it, it's a complex problem that need to be solved soon by the government.

The other issue of changes in the revision of BCR No. 9/2011 are some compliance testing parameters were reviewed again and the value is being checked again to know if there are some parameters that cannot be passed by many X-ray equipments or if the parameters were too difficult to be done for regular compliance testing. For example the parameter illuminance test and tube housing assembly leakage test. The value to pass the illuminance test is 100 lux [4], and we found that many X-ray only have 80 lux, base on the regulation this X-ray equipment was not comply with the regulation. We discussed this problem of implementation with qualified testers, experts and licensee before we decide to change the value of the parameters.

Other example of parameter issue is parameter tube housing assembly leakage test that apply to all X-ray equipment for regular test, some of the result from discussion is this test should only apply for new X-ray equipment or the X-ray equipment that being moved to another room.

Those are some discussion that have been made by government in implementing the regulation of BCR . No. 9 of 2011 on the compliance testing on Interventional and Diagnostic X-Ray equipment in order to enhance the radiation protection for patients and worker. The revisions of that regulation was expected to be implemented better in the facility so patients, workers and all other persons are not unnecessarily exposed to X-ray radiation in facility.

5. CONCLUSION

The radiation protection of the patients and worker can be enhanced by implementing the BCR No. 9 of 2011 on the compliance testing on interventional and diagnostic x-ray equipment. The BCR No. 9 of 2011 does not implement well in the facility because of some reason, such as not enough human resources to do the compliance test, and some other reason. The regulation need to be revised, the revisions of BCR was expected to be implemented better in the facility so patients, workers and all other persons are not unnecessarily exposed to X-ray radiation in facility.

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STATUS AND PERSPECTIVES OF THE DRL CONCEPT
Update of the German DRL for medical X-ray procedures

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Abstract

Radiology has undergone various developments in recent years. Therefore, the catalog of the German diagnostic reference levels (DRLs) for X-ray procedures were adapted to the current state-of-the-art of radiology. Different data sources (medical authorities, medical societies and institutions, and outcomes of research projects) were considered for updating the DRLs. For pediatric examinations, weight-adjusted DRLs were introduced. DRL values already existing before the update were lowered by 20%, on average. Furthermore, numerous DRLs were established for the first time, in particular for interventional procedures and computed tomography. As a further aid towards optimization, additional information was provided, such as the 25^{th} and 50^{th} percentiles of the dose distributions or, in the case of CT, scan ranges. Further recommendations for improving the implementation of the DRL concept in radiology departments, such as the implementation of dose management software or the registration of the patient's size were given to users of X-ray devices.

1. INTRODUCTION

The continuous man-made increase of radiation exposure to the population in industrialized countries is mainly due to the growing number of medical X-ray procedures. The German Federal Office for Radiation Protection (BfS) estimated the mean annual effective dose per capita from diagnostic examinations and interventional-radiological procedures in 2014 to 1.6 mSv [1]. Although the stochastic radiation risk for an individual to develop cancer in later life due to an X-ray procedure is generally small, the increasingly large number of people undergoing a procedure may translate to a considerable number of additional cancer cases [2]. It is therefore required not only to appropriately justify each individual procedure, but also to optimize the protocols used to reduce patient exposure [3]. However, the implementation of the optimization principle in daily clinical practice can be quite difficult taking into account different medical, technical as well as personal and economic aspects. Diagnostic reference levels (DRLs) have been shown to be an effective tool to support users in optimizing X-ray or nuclear medical procedures and, thereby, to protect patients against unjustified radiation exposures [4]. DRLs are levels of easily measurable dose-related quantities. They represent common (but not necessarily the best possible) exposure practice in a country for broadly types of equipment for typical procedures performed at standard-sized patients. They do not represent upper dose limits and may be exceeded when there are clinical reasons (e. g., when examining obese persons). However, appropriate local reviews and corrective actions should be undertaken without undue delay whenever there is a consistent and unjustified excess of DRLs.

DRL values should be updated on a regular basis when the exposure practice has changed. Since the preceding update of German DRLs for diagnostic and interventional X-ray procedures published in 2010 [5], radiologic practice has undergone various developments, such as the dissemination of innovative technologies, in CT in particular (e. g., increased number of digital detectors, different dose-saving features, iterative image reconstruction, automatic tube current and voltage modulation, automatic beam collimation). Recent reviews on radiation exposure indicate a high dose reduction potential by the application of innovative techniques [6]. Simultaneously, these new technologies have broadened the spectrum of imaging procedures. Therefore, the catalog of German DRLs for X-ray procedures was adapted to the state-of-the-art of radiology in 2016 [7].

2. METHODS

In Germany, the BfS is responsible for updating DRLs as well as for establishing values for further X-ray procedures. Different dose data sources were considered for the update in 2016:

(a) Medical authorities (ärztliche Stellen): In Germany, 21 medical authorities regularly control the quality of X-ray examinations and assist users in optimizing procedures. In this context, the authorities randomly acquire dose data for procedures for which DRLs exist and check whether the DRLs are consistently and unjustified exceeded. Data evaluated between 2010 and 2015 were anonymized and sent to the BfS.
(b) Medical societies and institutions: For the recent update, the BfS got access to data acquired nationwide by the German Society for Interventional Radiology and Minimally Invasive Therapy, the Institute for Applied Quality Improvement and Research in the Healthcare Sector, and different reference centers of the German mammography screeningprogram.
(c) A nationwide survey on CT practice performed in 2013/14[8].

In the context of a multi-stakeholder meeting, DRL values were set at the 75^{th} percentile of the corresponding dose parameter distribution if the corresponding procedure was considered as clinically relevant (frequent and/or high-dose procedure).

According to the recommendation of the ICRP [9], different weight and age intervals were established for classifying patients and establishing DRLs in pediatric radiology (cf. Table 1). DRLs for examinations of pediatric patients should be chosen according to their weight, primarily; DRLs for examinations of the patient's head should be chosen according to the age.

Table 1. Classification of pediatric patients according to their weight and age. The patient's weight and age should be considered when choosing the DRL for examinations of the body and the head, respectively.

Premature infant	Neonate	Infant	Toddler	Primary school child	Adolescent	Adult-sized adolescent
< 3 kg	3 - < 5 kg	5 - < 10 kg	11 -< 19 kg	19 –<32 kg	32 -< 56 kg	56 - <65 kg
	0 – < 3 m.	3 - < 12 m.	1 - < 5 y.	5 - < 10 y.	10 - < 15 y.	> 15 y.

m.: month(s), y.: year(s).

3. RESULTS

Several DRLs for interventional procedures and CT examinations that were newly established in 2016 are given in Tables 2 and 3.

DRLs for radiographic examinations were determined for 8 different anatomical regions and for up to 2 different projection angles. On average, the recent DRL values could be lowered by 16%. For examinations of the shoulder and the hip, DRLs were established for the first time. For mammography, the average glandular dose (*AGD*) were decreased by 20%.

The DRLs for fluoroscopic and interventional procedures were decreased by 19% and 31%, respectively. Before 2016, only two DRLs (percutaneous transluminal angioplasty, PTA, percutaneous transluminal coronary angioplasty, PTCA) had been established for interventional procedures. In 2016, these procedures did by far not represent the standard procedures in interventional radiology. Therefore, 10 DRLs were added to the DRL catalog.

In CT, DRLs were established for 20 different examinations. DRLs that existed before 2016 were decreased by 22%, on average. DRLs in CT were determined for different anatomical regions, for different clinical indications (e. g., examinations of hard contrast and low contrast structures of the pelvis), or represent specific technical procedures (e. g., prospective triggered CT coronary angiography). For further assistance, the default scan ranges and corresponding scan lengths were additionally given.

DRL values of radiographic, fluoroscopic and CT procedures performed in pediatric patients were decreased by 27%, 48%, and 16%, respectively.

Table 2. 25th, 50th, and 75th percentiles of the distributions of the *DAP* and the intervention time, and the DRLs for the PTA procedure in different body regions.

PTA within the	25th percentile		50th percentile		75th percentile		DRL
	DAP [cGy·cm^2]	*IT* [min]	*DAP* [cGy·cm^2]	*IT* [min]	*DAP* [cGy·cm^2]	*IT* [min]	*DAP* [cGy·cm^2]
pelvis	900	5.2	1,700	8,9	3,600	15	3,600
thigh	2,100	4.5	4,300	7,8	8,200	14	8,200
lower leg	600	7.7	1,000	13	2,000	20	2,500

PTA: percutaneous transluminal angioplasty, IT: total intervention time.

Table 3. Default scan ranges, standard scan lengths, 75th percentiles of the distributions of the $CTDI_{vol}$ and *DLP*, and the DRLs for some CT examinations. The dose parameters $CTDI_{vol}$ and *DLP* are defined for a single scan series.

CT examination	Scan range	L_{st} [cm]	75th percentile $CTDI_{vol}$ [mGy]	75th percentile *DLP* [mGy·cm]	DRL $CTDI_{vol}$ [mGy]	DRL *DLP* [mGy·cm]
Chest	C7 – adrenals	32	12	342	10	350
Chest low-dose	C7 – sinus	27	3.0	105	3.0	100
Prospective triggered coronary angiography	B5 – apex	12	20	328	20	330

L_{st}: standard scan length, $CTDI_{vol}$: volume CT dose index, *DLP*: dose length product, C7: 7th cervical vertebra, B5: 5th breast vertebra

4. DISCUSSION

In 2016, the catalog of German DRLs for X-ray procedures was updated to consider the development of technology and the change of exposure practice. DRLs that existed before 2016 were lowered by 20%, on average. Ten DRLs for interventional procedures and 12 for CT examinations were established for the first time. The involvement of different medical societies and institutions in the update process, as well as the provision of further parameters (such as total intervention time for interventional procedures, scan range and standard scan length for CT examinations) have strongly raised the awareness of the DRL concept among physicians, physicists and radiographers. In order to provide further advice for the correct use of the DRL concept and of single DRL values, a guideline for users will be published.

For improving the implementation of the DRL concept within the facilities as well as the optimization of medical procedures, the BfS recommends

(a) the implementation of modern dose management software in radiology departments for a systematic and permanent acquisition of dose-relevant parameters and the comparison with DRLs;
(b) to consider and record the size of patients (e. g., weight, body mass index, diameter of the body, or size specific dose estimate) for a systematic and reproducible optimization of procedures;
(c) the formation of a core group of physicians, physicists, radiographers, and IT-experts in radiology departments that is responsible for the systematic and consequent optimization of X-rayprocedures;
(d) to strongly support the training of medical staff at the devices (hands-onexercise).

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THE EYE LENS DOSES ($H_P(3)$) ASSESSMENT USING OSL DOSIMETERS.

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Abstract

Based on IAEA TECDOC recommendation No. 1731, H_{lens} is a measurement value of personal dose equivalent at 3 mm depth, $H_p(3)$, with a dosimeter worn as close as possible to the eye and calibrated on a phantom representative of the head. The lens of eye dose can be evaluated from dosimeter, worn at trunk or collar and dose algorithm, by the combination of $H_p(0.07)$ and $H_p(10)$ values while dose calibration is performed on slab PMMA phantom. In 2009, there was a report from ORAMED shown a new Monte Carlo approached to define the conversion factor for $H_p(3)$ using a new head shape phantom. In this study, a general Monte Carlo N-Particle Transport code, MCNPX, was applied by TINT to simulate the conversion coefficients from air kerma to $H_p(3)$, where $H_p(3)$ was calculated in terms of absorbed dose. The nanoDot dosimeters, inserted at depth 3 mm. in a new cylindrical phantom used for $H_p(3)$ measurement. They were irradiated with the beam incident of X-ray with N-series radiation qualities at an angle of 40° on the cylinder vertical central axis. Head phantom was rotated in horizontal axis from 0 to 60 degree of incidence. The results of the percentage differences between delivered doses evaluated from the conversion coefficient and $H_p(3)$ evaluated from the nanoDot vary with radiation qualities and angle of incidence were found to be not exceeding ±10%.

1. INTRODUCTION

In 2009, the Optimization of RAdiation protection for MEDical staff (ORAMED) presented a project which aimed to introduce new elements in the discussion on the quantity $H_p(3)$ and to propose the more suitable theoretical cylindrical phantom to better approximate the head inwhich the eyes are placed. A new Monte Carlo approach helped to define the operational quantity of $H_p(3)$ and guided the method for personal radiation monitoring laboratory to calibrate dosimeter for the lens of eye dose assessment. The ratios of $H_p(3)/K_a$ with the beam incident at an angle of 0^o and 40° were shown including with cylindrical phantom rotated in horizontal axis from 0 to 180 degree of incidence [1]. In the same ORAMED project, the MonteCarlo code PENELOPE was proposed by the French Atomic Energy Commission (CEA Saclay Nuclear Research Centre) to simulate a set of energy and angular dependent also using ICRU cylindrical phantom. The $H_p(3)$ values were determined in terms of absorbed dose, according to the definition of this quantity, and also with the kerma approximation as formerly reported in ICRU reports. The ratio of $H_p(3)/K_a$ conversion coefficients calculated in terms of kerma approximation and absorbed dose were shown in parallel mono-energetic photon beams [2]. In 2012, Behrens (Physikalisch-Technische Bundesanstalt (PTB)) presented air kerma to $H_p(3)$ conversion coefficients ($(h_{pK}(3;R,\alpha)_{cyl}$) for a new cylinder phantom for X and gamma radiation qualities defined in ISO 4037 [3]. These conversion coefficients were valid for the total air kerma which calculated using the mass energy transfer coefficient $(\mu_{tr}/\rho)_{E,air}$ [4]. The purpose of this study is to present the conversion coefficients from air kerma to $H_p(3)$ in terms of absorbed dose simulated by MCNPX. The delivered eye lens dose using these conversion coefficients were also compared with the eye lens dose assessment using nanoDot dosimeters.

2. MATERIALS AND METHODS

2.1 Materials

The cylindrical phantom used in this study composes of polymethyl methacrylate (PMMA) 40 slice rings (20 cm in diameter and 0.5 cm in slice thickness) which was designed at Meikai University. Small dosimeters can be inserted in the scoring volume at the depth of 3 mm from the surface of phantom. The nanoDot

dosimeters (Landauer Inc., USA), composes of aluminum oxide (Al_2O_3: C) crystal, whose thickness is 0.3 mm and diameter is 7 mm, were selected in this study from their small size. Measurements were read out using a microStar mobile reader (Landauer Inc., USA) by the luminescence process which is the same principle as optically stimulated luminescence (OSL) or InLight dosimeters where the irradiated dosimeters were stimulated by a quantum of visible green light from the light emitting diode (LED).

2.2 Methods

2.2.1 Calculation of $H_p(3)/K_{air}$ conversion coefficient

A general Monte Carlo N-Particle Transport code which developed by Los Alamos National Laboratory [5], namely MCNPX. It was applied to simulate the conversion coefficients from air kerma to $H_p(3)$. The set of scoring circular volumes which represented size of nanoDot dosimeters, were placed in various angular to the horizontal axis from 0, 10, 20, 30, 40, 50 and 60 degree at the depth of 3 mm from the surface of phantom, as illustrated in FIG1. The $H_p(3)$, in terms of absorbed dose, were simulated at each beam incident of X-ray with N-series radiation qualities, N-40, N-60, N80, N-100 and N120.The X-ray beam interact to the phantom at an angle of 40° to the cylinder vertical central axis, as illustrated in FIG2, and covered all 0 – 60 degree at horizontal axis. The angle of 40 degree was selected as close to the real phenomena when radiation interacted to the patient and scattered to medical worker head for interventional radiology application.

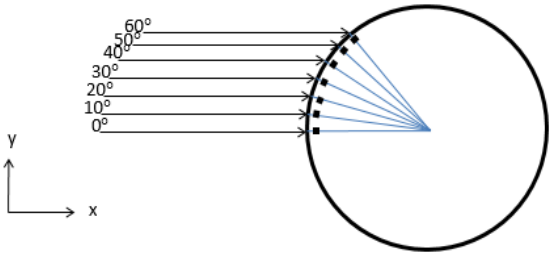

FIG. 1. The position of the scoring volumes from 0 to 60 degree of incidence on the horizontal axis.

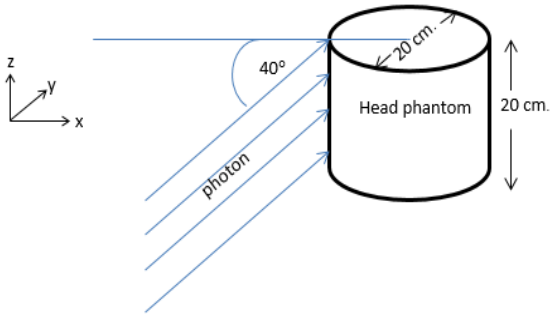

FIG. 2. Schematic view of beam incidence at 40 degree to the cylindrical phantom axis.

2.2.2 The eye lens dose assessment using nanoDot dosimeters

The calibration factors were evaluated from the ratio of delivered $H_p(3)$ and counts varied with radiation qualities. This delivered dose, 2 mSv, calculated from ratio of $H_p(3)/K_{air}$(Sv/Gy) from table 1 at 0 degree of incidence was chosen to irradiated to nanoDot. The eye lens dose assessment was evaluated by the set of nanoDot dosimeters inserted in the cylindrical phantom irradiated with X-ray beam of same qualities as used in simulation in 2.2.1 at Secondary Standard Dosimetry Laboratory (SSDL), Office of Atoms for Peace, Thailand. Delivered $H_p(3)$ calculated from conversion coefficients of table 1 were 0.5, 1 and 2 mSv at an angle of 40° on the cylinder phantom vertical central axis and each 0, 10, 20, 30, 40, 50 and 60 degree angle of incidence on horizontal axis. The air kerma values were traceable to Physikalisch-Technische Bundesanstalt (PTB), Germany. The irradiated nanoDot dosimeters were read out by a microStar reader at Thailand Institute of

Nuclear Technology (TINT), Thailand. This microStar reader was calibrated with an X-ray generator at 80 kVp which was traceable to National Institute of Standard and Technology (NIST), USA. After reading, the eye lens doses were calculated from the average counts readings multiplied by the calibration factor which varied with radiation qualities and angle of incidence.

3. RESULTS

The $H_p(3)/K_{air}$ conversion coefficients were simulated for mono-energetic photon beams from 33 keV up to 100 keV, energy range for medication, with the Monte Carlo N-Particle Transport code in terms of absorbed dose. This simulated conversion coefficient was tallied with f6 in unit of MeV/g and converted to J/kg

TABLE 1. $H_P(3)/K_{AIR}$ VALUES SIMULATED WITH MONTE CARLO N-PARTICLE TRANSPORT CODE IN TERMS OF ABSORBED DOSE.

	$H_p(3)/K_{air}$[Sv/Gy]						
E (keV)	0^0	10^0	20^0	30^0	40^0	50^0	60^0
33	1.2229	1.2195	1.2035	1.1794	1.1587	1.1115	1.0245
48	1.5161	1.5295	1.5012	1.4743	1.4500	1.4101	1.3335
65	1.6438	1.6457	1.6196	1.5977	1.5798	1.5398	1.4739
83	1.6154	1.6154	1.5943	1.5929	1.5796	1.5317	1.4761
100	1.5610	1.5755	1.5482	1.5553	1.5381	1.4979	1.4458

Picture 3. gives an overview of energy dependence of $H_p(3)/K_{air}$ conversion coefficients at depth 3 mm varied with each 0, 10, 20, 30, 40, 50 and 60 degree angle of incidence for cylindrical phantom.

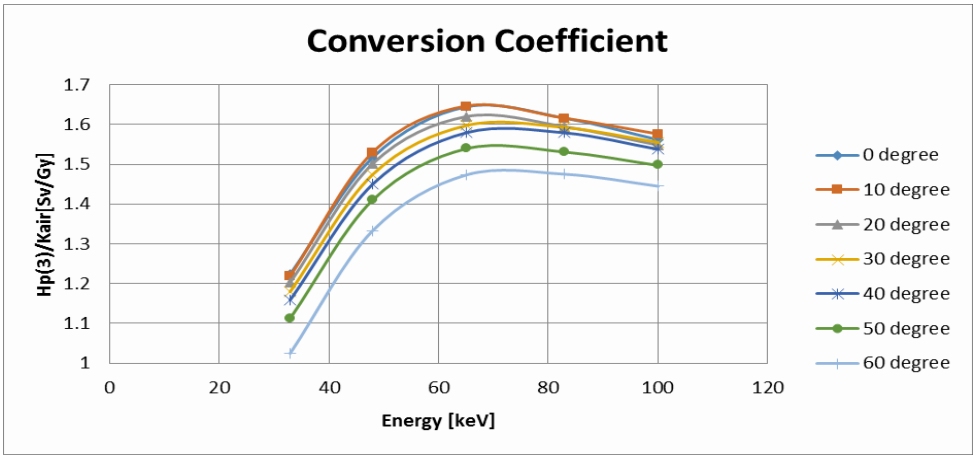

*FIG. 3. H_p**(3)**/K_{air} conversion coefficient versus photon energy and vary with angle of incidence.*

The delivered doses, $H_p(3)$ using conversion coefficients from table 1 were also compared with the eye lens dose assessment using nanoDot dosimeters varied with radiation qualities and angle of incidence. The comparison results showed that the percentage differences between $H_p(3)$ delivered dose by MCNPX and $H_p(3)$ evaluated from the measurement by nanoDot did not exceed ±10%.

TABLE 2. DELIVERED $H_P(3)$ DOSE EVALUATED FROM CONVERSION COEFFICIENTS COMPARED WITH $H_P(3)$ EVALUATED FROM NANODOT MEASUREMENTS.

E (keV)	$H_p(3)$ delivered dose (mSv)	$H_p(3)$ evaluated from nanoDot measurements (mSv)						
		0^0	10^0	20^0	30^0	40^0	50^0	60^0
33	0.50	0.48	0.49	0.46	0.50	0.51	0.50	0.47
	1.00	0.95	1.00	0.94	1.05	0.98	1.03	0.96
	2.00	1.87	1.87	2.00	2.04	1.94	2.08	2.01
48	0.50	0.47	0.50	0.51	0.52	0.50	0.51	0.49
	1.00	0.94	0.99	1.00	0.99	0.98	1.01	1.04
	2.00	1.95	1.96	2.04	2.04	1.99	2.00	2.01
65	0.50	0.50	0.50	0.49	0.51	0.50	0.50	0.50
	1.00	1.01	0.97	0.99	1.08	1.00	1.01	1.02
	2.00	2.04	1.92	2.00	2.09	2.03	2.12	2.08
83	0.50	0.55	0.50	0.48	0.51	0.53	0.50	0.54
	1.00	1.03	1.01	0.92	1.01	1.02	1.00	1.02
	2.00	2.05	2.01	1.98	2.03	1.98	2.04	2.15
100	0.50	0.49	0.51	0.48	0.50	0.52	0.49	0.50
	1.00	1.00	0.94	1.01	0.99	1.01	1.00	1.01
	2.00	2.06	2.08	1.92	2.03	1.98	2.00	2.06

4. DISCUSSION

The nanoDot dosimeter, an Aluminum oxide (Al_2O_3 :C) element, is designed for use in single point of radiation which over responded to low energy photons. The study of appropriate correction factors in a diagnostic working should be concerned. For the further study, $H_p(3)/K_{air}$ conversion coefficients, with $H_p(3)$ calculated in terms of kerma approximation at an angle of 40^0 on the cylindrical phantom axis will be evaluated.

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COMPARATIVE STUDY OF PATIENT DOSE AND STANDARD DOSE AT CT SCANNER IN MALI

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ABSTRACT

Comparative study of patient dose and standard dose at CT scans in Mali

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Aim: Compare the dose really received by the patient during a computed tomography (CT) scan with the standard radiation dose. **Material and methods:** A comparative study of the patient dose and standard radiation dose during CT scans was conducted hôpital du Mali from January 1St to December 31, 2015. 200 patients, 16 years old or more, were included in the study, according to the most frequent types of CT scans done in the unit. The study did not include CT scans for which automated dosimetric data were not recorded. CT scans were performed according to a standard protocol on a Siemens Somaton 16® device installed in 2012. The dose-length-product (DLP) in mGy.cm and the average effective dose by anatomical region in mGy have been analyzed. The results were compared to the diagnostic reference norm (NRD). **Result:** Repartition of our 200 CT scans, was as follow: lumbar (33%), brain without contrast injection (26%), brain with contrast injection (22%), abdominal-pelvic (12%), chest (6%), chest-abdominal-pelvic (5%). The DLP ranged from 700 to 1400 for lumbar (NRD = 700), 1001 to 5501 (NRD = 1000) for abdominal-pelvic, 2001 to 4000 (NRD = 800) for chest, 1051 to 2050 (NRD = 1050) for brain (injected or not). The calculated mean effective dose was in all cases higher than that advocated by ICRP103. **Conclusion:** In view of these results, it seems necessary to establish a culture of radiation protection among the radiologists and CT scan operators. A modified variant of the protocol of chest-abdominal-pelvic scan is being evaluated in the Unit as a result of the wide gap between our values and those of the ICRP Publication 103. Further study on a bigger sample of CT scans including other parameters like the Coumputed Tomography Dose Index volum and the quality of CT scan image is desirable for the purpose of reducing patient doses. **Keywords:** Patient dose, standard radiation dose, Computed tomography, Radiation Dose.

COMPARATIVE STUDY OF PATIENT DOSE AND STANDARD DOSE AT CT SCANNER IN MALI

Siaka Sidibé, Mohamed Traoré, Mody Abdoulaye Camara, Salia Coulibaly, Koniba Diabaté, Apho Sallé Koné ép. Bagayoko, Adama Diakité, Idrissa Mama Diarra. Bamako, Mali.

1. Introduction

Medical practices for therapeutic or diagnostic purposes are the main source of exposure to ionizing radiation of artificial origin [1, 2, 3]. In this context, radiation protection of patients is a major and legal concern in Mali [4]. We have in this framework undertaken this work whose purpose was to compare the dose received by the patient during a CT scan in Mali to the reference dose.

2. Material and method

It is a comparative study of doses during CT scan's examinations at the Hôpital du Mali from January 1St to December 31, 2015. The reviews have been conducted on a Siemens SOMATON 16® scanner type installed in 2012. Were included in the study all patients aged at least 16 years for which one of the following CT scan have been done: lumbar spine without contrast injection, cerebral without and or with intravenous injection of contrast (IVC), thorax with IVC, abdominal-pelvic with IVC, chest-abdominal-pelvic (TAP) with IVC. These reviews were selected due to their high frequency in our practice and realized according to a standard protocol. Were excluded from the study reviews for whom automated dosimetric data have not been saved. The dose-length product (DLP) in mSv.cm and the average effective dose by anatomical region examined in mSv were CT scan parameters used to assess the level of patient's irradiation [5, 6, 7]. The results of DLP values distributions by acquisition were compared to currently diagnostic reference norms (NRD) [5, 6, 7].

3. Results

A sample of 200 patients met our inclusion criteria. It was CT scan for lumbar (33%), brain without injection of contrast (26%), brain with IVC (18%), abdominal-pelvic without then with IVC (12%), chest without then with IVC (6%), TAP without then with IVC (5%). The distribution by sex and age, as well as the comparison of the dosimetric parameters to the NRD are represented in **figures 1 to 7**. The average effective dose in mSv calculated was 2.8 for the cerebral vs 1.6 (without IVC) and 1.7 (with IVC) according to the CIPR103, 13.09 for the lumbar vs 11 according to the CIPR103, 13.9 for the chest vs. 8 according to the CIPR103, 38.4 for the abdominal-pelvic vs 15 according to the CIPR103, 68.3 for the TAP vs 18 according to the CIPR103.

4. Discussion

The estimation of the risk associated with individual exposure to ionizing radiation is generally estimated by the effective dose. Our study suffered some limitations like lack of quality image evaluation. In fact it is established that in medical imaging, the dosimetric aspect should not be divorced from the quality of the images [1, 2, 8]. Among the 200 exams held, CT for the exploration of the lumbar spine was 33%. In the literature, the abdominal-pelvic scanner represented 30% and lumbar spine 14.9% of examinations [1, 2, 3, 8]. This predominance is certainly linked to the frequency of the lumbar spine's pathologies in our study population who had an age greater than or equal to 46 years in 60.5% of cases. As showed in our study PDL value during brain CT scan fluctuates between 1095,81 and 2051,56 mGy.cm with for a majority of patients who received a dose between 1151 and 1250 mGy.cm. So, our DLP values are superior to the NRD accepted in the United Kingdom (NRD $\leq$ 930mGy.cm), in France (NRD $\leq$ 1050mGy.cm), but remain mostly close to the data acceped in Canada (NRD $\leq$ 1352mGy.cm) [5, 6]. The same statement is noted in lumbar, chest, chest-abdominal-pelvic CT scans. Similarly, the average effective dose calculated in our series was something either review, superior to that

advocated by CIPR103 [6, 7]. These results are certainly due to the length of the scan area, because in all cases a standard protocol of scanning was selected by the CT scan operator.

5. Conclusion

According to these results, it seems necessary to establish in teams of radiologists and CT scan operators a true culture of radiation protection. Already, a modified variant of the TAP protocol, is being evaluated in the service of the fact of the wide gap between our values and those of the CIPR103. A work on a larger series including additionnal parameters like the computed tomography dose index volum and the CT scan image quality is desirable.

6. Figures

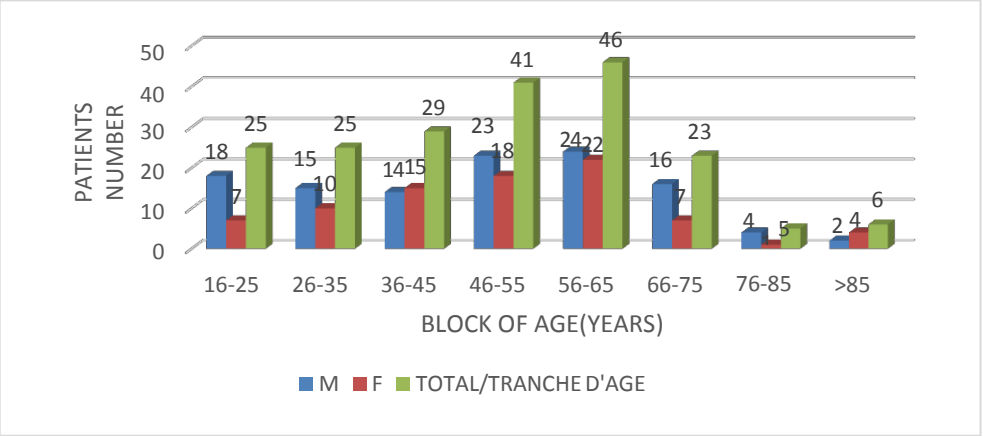

Fig. 1: Distribution of patients based on age and sex.

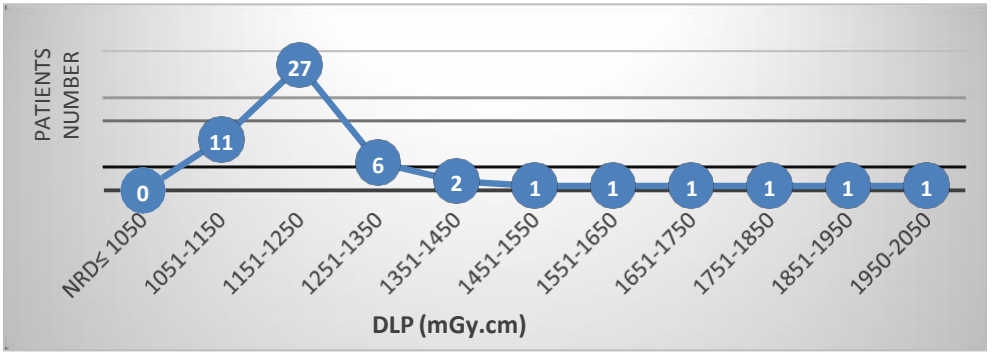

Fig.2: Comparison of the DLP of CT of the brain whithout IVC to the NRD

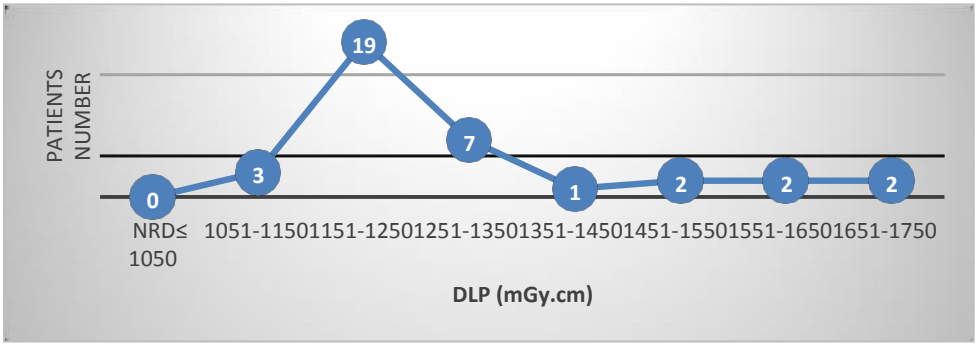

Fig. 3: Comparison of the DLP of CT of the brain whith IVC to the NRD

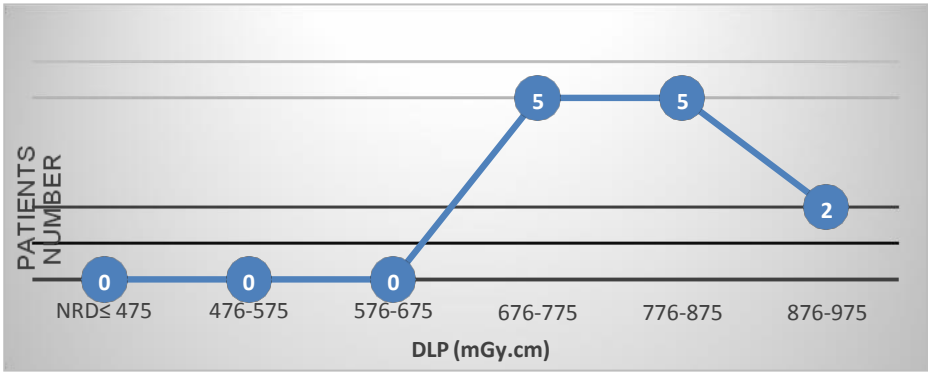

Fig. 4: Comparison of the DLP of CT of chest whith IVC to the NRD

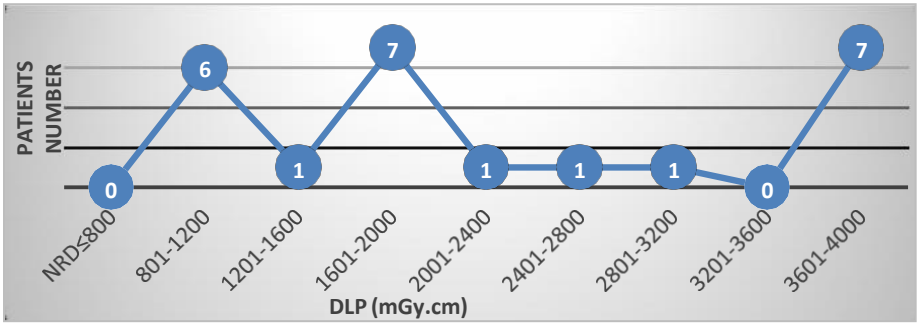

Fig. 5: Comparison of the DLP of CT of the abdominal-pelvis whith IVC to the NRD

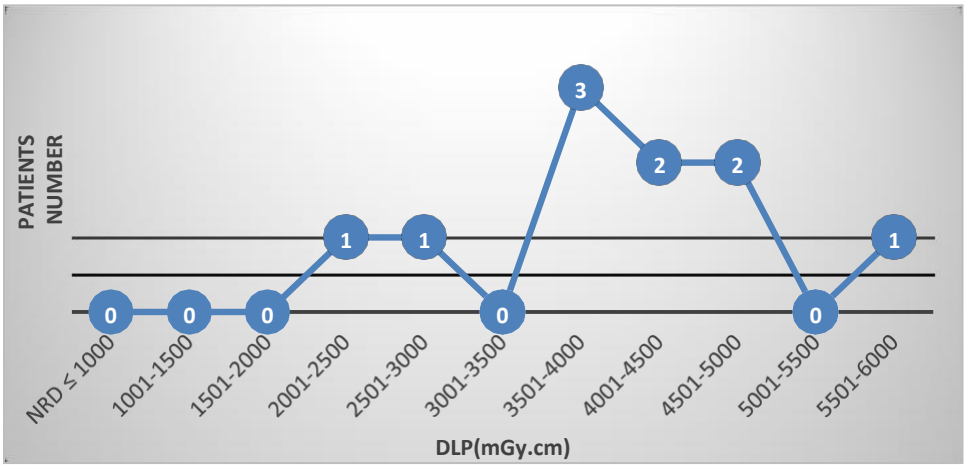

Fig. 6: Comparison of DLP of CT examination of the TAP whith IVC to the NRD

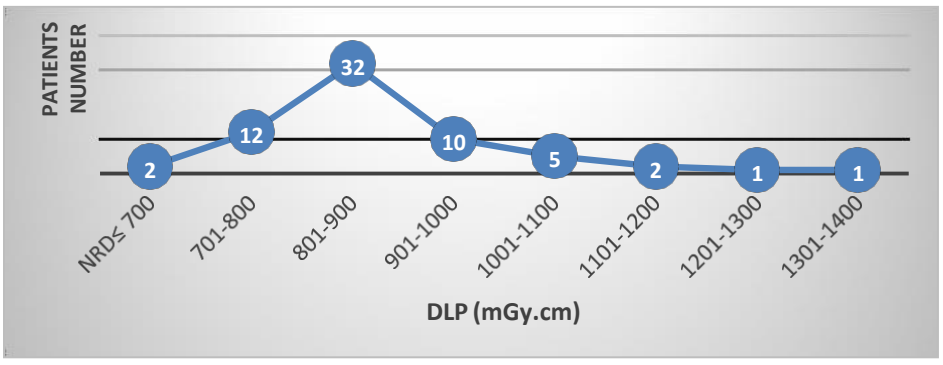

Fig. 7: Comparison of the DLP of CT examination of lumbar spine whithout IVC to the NRD

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THE WAYS OF MEDICAL EXPOSURE OPTIMIZATION FOR CONVENTIONAL DIAGNOSTIC RADIOLOGY IN UKRAINE

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Abstract

According to ICRP and IAEA recommendations optimization of radiation protection for Diagnostic Radiology exposure should be based on the monitoring of patient doses, development of diagnostic reference levels (DRLs) at clinically acceptable image quality and implementation of quality control program. In paper the results of approbation of quality control program in X-Ray Diagnostic Departments of Ukraine are presented. Program included the complex of control tests for the technical parameters of X-Ray units, image receivers and study of patient doses. There were tested 110 radiography units, 32 fluoroscopy and 12 mammography units. The DRLs were determined for 12 radiography types (11,300 direct measurements and calculations), three fluoroscopy types (about 600 measurements and calculations) and mammography (about 500 average breast doses). It was established that reliable estimation of 'standard' patient doses could be received for every X-Ray diagnostic unit on the base of quality control tests and results of national survey of work's technique and exposure data. Implementation of the developed quality control program with standardized methods of control of technical characteristics for radiography, fluoroscopy and mammography units, estimation patient doses in comparison with DRLs, control diagnostic image quality will facilitate to optimization of medical exposure, reduce the population collective doses in Ukraine.

1. INTRODUCTION

In Ukraine, as in most countries of the world, medical diagnostic exposure forms the largest collective dose of the population (after natural radiation sources), which, accordingly, increases the risk of radiation-induced cancers. Reducing collective doses and radiation risk is possible by optimization of medical exposure: reducing of patient doses as low as possible while maintaining an acceptable quality of the diagnostic image. According to ICRP and IAEA recommendations optimization of radiation protection of patients in Diagnostic Radiology should be based on the monitoring of patient doses, study of the dose distributions for the most common diagnostic examinations or procedures with the highest patients' doses and the establishment of national diagnostic reference levels (DRLs) [1, 2]. The next way of optimization of medical exposure is the implementation of quality control programs for X-ray equipment in clinical practice. The evaluation of technical state of the X-Ray units and chosen technique parameters in practice for diagnostic procedures gives a possibility to study the influence of technical parameters on the doses and image quality [3, 4]. In paper the results of the study of patient doses for the most common types of conventional of X-ray diagnostic examinations are presented, the ways of optimization of medical diagnostic exposure are determined.

2. MATERIALS AND METHODS

At the first stage of research on the medical exposure optimization in Diagnostic Radiology the patients' doses during various types of X-ray diagnostic procedures were studied in frame of large-scale investigations of X-Ray Diagnostic Departments in different regions of Ukraine. The patients' doses were evaluated by two methods [5]:

- Direct dosimetry using ionization chambers for measurements of "dose-area product" (DAP) in fluoroscopy, and thermoluminescent dosimeters (TLD) – for measurements of entrance surface dose (ESD) in diagnostic radiography;
- Indirect dosimetry – the calculation of DAP and ESD using the values of radiation output of X-ray units for different anode voltages, technique parameters of examinations and exposure data.

The patients' doses were studied for the following X-ray diagnostic examinations:

— 12 types of radiographic examinations (chest, 3 parts of spine, pelvis, skull in main projections) and fluorography, in total there were estimated about 11,300 entrance surface doses;
  - 5,500 measurements of the ESD_{meas} values by TLD dosimetry;
  - 5,780 calculations of ESD_{cal} values.

— 3 types of fluoroscopy (chest, Ba meal, Ba enema), there were about 600 measurements and calculations of DAP values.

— mammography – about 500 calculations of the average glandular dose (AGD) in the breast.

At the second stage of the research, the influence of the technical state of the X-Ray units, the image's receivers and used techniques of diagnostic examinations to patient doses and the image quality were studied. In according with European Guidance No. 162 [3] it was developed the quality control (QC) program which included the complex of control tests of the technical parameters of X-Ray units, image receivers and estimation of patient doses for radiography, fluoroscopy and mammography. For carry out of all tests of QC program there were used Dosimeter Piranha R&F/M 657, Image Quality Phantom FLURO for R/F, PAVO Attenuation Body for Fluro Phantom and Mammo Phantom CIRS (Model 011A). On each examined X-ray unit the doses of "standard" patient were evaluated for most common X-ray examinations. The total image quality index was defined as the ratio of the sum of positive tests in according with image criteria to the full number of performed tests, its value ranged from 0.0 to 1.0.

3. RESULTS AND DISCUSSION

The national DRLs values for most common radiography examinations were established according to EC recommendations [4] as third quartiles of distributions of average ESD values for 'standard' patients which were estimated from dose measurements on each examined X-ray unit. Due to the fact that the direct measurements of patients' doses can not be carried out for all X-Ray units, so the direct measured ESDs for patients were compared with calculated values of ESDs for the same patients using the radiation output data of the X-Ray units, technical exposure data. It was established the high degree of correlation between the calculated and measured ESD values (R = 0.92-0.97), although in most cases the calculated values of the doses were 20-25% lower than the measured values. The results of routine monitoring of X-ray machines (the checking of radiation output) and data collection of national survey about exposure parameters and conditions of examinations were allowed to asses the "standard" patients' doses for large numbers of X-Ray diagnostic units with acceptable errors. The forms of exposure data collection were proposed by IAEA in frame of regional project RER9162.

The histograms of DRL values for 9 types of radiographic examinations (direct measurements of patients' doses) are presented in comparison with DRL values estimated from distributions of calculated ESDs and IAEA Guidance Levels for Diagnostic Radiography [2] (Fig. 1).

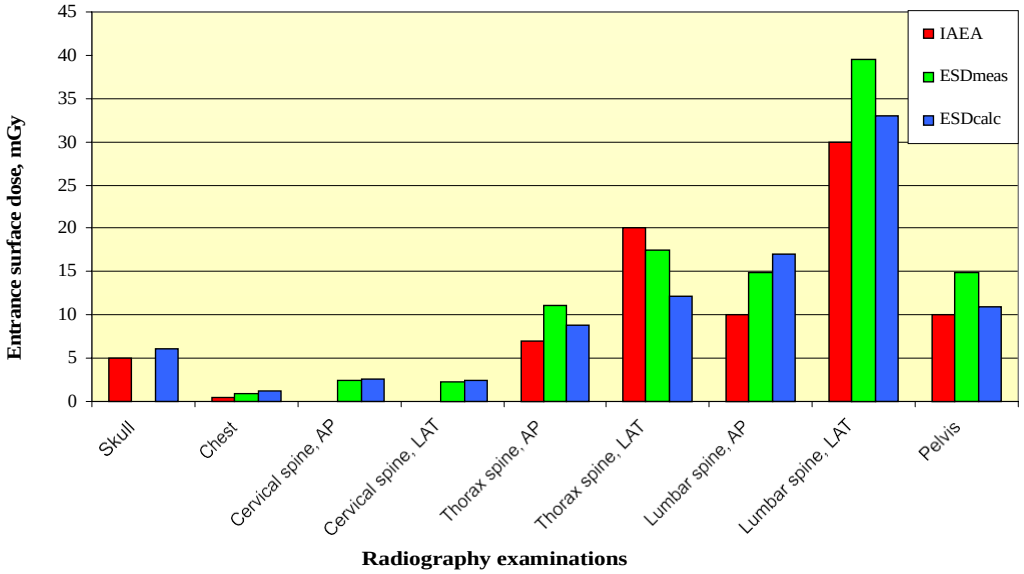

FIG. 1. Comparison of national DRLs in Ukraine with IAEA Guidance Levels for Diagnostic Radiography

As it can be seen from Fig. 1, for the majority of radiography examinations (except Thorax spine, LAT) the national DRLs based on results of the measured ESDs exceeded the IAEA Guidance Levels for Diagnostic Radiography in 1.5-2.5 times. The established DRLs for the most common radiographic examinations have been approved by the State Nuclear Regulatory Inspectorate of Ukraine as national diagnostic levels for Radiography and included into "General Safety Rules for using Radiation Sources in Medicine" (2017).

For study of the technical parameters influence on the patients' doses and image quality, all X-Ray units for radiography were contingently divided into 3 groups: Group 1 – the old X-ray machines, used more than 15 years old (film imaging systems); Group 2 – modern X-ray machines produced in Ukraine, used less 10 years old (film and digital imaging systems); Group 3 – modern foreign X-ray machines (digital imaging systems). The distribution of mean values of ESDs for radiography Chest (PA) and Lumbar spine (AP) in the three groups of X-Ray machines is shown in Fig. 2.

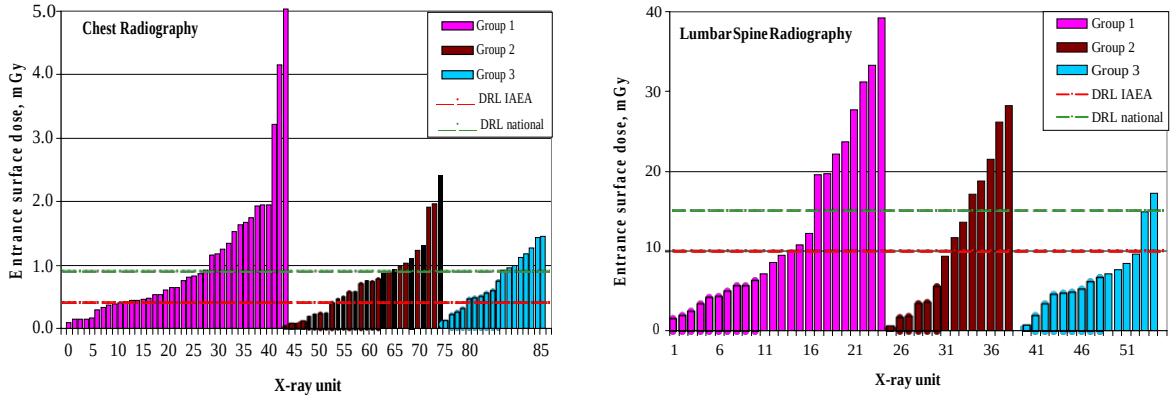

FIG. 2. The mean values of the ESDs for radiography Chest (PA) and Lumbar spine (AP) in 3 groups of X-Ray Units

As can be seen from Figure 2, the highest values of ESDs are observed for Group 1 X-Ray Units. The mean values of ESDs in this group for Chest radiography are higher than the doses in other groups by factor 1.4, for radiography of the Lumbar spine (AP) - by factor 1.2 (Group 2) and 1.9 (Group 3).

The total quality index (on all proposed criteria) for X-Ray units "Group 1" did not exceed 0.6 at the maximum value of 1.0. The main reasons for the high doses and insufficient quality of the obtained images were the problems of the technical state of the X-Ray units, including the absence of diaphragm and light indication of the radiation field, the inadequate general filtration or the absence of additional filters, and the choice of non-optimal technique parameters for diagnostic investigations.

A similar situation was observed with the patients' doses (DAP) for X-ray machines for fluoroscopy. The examined fluoroscopic machines also were divided into three groups: Group 1 – X-Ray units with phosphor screens (without an X-ray amplifier); Group 2 – with analog image visualization systems; Group 3 – modern fluoroscopy units with digital imaging systems. The distributions of average values of measured DAP during fluoroscopy procedures Ba meal and Ba enema for selected groups of X-Ray units are shown on figure 3.

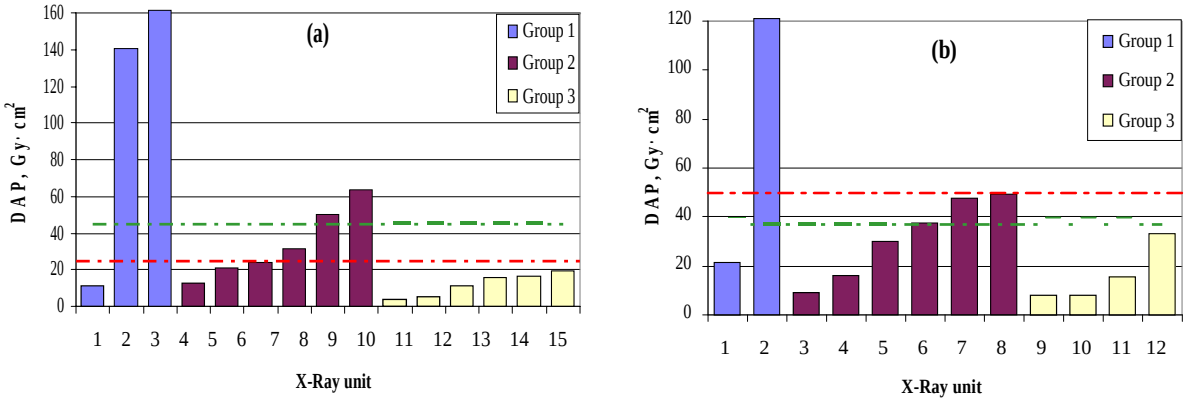

FIG. 3. Distributions of measured DAP for fluoroscopic procedures: Ba meal (a) and Ba enema (b)

In Fig. 3-a, the red dotted line indicates the DRL for the Ba meal procedure in European countries – 25 Gy·cm^2 according to the EC Guidance 109 [4], the green line is 36 Gy·cm^2 that accords to the third quartile of distribution of measured DAP in surveyed X-Ray units of Diagnostic Departments in Ukraine. For Ba enema

procedure DRL in European countries is 50 Gy·cm^2 (red dotted line) according to the EC Guidance 109 [4], the third quartile of distribution of measured DAP in this investigation is 37 Gy·cm^2, green line (Fig. 3-b).

It was established that the mean value of patient doses during Ba-meal procedures for Group 1 – X-Ray units with phosphor screens (direct fluoroscopy) was 3.4 times higher than for X-Ray units with analog systems of image visualization (Group 2) and 8.8 times higher than for Group 3 – X-Ray units with digital imaging systems. The DRL for Ba-meal procedure was 36 Gy·cm^2 that exceed European DRL in 1.4 times. If X-Ray units for fluoroscopy procedures with phosphor screens (without X-ray amplifier) will be excluded from the practice of Diagnostic Departments in Ukraine the DRL for Ba-meal procedure could decline to 24 Gy·cm^2, which will be in accordance with EC Guidance 109[4].

The mean value of patient doses during Ba-enema procedures for Group 1 X-Ray units (direct fluoroscopy) was 2.3 times higher than for X-Ray units of Group 2 (analog systems of visualization) and 4.4 times higher than for Group 3 (digital imaging systems). Nevertheless for Ba-enema procedures in this investigation the DRL was 35 Gy·cm^2 while European DRL is 50 Gy·cm^2 [4].

Comparison of patients' doses with the obtained image quality on X-Ray units for fluoroscopy showed that for all types of analogue devices (Group 1 and Group 2), the entrance surface dose rate was 1.5 to 7.5 times higher than the IAEA Guidance level of dose rate for normal fluoroscopy - 25 mGy/min [2], while the image quality was bad or not acceptable (most image quality criteria were not met). On X-ray units with a digital image receiver (Group 3), the dose rate on the patient's body surface was 4-20 mGy/min (less IAEA Guidance level), and the diagnostic image quality was an acceptable or very good (all image quality criteria were met).

These results demonstrate the unreasonableness of use in the practice in Ukraine the fluoroscopy analog devices with phosphor screens (without image intensifier).

Among surveyed mammography X-Ray units with digital image receivers were machines of Ukrainian (two generations) and import manufacture. It was found that average glandular dose for breast thickness 45 mm on almost for all types of mammography X-Ray units did not exceed acceptable levels - 2.5 mGy [6], but for Ukrainian mammography X-ray units of the first generation ((in using more than 10 years), the image quality of test objects in Mammo Phantom was extremely low.

Thus, developed and tested QC program for radiography, fluoroscopy and mammography equipment can be implemented in practice. Program includes necessary tests and basic equipment for quality control; the forms of protocols, the methods for assessment patient doses on different types of X-Ray units. The implementation of QC program into the practice of X-Ray Diagnostic Departments should be very useful, in case of exceeding the DRLs on a particular X-Ray unit or bad results of the control tests according to the established quality criteria, corrective actions should be taken while maintaining an acceptable quality of the diagnostic image.

4. CONCLUSION

Introduction of a national quality control program with standardized methods of control of technical characteristics for radiography, fluoroscopy and mammography equipment, estimation the doses for 'standard' patient and comparison with DRLs, control diagnostic image quality will promote to optimization of medical exposure, reduce the population collective doses and radiation risks of medical diagnostic exposure in Ukraine.

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WEB BASED TOOL FOR UPDATE OF DIAGNOSTIC REFERENCE LEVELS AND A SUPPORT FOR OPTIMIZATION

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Abstract

The Swedish Radiation Protection Authority have developed a web-based tool for radiological departments to register local diagnostic reference levels (LDRL) and to be used as a supporting tool when optimizing examination protocols. A radiological department will in real time be able to compare the LDRLs from their equipment with other radiological departments in Sweden, but also receive a real time evaluation of haw they perform in relation to national diagnostic reference levels (NDRL). When comparing to their own reported LDRLs with others performing the same examinations it will be possible to access other radiological departments' clinical examination protocol as well the brand and model of their equipment. This web-based tool, DosReg, has been developed for six different modalities: Computer tomography, Nuclear medicine, Mammography, Interventional procedures, Conventional radiology and CBCT dental. LDRL data that is collected will be the ground of setting new NDRLs, which Sweden have decided to do every fourth year for both adults and paedriatric patients. DosReg will also make it possible for the authority to overlook trends within radiology, and monitor if optimization of examination protocols is being performed.

1. INTRODUCTION

Sweden have had a system for national diagnostic reference levels (NDRL) since 1999 when a pilot study generated data to establish NDRLs for 12 different diagnostic examinations within several modalities. The NDRL was set as the third quartile of the distribution of local diagnostic reference levels (LDRL). Mandatory reporting of LDRL to SSM have since then taken place three times (2004, 2008 and 2013). Each reporting period has resulted in published reports, where data has been analysed and the national results have beenpresented.

The introduction of NDRLs have had a major impact on the radiation protection and significantly reduced the radiation dose to the population. The collective dose to the Swedish population from medical exposures is estimated to 5800 manSv per year. Approximately 1000 manSv is averted yearly in Sweden compared to the base year 1999. 60% of this can be explained by the introduction of NDRLs and 40% is due to the change from film to digital receptors.

At these three occasions LDRL data has been reported manually, excel files have been filled in and sent to SSM, this system has been time consuming and leading to that the results in published reports have been available for the users over 3 years after they have collected and reported the LDRL data. Another identified problem has been that the examinations have been too unspecific, for example abdomen with contrast could be a low dose examinations of the aorta or high dose examinations of the liver looking for metastasis.

The intention when developing "DosReg" has been to facilitate reporting of LDRL, update of NDRL and estimate collective doses from medical exposures. DosReg could also be used by professionals in their optimization work, doses and protocol settings can easy be compare between different sites with the same equipment.

2. METHODS

In 2015 SSM used as a pilot a modified version of ARPANSA National Diagnostic Reference Level Survey for CT examinations [1]. With gained knowledge from this pilot, SSM decided to develop an own web-based dose registration tool, named DosReg. During the ARPANSA pilot it was clear from discussions with medical physicist

in the field that there was need for active support in the optimization process, as todays modern equipment with iterative reconstructions et cetera are difficult to optimize as there are many parameters that can be changed to improve image quality, while keeping the dose to the patient as low as possible.

DosReg was therefore developed to fulfil the needs of the authority in collecting LDRL data from a number of different radiological procedures, but also to fulfil the needs of the medical physicist in the field as an active optimization support.

SSM have used different user groups for each modality, with 3 - 4 medical physicists specialized in each modality. These user groups took an active part in deciding which examinations that should be included, in most cases those that gave the highest contribution to the population dose. When it came to the optimization process, these user groups where fully responsible for which protocol parameters that should be registered and available for others to support them when optimizing protocols.

2.1. Structure of DosReg and launching of different modalities

DosReg is a web portal from where the user can select which modality they would like to report. The first step is to register the equipment, brand and model, the second step is to register the protocol parameters and finally to collect and report dose data to SSM.

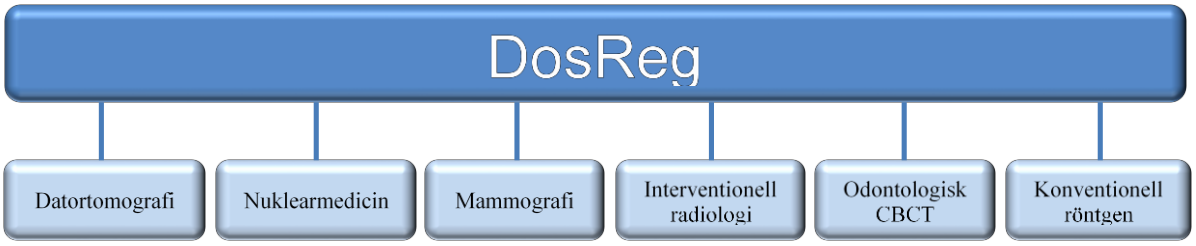

Figure 1. The structure of DosReg with the different underlying modalities

Computer Tomography was the first modality to be launched, 1st of September 2016, to be used by the radiological departments in Sweden. The CT modality has 8 examinations for adults and 3 examinations for paediatrics, all examinations are specified with diagnostic issue, for example; Thorax with contrast must be examinations where the purpose has been to look for tumours or metastasis.

In the spring of 2017 Nuclear medicine and Mammography was launched and the remaining three modalities will be available towards the end of the summer 2017.

2.2. Number of registrations in Sweden

The system has been designed for reporting and to support the optimization process.

Modality	Nº systems	Nº protocols	LDRL/yr
CT	144	8	1152
Nuclear medicine	32	15	480
Interventions	300	5	1500
Conventional x-ray	1000	10	10000
Mammography	167	1	167
CBCT	144	3	432
			13731

Table 1. Calculation of the number of LDRL registrations that DosReg must be able to handle on a yearly bases. Nº systems, is the number of systems installed, in Sweden, Nº protocols the number of protocols in DosReg

According to the Swedish regulations, LDRLs shall be measured at least every third year or after any changes of the procedure or equipment. From 2018, it will be mandatory to use DosReg for reporting data to SSM. The use of DosReg is expected to be relatively high during the first year, assuming between 9-11,000 registrations. Thereafter, the number of annual registrations is expected to decline but will probably be around 7-9,000 per year.

2.3. Weight intervals

The weight interval for adults has been increased from 60-80kg to 60-90kg, as the average weight has increased in Sweden with roughly 10kg since 1980. The increase in weight interval has been made to make it easier for the radiological departments to collect the needed 20 patients per examination that is the lower limit for establish of LDRL for adults.

The approach for paedriatric patient is different as the weight of infants can be less than 2 kg and for obese teenagers might surpass 100 kg. To be able to cover this wide range of patients SSM have decided to adopt the idea with DRL-curves [2], data has been collected from Swedish Children Hospitals to establish Swedish DRL-curves [3].

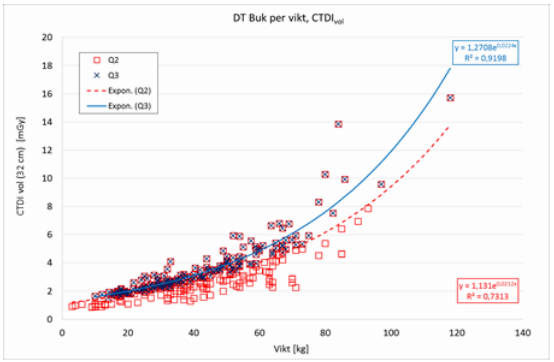

Figure 2. CTDIvol (mGy) as a function of patient weight for CT abdomen examinations. Q2 (red quadrants) and Q3 (blue crosses). Total number of examinations are 304 from four hospitals. All CTDIvol values are for 32 cm PMMA phantom. [3]

To be able to create DRN-curves, exposure data for other modalities (NM, Conventional Radiology and Interventional procedures) and paedriatric exams will be collected with DosReg during 2-3 years, this data will then be used to create DRL-curves for remaining modalities and examinations/treatments.

2.4. Reporting LDRL to DosReg

Radiological departments needs to report 20 adult patients and 10 paedriatric patients, for each examination that SSM has issued NDRL for. Before the data is sent to SSM, the medical physicist will be able to control that all data points are correct, as all patients dose data points are presented in graphs, either based on weight or on body mass index (BMI).

Figure 3. CTDIvol data is presented as a function of weight and as a function of BMI. Yellow triangles are men and green squares are women.

DosReg will then calculate the LDRL for that specific site and immediate present it in a histogram where it will be compared with other radiological departments and if it is in compliance with NDRL.

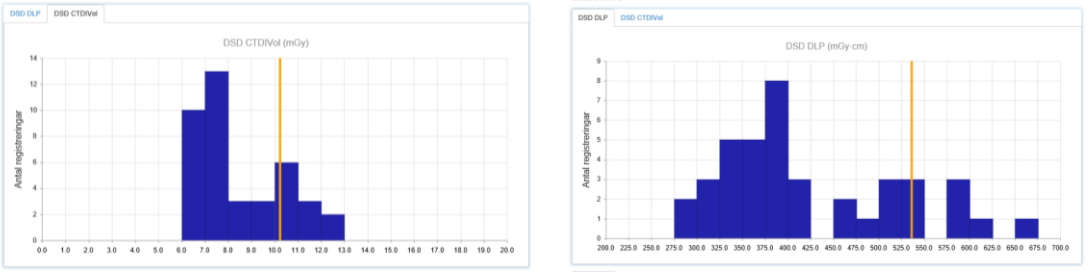

Figure 3. CT abdomen with contrast, the reporting clinics average DSD is presented as a yellow line, the blue histograms are DSDs from other clinics in Sweden. Both CTDIvol and DLP shows a dose variation of a factor 2.

Exposure data for all modalities will been collected during 2017, but it not be mandatory for the radiological departments to use DosReg before 2018. Exposure data from CT examinations has been collected since 1st of September 2016, which explains why the majority of data reported by July 2017 comes from CT (246).

3. RESULTS

DosReg has been received with enthusiasm among medical physicist that have been involved in workshops and those that have started to use DosReg as support in their work with optimization of protocols. During first 6 months of 2017 nearly 300 registrations of LDRLs have been made. DosReg will be in full use from February 2018 and the first yearly report will be published in early 2019.

4. DISCUSSION

Diagnostic reference levels are an important tool to promote optimization of protection within the radiological departments. NDRLs must be updated and the feedback on the reported LDRL should be immediate as this will encourage the users to improve the protocols that are in use. The ability to see other radiology departments protocols will make it easier to identify shortcomings in the own procedures or equipment.

Paedriatric patients can weight from a few kilos to 100 kilos. This large spread in weight makes DRL-curves more suitable than a single value.

With a web-based dose registration software, data can easily be collected and NDRL updated. However with the pragmatic approach that are applied in Sweden, where the NDRL are selected as the third quartile of the distribution of LDRL, the NDRL should not be changed too often. A suitable frequency can be every four year, at this time 50% of all equipment has in averaged been exchanged.

5. CONCLUSIONS

DosReg has shown to be an efficient tool for reporting of LDRL and support in optimization of protection. It is also an effective tool for the authorities supervision, updating of NDRL as well as collecting data for population dose estimations, .It will also be possible for the authorities to track changes in procedures as trend analysis can be made automatically.

ACKNOWLEDGEMENTS

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ESTABLISHMENT OF DIAGNOSTIC REFERENCE LEVELS (DRLS) FOR COMMONLY PERFORMED CTS IN THAI CANCER HOSPITALS

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Abstract

The aim of the paper was to establish diagnostic reference levels (DRLs) for commonly performed CT examinations in Thai cancer hospitals. Eight Thai cancer hospitals were surveyed. Each has its own imaging facility with a CT scanner. Each facility was asked to fill out a questionnaire regarding all CT examinations in 2016 for 4 regions i.e. brain, neck, chest and abdomen. Values of DRLs were established by using the 75thpercentile of $CTDI_{vol}$ (mGy) and DLP (mGy•cm). 2,464 CTs comprise of 576, 588, 656 and 644 examinations for brain, neck, chest and abdomen, respectively. The 75thpercentile of $CTDI_{vol}$ (mGy) and DLP (mGy•cm) of brain CT were 77.30 and 1198.80, respectively. For neck CT were 19.20 and 541.90, respectively. For chest CT were 24.30 and 771.84, respectively and for abdomen CT were 21.00 and 845.65, respectively. The paper established values of DRLs using the 75thpercentile of $CTDI_{vol}$ (mGy) and DLP (mGy•cm) for commonly performed CTs among 8 Thai cancer hospitals. The values are higher than data reported from European countries. Strategies for CT dose optimization should be applied in order to minimize patient's radiation exposure or follow ALARA (as lower as reasonably achievable) principle.

1. INTRODUCTION

Currently, CT is a powerful clinical equipment for the diagnosis and follow-up patients with cancers. It provides high quality, faster, painless, noninvasive and accurate imaging which results in significant benefit to clinical management. However, when compared with conventional X-ray imaging techniques, CT involves higher radiation doses to the patient [1].

Although, there are no legal dose limits for patients exposing radiation from diagnostic imaging. However, any radiation examinations should carry out the two basic principles of radiation protection, i.e. justification (providing more benefit than harm to the patient) and optimization (following the ALARA principle). The core of optimization is to first establishment of diagnostic reference levels (DRLs), as proposed by International Commission on Radiological Protection (ICRP) in 1996 [2]. DRLs allow the identification of abnormally high dose levels by setting an upper threshold, which standard dose levels should not exceed when good practice is applied. The ICRP recommends DRLs based on relevant local regional or national data [3]. In Thailand, there are no national DRLs for Thai patients with cancers.

The aim of the paper was to establish DRLs for most common CT examinations in Thai cancer hospitals affiliated with Department of Medical Service, Ministry of Public Health, Thailand, by using two dosimetric quantities i.e. volume computed tomography dose index ($CTDI_{vol}$) and dose length product (DLP).

2. METHODS

2.1 Patient doses

Patient doses ($CTDI_{vol}$ and DLP) were surveyed from eight Thai cancer hospitals. Each has its own imaging facility with a CT scanner. Each facility was asked to fill out a questionnaire regarding 4 frequently requested CT examinations performed in 2016 i.e. brain, neck, chest and abdomen regions.

2.2 Data analysis

Statistical analysis was performed using SPSS v. 18.0 for window. Quantitative variables are expressed as mean ± standard deviation. Values of DRLs were established by using the 75thpercentile of $CTDI_{vol}$ (mGy) and DLP (mGy•cm).

3. RESULTS

The patient doses were collected from 2,464 CT examinations of 8 CT scannersin 8 cancer hospitals during 2016. Results of the statistical analysis of the $CTDI_{vol}$ and DLP are presented in Table 1.

TABLE 1. Descriptive statistics of the dose distribution found across the 8 CT scanners surveyed in DLP (mGy·cm) and $CTDI_{vol}$ (mGy)

Exam	n	Range	Mean±SD	75th percentile
Brain				
DLP	576	468-2170	1082±275	1198.80
$CTDI_{vol}$	576	12-122	65±19	77.30
Neck				
DLP	588	70-864	433±160	541.90
$CTDI_{vol}$	588	4-30	16±5	19.20
Chest				
DLP	656	109-2094	630±318	771.84
$CTDI_{vol}$	656	5-34	17±7	24.30
Abdomen/pelvis				
DLP	644	145-2233	714±327	845.65
$CTDI_{vol}$	644	5-59	17±6	21.00

4. DISCUSSIONS AND CONCLUSIONS

This is the first time of a national survey on radiation doses from CT examinations for cancer patients. The paper established values of DRLs using the 75thpercentile of $CTDI_{vol}$ (mGy) and DLP (mGy•cm) for commonly performed CTs among 8 Thai cancer hospitals. The values are higher than data reported from European countries [3, 4, 5, 6, 7]. Strategies for CT dose optimization should be applied in order to minimize patient's radiation exposure or follow ALARA (as lower as reasonably achievable) principle.

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ADULT PATIENT DOSES IN COMPUTED TOMOGRAPHY EXAMINATIONS IN THREE REGIONS OF ALGERIA: PREMILINARY RESULTS TO ESTABLISH NATIONAL DRLS

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Abstract

A pilot study has concerned the most frequent CT examinations at five sites in the north, east and west of Algeria. The survey has included the recording of CT parameters and adult patient dose (CTDIvol, and DLP) of the head, thorax, abdomen, Abdomen-Pelvis, lumbar spine and thorax-abdomen-pelvis. Data were collected on 9 CT scanners (4-320 slices). The rounded 75th percentile of the dose spread was calculated by compiling all results. Around 900 patients underwent this survey. Regarding the range of doses recorded, large variations were evident. CTDIvol and DLP values among the scanners has been also analysed to estimate the heterogeneity of the patient doses between the departments. The results revealed significant discrepancies in dose values among the CT scanners. The rounded 75th percentile seems to be higher in some examinations comparing to those published in the literature. The ratio of the maximal to minimal dose indicators confirms the need to optimize our practice, in view of the fact that these are the first formulated DRLs in Algeria. However, these results provide a starting point for institutional evaluation of CT radiation doses.

1. INTRODUCTION

CT is a powerful clinical tool for the diagnosis and management of patients. Therefore, judicious use of the modality requires strict adherence to the principles of radiation protection [1]: justification and optimisation and to ensure that the risk to patients does not outweigh the benefit gained from the technique.

In Algeria, CT has undergone dramatic developments, with the introduction of multidetector technology, enabling CT machines to provide higher resolution and faster scan times as well as longer scan ranges. As a result, the numbers of examinations have increased to the extent that CT has made a substantial impact on not only patient care, but also patient and population exposure from medical X-rays. This relatively high dose modality,

which represents about 3–7% of all X-ray examinations, contributes up to 41% of the collective dose from diagnostic radiology in some countries [2, 3].

The aims of this study are: (1) to estimate patient dose for multi-detector-row CT examinations in different regions of the country, (2) identifying the distribution of dosimetric parameters for the most frequently performed indication-based CT examinations of adult patients, (3) to establish DRLs and compare results with literature.

2. METHODS

2.1. Participing institutions

Five sites from public and private sectors have been selected: three teaching university hospital (CHU Bab el Oued, CHU Blida, EHU Oran), one private hospital (Hopital Chahids Mahmoudi , HCM Tizi Ouzou) and one private medical imaging centre (Centre d'imagerie médicale, CIM Cheraga). The study was carried out with 9 CT units in the north, east and west of the country. All scanners surveyed had multislice capability ranging from 4 to 320 slices. Table 1 summarizes the scanners according to their manufacturers.

2.2. Patient population and CT procedures selection

A total number of 900 adult patients underwent CT exams, 53% of whom were female (see Table 2). All data were collected during 2015-2016. The patient age ranged from 16 to 97 yrs. and 16 to 93 yrs. for women and men, respectively. The most frequent CT examinations selected are based six body part: head, thorax, abdomen, thorax-abdomen, lumbar spine and thorax-abdomen-pelvis. All examinations considered are without contrast media.

2.3. Technical data and CT dose quantities

Structured form for data collection was established and used in all considered facilities. For each examination, patient doses (CTDIvol and DLP) and technical parameters (kVp, mA, scan time per rotation, collimated beam width, scan range and pitch) were recorded from the dose report. The number of the recorded examination data was approximately the same between the investigated CT scanners. Data collected for 20 adult patients for each type of CT examination on each CT unit are expressed as median (range). The rounded 75th percentile was used to calculate a DRL by compiling all results from the nine scanners participing in this study.

2.4. Establishment of Diagnostic reference level

At the core of optimisation is the establishment of diagnostic reference levels (DRLs), first proposed by the International Commission on Radiation Protection (ICRP) in 1996 [4] and subsequently introduced into Algerian legislation [5]. DRLs were calculated for all types of CT examinations in the survey as the third quartiles of CTDIvol and DLP value distributions.

3. RESULTS ANS DISCUSSIONS

Parameter settings for different CT protocols obtained in the survey are presented in Table 2. A large variation in all parameters, except the voltage, was observed. This resulted in a considerable variation of the dosimetric quantities, as shown in Table 3. Regarding the range of doses recorded, large variations were evident. The ratio of the maximal to minimal in DLP values was 7 for head, 14 for thorax, 22 for abdomen, 30 for abdomen-pelvis, 7 for lumbar spine and 12 for thorax-abdomen-pelvis. These results stress the need to pay attention to the optimization of the clinical protocols.

CTDIvol and DLP values among the 9 scanners has been also analysed to estimate the heterogeneity of the patient doses between the departments and between CT scanners. The results revealed significant discrepancies in dose values among the CT scanners. As an example, for CT head examination, 50% of the of CTDIvol values are greater than those recommended with only 33% of the DLP values below those published in the literature [5-6]. It was observed that lowest values have been recorded on CT scanners used in emergency departments where the most frequent exam performed is 'head CT'. Such dose discrepancies may be attributed to differences in CT

equipment and to local scan protocols. It may also point to a lack of understanding or manipulation of parameters, especially in delimiting the scan length.

The resulting DRLs, in term of CTDIvol and DLP, are represented in Table 4 and compared to literature for each examination. The 75th percentile of the CTDIvol and DLP distributions of the survey presented here is generally close to others studies [6-8]. However, for few examinations such as head and abdomen, deviations were observed due especially to the scan length selected.

4. CONCLUSIONS

The results of the first survey of CT doses in Algeria have been presented and DRLs proposed. The survey highlights the substantial variations in practice in the same centre for similar types of examination and similar patient group. Such observations indicate the need for improvement through implementation of measures to keep all doses within acceptable ranges for the clinical purpose of each examination. This work will be used to set updated values for the new technologies and practices introduced in our medical departments that may allow lower dose levels to be achieved and be appropriate for the local circumstances.

5. TABLES

TABLE 1. CT UNITS INCLUDED IN THE STUDY

Region	Site	CT Scanner (Model)	No. of slices	Manufacture	Year of installation
North	CHU Bab el Oued	Asteion	4	Toshiba (Japan)	2005
		Eclos	16	Hitachi (Japan)	2009
		Somatom Sensation	16	Siemens (Germany)	2005
		Aquilion One	320	Toshiba (Japan)	2008
	CIM Cheraga	Aquillion prime	160	Toshiba (Japan)	2015
East	HCM, Tizi ouzou	Revolution Evo	64	GE (United States)	2015
West	CHU Blida	Activion	16	Toshiba (Japan)	2011
		Brilliance	64	Philips (Netherlands)	2013
	CHU Oran	Optima	64	GE (United States)	2014

TABLE 2. RANGE OF PARAMETER VALUES FOR ADULT EXAMINATION PROTOCOLS

CT protocols	Tube voltage (kV)	Tube Current (mAs)	Scan length (cm)
Head	100-120	100-400	8-30
Thorax	100-120	30-387	16-47
Abdomen	80-120	30-300	12-55
AP	100-125	25-300	22-63
LS	100-120	75/10-451	21-42
TAP	100-120	25-400	37-80

TABLE 3. STATISTICS VALUES OF DOSES FROM CT EXAMINATIONS IN THIS STUDY

CT protocols	CTDIvol (mGy)		DLP (mGy.cm)	
	Median	Range	Median	Range
Head	61.8	17 -94	1139	313- 2414
Thorax	12.7	2.1-38.2	404.4	78.5-1108.4
Abdomen	14.3	2.8-40	446.3	63.7-1443
AP	14.5	2.6-67.5	614.4	91-2806.4
LS	24.4	7.2-40	765.2	198-1542.4
TAP	12.8	2.8-38.2	697.3	162-1987

TABLE 4: SUGGESTED ADULT DRLS AND PUBLISHED VALUES FOR CTDI (mGy) AND DLP (mGy. cm)

	Present study		France[6]		Switzerland [7]		Italy [8]	
	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP
Head	74.5	1284.6	65	1050	65	1000	69	1312
Thorax	15.2	520.2	15	475	10	400	15	569
Abdomen	20	778.2	-	-	15	650	18	555
AP	16.7	921.8	17	800	15	650	18	920
LS	31.1	840.7	45	700	30	850	42	888
TAP	13.3	854.5	20	1000	15	1000	17	1200

6. FIGURES

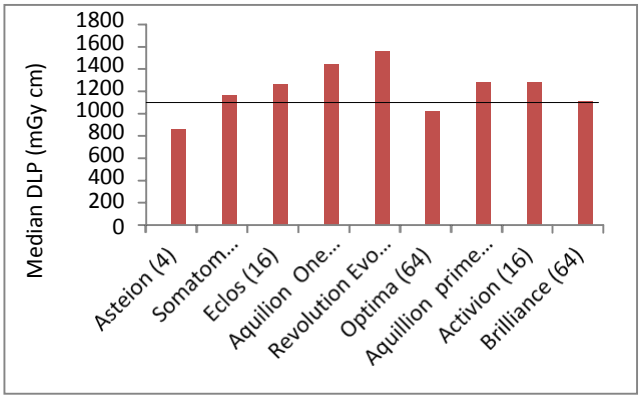

Fig. 1. Variation of DLP for head CT among scanners

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INTRAORAL EXPOSURES IN PORTUGAL - FROM 1990 TO 2017

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Abstract

Data from dental intraoral radiography quality controls was gathered from 1196 units (22% of the licensed X-ray units existing in Portugal), using film and digital image systems, between 2016 and 2017. The measured median incident air KERMA for superior molar tooth was 0,9 mGy. Comparisons with a 1990 published survey from dental exposures in Portugal were made. A 85% KERMA reduction was observed (6,0 mGy for the 1990 survey), which can be attributed to technical advances in the x-ray image receptors, as well as the establishment of Decree-Law 180/2002 that states the criteria for acceptability of radiological units. It was also observed an increase of x-ray exams, which is related to an increase of dental practitioners.

1. INTRODUCTION

Dental radiography is the most frequently conducted X-ray examination and it accounts for, at least, one third of all radiological examinations in most countries [1]. The most common techniques involve intraoral radiography, either to provide an image of the upper and lower teeth together (bitewing radiography) or to demonstrate full tooth structure, including pulp, root, and gum anatomy (periapical radiography) [3]. Although exposures to individual patients are low, the contribution to population dose is not negligible and a continuous update of data concerning the frequency of exposures and radiation doses is necessary, due to:

a) The increasing of direct digital imaging systems - Doses associated with charge coupled devices (CCDs) and computed radiography systems (photostimulable phosphor luminescence technology) have been reported to be 50% and 80% lower, respectively, than those associated with film techniques [3].
b) The increasing in dental healthcare – The number of dental practioners has increased from 1538 (in 1990) to 9338 (in 2016) [5].

According to the European Commission guidelines, all radiographic units, intraoral X-rays included, must have a quality control program that accesses the equipment radiation and image quality [6]. The Portuguese Decree-Law 180/2002 demands that quality control tests must be performed annually in intraoral units. [8]

The resulting quality control data of air KERMA was compared with data from a survey, conducted between 1989 and 1990 [7], in order to evaluate the present state of intraoral exposures in Portugal.

2. METHODS

2.1. The 1990 survey

In 1989 and 1990, Carvalho et al, conducted a nationwide survey in Portugal involving 250 units, covering about 25% of existing apparatus, estimating the annual frequency of dental radiographs and patient doses [6]. The survey was carried out by mail and dental practitioners were sent questionnaires (to collect information concerning the X ray unit, film type and annual number of dental radiographs), a dosimetric card and a film processing card to evaluate quality of processing. The dosimetric card included 6 TLD rods, aluminium filters and one radiographic film to evaluate entrance dose, HVL (half value layer), tube filtration and radiation size. The film processing card included two films, one to be developed in participant´s facilities and other to be exposed and revealed in a laboratory under standard conditions. By comparing optical densities

the quality of film processing was evaluated. Participants in the survey were to irradiate the cards in close contact with the X ray unit cone extremity, setting factors in routine usage for a superior molar tooth.

2.2. The 2016 quality controls

According to the Portuguese law [8], quality control tests are made annually in intraoral units across the countries which results in a large number of data. Between September 2016 and April 2017, 1196 units (22% of the operational X-ray units existing in Portugal), using film and digital image systems, were tested by a team of radiation protection experts.

Calibrated semiconductor dosimeters (Raysafe X2), were placed perpendicularly to the central axis and centred with the X ray unit cone extremity and five exposures were made. Incident air KERMA for superior molar tooth was measured.

In order to estimate the annual workload of the institution, dental professionals provided about the annual number of dental radiographies performed.

3. RESULTS

The measured 2016 median incident air KERMA for superior molar tooth was 0,9 mGy (0,8 mGy for digital detectors and 2,3 mGy for film). Digital detectors were found in 84% of the tested units.

Comparisons with the 1990 air KERMA are described in the Tables section. In Table 1 measured air KERMA for molar tooth radiography is described and, in table 2, a more detailed analysis is done, by categorizing the units by their tube voltage. Table 3 presents a comparison concerning the number of dental practitioners, frequency of examinations and dose to the population per 1000 inhabitants.

4. DISCUSSION

It was observed a 85% dose reduction (median values) in the 2016 data compared to the 1990 study which can be attributed to technical advances in the X-ray image receptors. Presently, digital detectors are the most used technique, representing 84% of the tested image systems. Most X-ray units also operate in higher tube voltages (Table 2) which contributed to lower doses. The publication of the Decree-Law 180/2002 that stated the criteria for acceptability of radiological units, and their implementation by the Portuguese authorities, also explains this finding.

It was observed an increase of X-ray exams, which is directly related to an increase of dental practitioners. This, combined with the growing simplicity in performing intraoral radiographies, results in a dose increase of about 17% per 1000 habitants.

5. CONCLUSIONS

In the studied period, although the radiation dose to individual patients had a significant reduction, the total dose in the Portuguese population increased in intraoral exams.

6. TABLES

TABLE 1. Measured Air KERMA (AK) for molar tooth radiography in 1990 and 2016

	Median	Lower quartile	Upper quartile	Minimum value	Maximum value
AK 1990 (mGy)	6,0	4,1	12	0,6	45
AK 2016 (mGy)	0,9	0,6	1,3	0,1	11

TABLE 2. Air KERMA (AK) for molar tooth radiography in 1990 and 2016 with exposure range

(kV)	Measured air KERMA 1990			Measured air KERMA 2016		
	Median	Range	Units	Median	Range	Units
50	9,0	0,63 – 46	41	1,4	0,5 – 11	8
60	9,1	2,7 – 32	43	0,7	0,1 – 11	248
65	4,4	1,8 – 17	46	1,1	0,3- 10	215
70	3,6	1,7 - 10	11	0,8	0,1 -6,7	709

TABLE 3. Comparison between 1990 and 2016 data – number of dental practitioners, frequency of examinations and dose to the population per 1000 inhabitants

	ental practitioners	X-ray exams per 10^3 inhabitants	Dose (mGy) per 10^3 inhabitants
1990	1538	86	516
2016	9338	671	603

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MEASUREMENT OF DOSE AREA PRODUCT RECEIVED BY ADULT PATIENTS UNDERGOING DIGITAL RADIOGRAPHY EXAMINATIONS IN UTTARAKHAND, INDIA AND ESTABLISHMENT OF LOCAL DIAGNOSTIC REFERENCE LEVELS

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Abstract

The present study aimed to measure dose area product (DAP) received by patients during digital radiography (DR) examinations and to establish local diagnostic reference levels (LDRLs) in Uttarakhand state of India. DAP received by 1128 patients undergoing 10 commonly performed DR examinations, viz. chest (AP, PA), cervical spine (AP, LAT), thoracic spine (AP, LAT), lumbar spine (AP, LAT), abdomen and pelvis, were measured at 15 DR rooms in 5 major medical centres of the state. Wide variation was observed among DAP values for similar DR examinations performed in different rooms, which was mainly attributed to the variation in operator specific selection of exposure factors and collimator settings. The third quartile of the distribution of DAP values for a given examination was calculated to establish LDRLs. The majority of the measured dose data were either comparable to or lower than the DRLs proposed by European Commission (2014). The LDRLs presented in the paper may be adopted by radiology practitioners of the state to reduce patient dose without compromising the required diagnostic value of the image.

1. INTRODUCTION

Diagnostic X-ray imaging is the largest contributor to total population radiation exposure from man-made radiation sources [1]. The increased use of diagnostic X-rays is attributed to the advent of more sophisticated technology and increased reliance on non-invasive methods in medical applications. In view of its potentially adverse health effects, radiation exposure resulting from diagnostic X-ray examinations should necessarily be monitored and controlled. The International Commission on Radiological Protection (ICRP) has recommended the use of diagnostic reference levels (DRLs) for patients with the objective to help avoid radiation dose to the patient that does not contribute to the clinical purpose of the image [2]. DRLs for diagnostic radiography examinations are generally expressed in terms of entrance skin dose (ESD) or dose area product (DAP). The DAP is potentially more reliable than ESD because it correlates with the total radiation energy delivered to the patient by taking into account not only the magnitude of radiation dose but also the size of the radiation field [3]. In addition, it can be obtained from direct measurement using a transparent ionization chamber (DAP meter) without interfering with the X-ray examination.

In India, national DRLs for diagnostic X-ray examinations have been proposed in terms of ESD [4, 5], but no study is available on the measurement of DAP for these examinations. The present study aimed at measuring DAP received by patients during commonly performed diagnostic radiography examinations in a few major medical centres of Uttarakhand state of India and to use the obtained data to establish local diagnostic reference levels (LDRLs).

2. METHODS

This study included the measurement of DAP received by 1128 patients in 15 digital radiography (DR) rooms of 5 major medical centres during 10 commonly performed X-ray examination: chest (AP, PA), cervical

spine (AP, LAT), thoracic spine (AP, LAT), lumbar spine (AP, LAT), abdomen and pelvis. Prior to measurements, each DR machine was subjected to detailed performance evaluation checks e. g. kVp, mA and timer accuracy, total filtration, half value layer (HVL), output consistency, dose and mA linearity, collimation and beam alignment. All the selected DR machines were recently installed over a period of two years. A difference of as high as 17% was found between the beam outputs of any two DR machines. The study utilized a DAP meter (Model: Diamentor CI-L981196, PTW, Freiburg, Germany), that was calibrated to measure the DAP values in the range of tube potentials 50-150 kV with an accuracy of 0.1 mGycm^2. The obtained DAP data was statistically analyzed and the range, mean, standard deviation (SD), median and third quartile DAP values were calculated. The third quartile of the distribution of measured DAP values for each X-ray examination was taken as LDRL.

3. RESULTS

Table 1 presents the patient characteristics and technical parameters selected for the diagnostic X-ray examinations included in this study. Fixed FFDs of 180 cm and 100 cm were used for chest PA and rest of the X-ray examinations respectively. Descriptive statistics of DAP values recorded for each examination performed in different DR rooms has been shown in Table 2. The extent of variation of DAP for an X-ray examination is indicated by the ratio of maximum to minimum DAP values for the examination, which ranged from 4.02 for cervical spine LAT to 13.28 for pelvis. Fig. 1 compares the mean values of DAP obtained for different DR examinations in the selected centres. The third quartile values of the measured DAP distribution for various diagnostic X-ray examinations were designated as LDRLs for Uttarakhand state of India. Their comparison with the established international DRLs is shown in Fig. 2.

TABLE 1. SUMMARY OF PATIENT CHARACTERISTICS AND TECHNICAL PARAMETERS SELECTED FOR THE DIGITAL RADIOGRAPHY EXAMINATIONS

Examination	No. of patients	Weight (kg)	Age (years)	FFD (cm)	FSD (cm)	Collimation (cm)		kVp	mAs
						X	Y		
Chest AP	54	40 - 82	22 - 69	100	75 - 83	34 - 52	32 - 40	64 - 90	15 - 40
Chest PA	247	35 - 92	15 - 89	180	154 - 162	35 - 55	35 - 65	55 - 85	10 - 35
Cervical spine AP	91	42 - 85	21 - 85	100	73 - 79	17 - 32	22 - 31	55 - 75	10 - 35
Cervical spine LAT	91	42 - 85	21 - 85	100	76 - 82	15 - 35	20 - 40	57 - 85	9 - 26
Thoracic spine AP	88	45 - 85	18 - 92	100	76 - 82	20 - 46	28 - 50	64 - 91	53 - 75
Thoracic spine LAT	86	45 - 85	18 - 92	100	59 - 72	22 - 45	36 - 52	70 - 97	25 - 50
Lumbar spine AP	155	50 - 95	18 - 90	100	70 - 80	23 - 52	34 - 55	64 - 105	45 - 90
Lumbar spine LAT	174	50 - 95	18 - 90	100	65 - 73	23 - 45	28 - 60	78 - 110	50 - 97
Abdomen	69	45 - 95	20 - 65	100	68 - 78	31 - 51	42 - 69	63 - 90	35 - 68
Pelvis	73	45 - 80	22 - 92	100	73 - 82	25 - 45	25 - 45	64 - 88	25 - 45

TABLE 2. MEASURED VALUES OF DAP (cGy-cm^2) FOR 10 DIGITAL RADIOGRAPHY EXAMINATIONS

Examination	Range	Mean	SD	Median	First quartile	Third quartile	Max/Min
Chest AP	11.57 - 80.38	35.20	26.25	22.23	15.37	57.26	6.95
Chest PA	5.1 - 34.2	20.61	6.19	21.38	17.42	24.07	6.70
Cervical spine AP	10.77 - 45.34	28.58	9.66	28.65	22.33	36.96	4.21
Cervical spine LAT	16.56 - 66.66	44.41	12.83	45.88	35.09	54.46	4.02
Thoracic spine AP	41.62 - 202.61	119.07	44.44	120.19	97.82	146.25	4.87
Thoracic spine LAT	71.94 - 309.01	165.34	67.45	140.83	122.27	184.68	4.29
Lumbar spine AP	41.55 - 274.87	159.39	45.99	150.79	129.77	183.4	6.61
Lumbar spine LAT	72.93 - 654.29	354.33	118.89	327.98	269.28	415.99	8.97
Abdomen	35.13 - 343.91	193.55	96.49	174.93	132.06	290.54	9.79
Pelvis	25.67 - 340.99	208.92	70.15	205.62	180.46	245.52	13.28

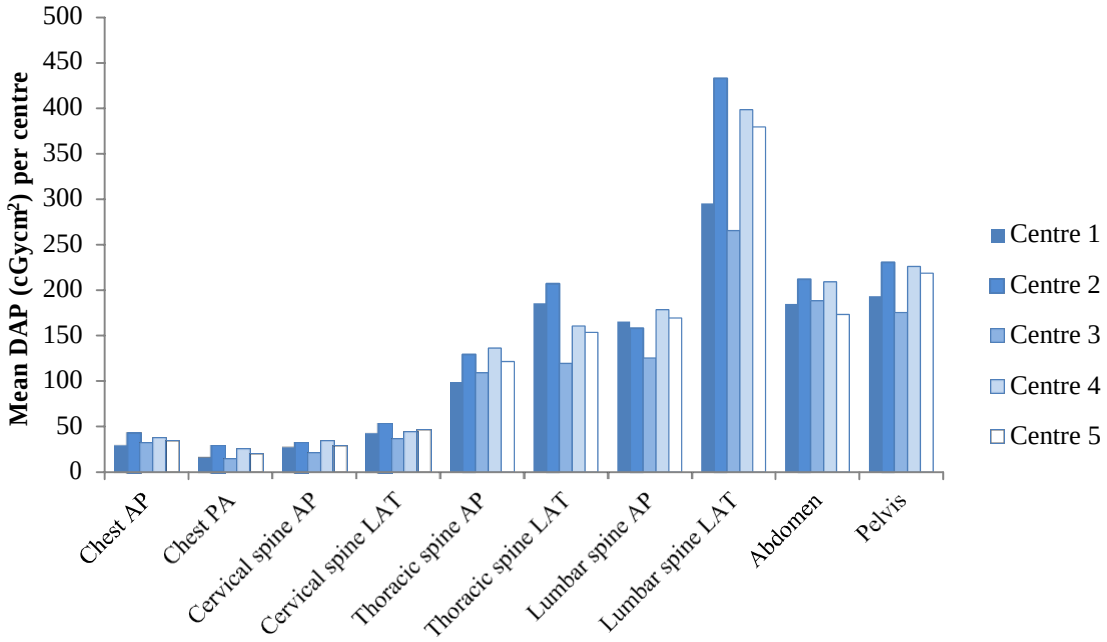

FIG. 1. Comparison of mean DAP (cGy.cm^2) values per centre

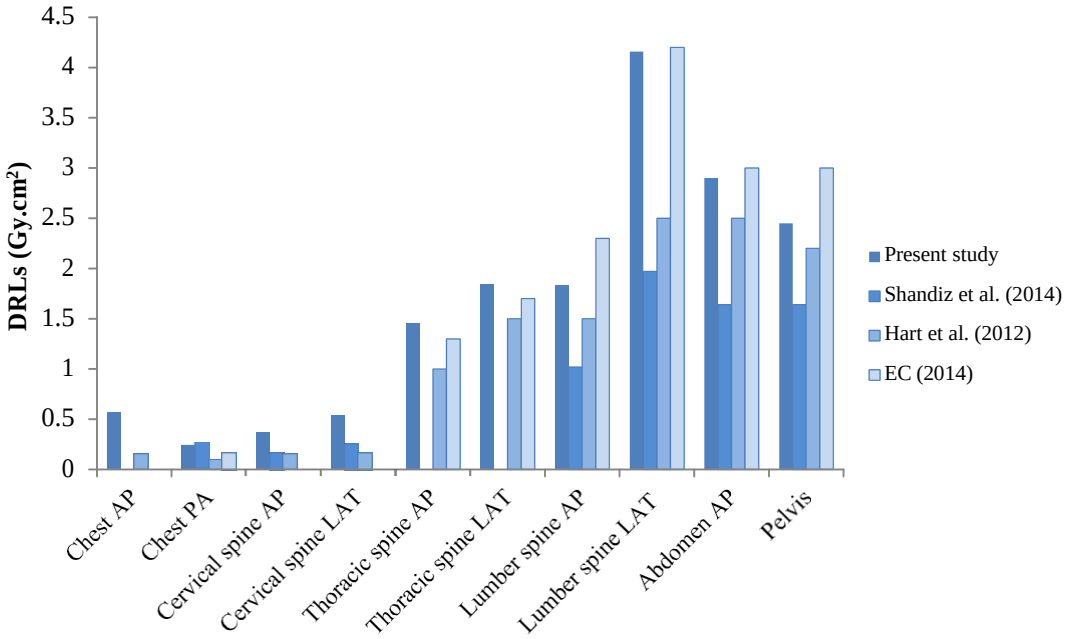

FIG. 2. Comparison of LDRLs of present study with the established international DRLs

4. DISCUSSION

The reason for the observed variability in DAP values measured in different X-ray rooms is multifactorial which includes different X-ray beam outputs as well as the wide variation in the operator specific selection of exposure technique and exposure parameters. Variation in X-ray tube output was minimized by including recently installed DR machines and ensuring the consistency of the tube outputs for individual machines. Evidently, main

reasons for the variation in dose were the improper exposure factors and poor collimation practice employed in different rooms for similar X-ray examinations. In general, the proposed LDRLs in this study are higher than the DRLs provided by Shandiz et al. [6] and Hart et al. [7], whereas majority of them are either comparable to or smaller than the DRLs recommended by the European Commission (EC) [3]. The data obtained in this study represent the local practice and provide a useful baseline for comparing current patient doses at individual X-ray centres of the region.

5. CONCLUSION

Measurements of DAP were carried out for patients undergoing common diagnostic X-ray examinations in a few major centres of Uttarakhand state of India. The implementation of LDRLs established from this study should achieve optimization of radiation protection by identifying factors that are responsible for increased patient dose.

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