Estimates and Radiological Implications of Dose Distribution to Female Patients Undergoing Fluoroscopy Examination at Ondo State Trauma and Surgical Centre, South West Nigeria

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ABSTRACT

Fluoroscopy is one of the medical imaging modalities used by physicians to image the internal organs of the body; during this imaging process, patients may be exposed to high radiation doses. These high exposure rates can lead to radiation-induced cancer risks in patients. This study calculated the dose area product (DAP) of female patients, determined the organ and effective organ doses received by the patients, and assessed the risk of radiation-induced cancer due to radiation exposure at a government-owned hospital in Ondo State, South West Nigeria. These were with a view to provide information on dose limit for best practices in fluoroscopy examination and reduce the risk of radiation-induced cancer to these patients.

The data for this study were obtained from the Radiology Department, Trauma and Surgical Centre, Ondo State. The procedures studied in this work were predominately orthopedic procedures such as abdominopelvic surgery,acetabular reconstruction, conventional/CT myelogram, barium enema, HSG, and humeral surgery/ext. fixation.

X-ray exposure parameters were obtained for female patients that underwent fluoroscopic examination. The radiation output (beam quality) of the machine was obtained and used to calculate patient exposure. DAP was calculated for each examination. Calculation of organ and effective doses for each patient was done using the Personal Computer X-ray Monte Carlo (PCXMC) software. Estimation of the risk of radiation-induced cancer was deduced from the value of effective dose to patients using PCXMC version 2.0.

The DAP calculated in this study ranged from 275 to 22,536 mGy.cm^2 with a mean of 4399 mGy.cm^2. The effective dose (mSv) to patients ranged from 0.001 mSv to 3.253 mSv. The average effective dose was 0.359 mSv. The adolescents (0–15 years) had the highest mean effective dose of 0.704 mSv. Age 16–30 had the lowest mean effective dose of 0.029 mSv. The estimated risk to fatal cancer associated with exposure to radiation in this study was 235 ± 2 (per million patients).The study showed that the group with the highest risk of cancer was within the age group 0–15 years.

This study concluded that the risk of radiation-induced cancer risk at the center,which was higher than recommended limits, requires an urgent need for standardization of procedures in fluoroscopy examinations. This can be achieved by employing a comprehensive quality control and assurance program, training of technicians, and x-ray equipment calibration in all radiology departments.

Keywords: Fluoroscopy, Effective dose, Organ dose, Cancer, Radiation

INTRODUCTION

The number of diagnostic x-ray procedures carried out each year has been on the gradual increase for some years now; this increase has been witnessed not only in the developed world but also in developing countries such as Nigeria. Although the number of patients undergoing x-ray examination and indeed diagnostic centers in Nigeria is on the increase, many of these centers do not have the proper knowledge, equipment, and expertise to monitor patients' dose and the associated risk from such exposures.

A recent study published in the *British Medical Journal* suggests that tests involving the use of radiation (including fluoroscopy) for diagnosis prior to age 30 increases the chances for cancer developing. X-rays have higher wavelengths than visible light, microwaves, and radio waves. X-rays in the diagnostic range typically have energies between 20 KeV and 150 KeV (Linda & Scott, 2011).

Fluoroscopy is an imaging technique that uses x-rays to produce real-time visualization of the internal structures in the body (Akinlade et al., 2012). Fluoroscopy like conventional x-ray uses x-ray beams to produce internal images of the body. In fluoroscopy, the x-ray beams are emitted (using either the continuous mode or pulsed mode fluoroscopy) and the images of the body structures are displayed on a screen, producing a real time, dynamic image. These images are used to evaluate the anatomy and physiology of body organs and tissues.

One major difference however between conventional x-rays and interventional fluoroscopy is that the radiation dose in fluoroscopy is higher than that in plain x-ray (Akinlade et al., 2012), and with increasing radiation dose also comes an increase in the risk of radiation-induced detriments.

The radiation dose from fluoroscopy depends on different factors, some of which are the type of examination, the patient size, the equipment, the technique, and the operator (Mahadevappa, 2001).

Fluoroscopically guided medical procedures are an important part of modern medical practice. Their ability to give real-time dynamic images makes fluoroscopy a very important diagnostic tool (Mahadevappa, 2001). Examples of fluoroscopically guided medical procedures are intracranial, facial or spinal embolism, transjugular intrahepatic portosystemic shunt (TIPS), vertebroplasty, etc. (Donald et al.,2010).

As important a tool as fluoroscopy is, if a patient is unduly exposed to high radiation dose while undergoing this procedure, the radiation detrimental effects can range from skin burn to cancers and eventually to death (Anupam et al., 2015).

One method to ensure the safety of patients undergoing fluoroscopy is to have accurate information about the quantity of effective dose delivered to the patient as well as to ensure that internationally recommended safety dose limits are not exceeded (International Commission on Radiological Protection, 1991;International Commission on Non-ionizing Radiation Protection, 1998).

Dose area product (DAP) is a quantity that gives details about the product of the surface area of a patient that is exposed to radiation at the skin entrance multiplied by the radiation dose at this surface. DAP measurements are suitable for achieving optimum degree of safety during radiological examination (including fluoroscopy) of patients (Akinlade et al., 2012; Zweers et al., 1998; Mahadevappa, 2001; Jumaa, 2014).

In Nigeria, most of the studies on patient dosimetry in the area of X-ray examinations are usually dosimeter based measurements of either entrance skin dose (ESD) or the effective dose (International Commission on Radiological Protection 1991, Ogundare 2004). However, the DAP received by patients from the examination procedure is neglected. This study is aimed at measuring the DAP received by patients undergoing fluoroscopy examination in a diagnostic center in Nigeria and its use in estimating patient organ and effective doses. It is anticipated that the results from this study would provide useful means of estimating DAP and effective dose received by patients during fluoroscopy examination, thereby providing information on dose limit for best practices in patient dose estimate in diagnostic radiology. During fluoroscopy, the x-ray tube potential difference (kV), tube current (mA), and time of exposure are usually recorded for each patient. Therefore, the DAP can be calculated using the following equation (Jumaa, 2014; Theocharopoulos, 1992).

$$DAP(mGy.cm^2) = L(mAs)D_o\left(\frac{mGy}{mAs}\right)A_{(FSD)}(cm^2) \quad (1)$$

where L is the tube loading expressed in milliampere-seconds, D_o is the normalized beam output in milligrays per milliampere-second at 100 cm, FSD is the focus to skin distance, and $A_{(FSD)}$ is the cross-sectional area of the beam on the skin of the patient which was obtained from the collimator of the machine.

MATERIALS AND METHODS

Ondo State Trauma and Surgical Centre

The Ondo State Trauma and Surgical Centre (OSTSC) was selected for this work after considering many factors, some of which are its location and its ownership of state-of-the-art equipment. OSTSC is located in Ondo State, which is a state neighboring the Osun, Edo, and Ekiti states, South West Nigeria. As a result of this strategic location, OSTSC attracts patients not just from within Ondo but from all its surrounding cities and states as well as beyond. Secondly, the inadequacies in the Nigerian healthcare system in the area of diagnosis and treatment make OSTSC a prime choice for patients in search of quality, fast, and reliable health care. The above reasons and many more make it of paramount importance that the center is aware of the radiation dose and any radiation-associated risk that its patients are exposed to during radio-diagnosis, specifically in the area of fluoroscopy.

At the time of this study, the department has two fluoroscopy machines. One fluoroscopy unit is located within the x-ray suite of the department while the other fluoroscopy unit is located within the orthopedic theatre suite of the center. The model of the fluoroscopy machine inthe x-ray suite and surgical suite is the Brivo OEC 850. The Brivo OEC 850 is a digital mobile C-arm manufactured in year 2010. Hence, the units are 5 years old at the time of this study. The total filtration of the x-ray tube is 3.5 mm Al for both machines. This value of x-ray filtration was the same for both quality control and clinical use.

Patient Demographic Details and X-Ray Technical Data

The number of patients selected for this study was 40. The age of each patient was obtained from their case file.

It is important to note that although the Brivo has the ability to automatically calculate the DAP value for each patient, the center at the time of this study was not in the habit of storing patient DAP values during/after each procedure. Therefore, an indirect route had to be employed in calculating the DAP value. Focus on skin distance, field size, x-ray exposure parameters such as tube potential (kVp), tube current (mA), and the exposure time (s) were obtained for each patient from the information contained in the hospital card of the patients whounder went a fluoroscopic examination at the center during the period of this study.

Determination of Beam Output (mGy/mAs)

Exposure (µSv/mAs) of the X-ray machine was measured using a Si PIN photodiode-based radiation dosimeter gotten from one of the tertiary medical institutions; the instrument had been calibrated at a secondary dosimetry laboratory located within Nigeria. The measurement was done at various peak kilo voltage settings ranging from 40–100 kVp at an increment of 20 kVp and fixed value of milliampere-second. The exposure values were converted to beam output values in milligray per milliampere-second by applying the expression by Knoll (2000) in equation 2.

$$1Sv = 1Gy \times W_R \tag{2}$$

where W_R is the radiation weighting factor. For photons, W_R is 1.

All the measurements were carried out at a fixed focus to detector distance of 100 cm (FDD = d = 100 cm). The beam output (mGy) of the x-ray machine was then obtained using the following equation by Sharma et al.(2015) as shown in equation 3:

$$Ouput(mGy) = K * kVp^n * mAs * \frac{1}{d^2} \tag{3}$$

where K is the slope of the curve of the plot of mGy/mAs against kVp^2 at a fixed distance (100 cm). The value of n depends on the type of x-ray generator used; for the fluoroscopy machine used in this study, n was 3.54.

DAP (mGy.cm²)

From the value of dose calculated using equation 2 and the values of the beam width and beam height measured, the DAP was calculated using equation 4 by Theocharopoulos et al.(1992).

$$DAP(mGy.cm^2) = L(mAs)D_o\left(\frac{mGy}{mAs}\right)A_{(FSD)}(cm^2) \tag{4}$$

where L (mAs) is the product of the tube current and time of exposure, D_o (mGy/mAs) is the absorbed dose, and $A_{(FSD)}$ (cm^3) is the area of the irradiated body.

Computation of Organ and Effective Doses Using PCXMC

Calculation of organ and effective doses for each patient was done using the Personal Computer X-ray Monte Carlo software (PCXMC).

Estimate of the risk of radiation-induced cancer was deduced from values of effective dose to patient calculated with PCXMC with the present tissue weighting factors (W_T) of the International Commission on Radiological Protection publication 103 (2007).

RESULTS

X-Ray Beam Quality (Radiation Output) Measurements

Tube output values in milligray per milliampere-seconds are shown in Table 1.

A graph of tube output (mGy/mAs) against the tube voltage (kVp) is shown in Figure 1.

The calculated value of the gradient (K) of the plot of tube output against tube voltage was obtained to be 1.6×10^{-4}, and the beam output of the X-ray machine in milligrays calculated using equation 3 was 0.168 mGy.

The patients' ages ranged from 4–84 years with a mean of 43 years.

X-Ray Exposure Parameter

The mean values of exposure parameters (kV and mAs), which were selected by the radiographers for the different common

Table 1. Fluoroscopy Machine Exposure (mGy/mAS)

	Absorbed Dose for Various Peak Kilovoltage Values			
OSTSC	**40 kVp**	**60 kVp**	**80 kVp**	**100 kVp**
Exposure(mGy/mAs)	0.151	0.154	0.158	0.163

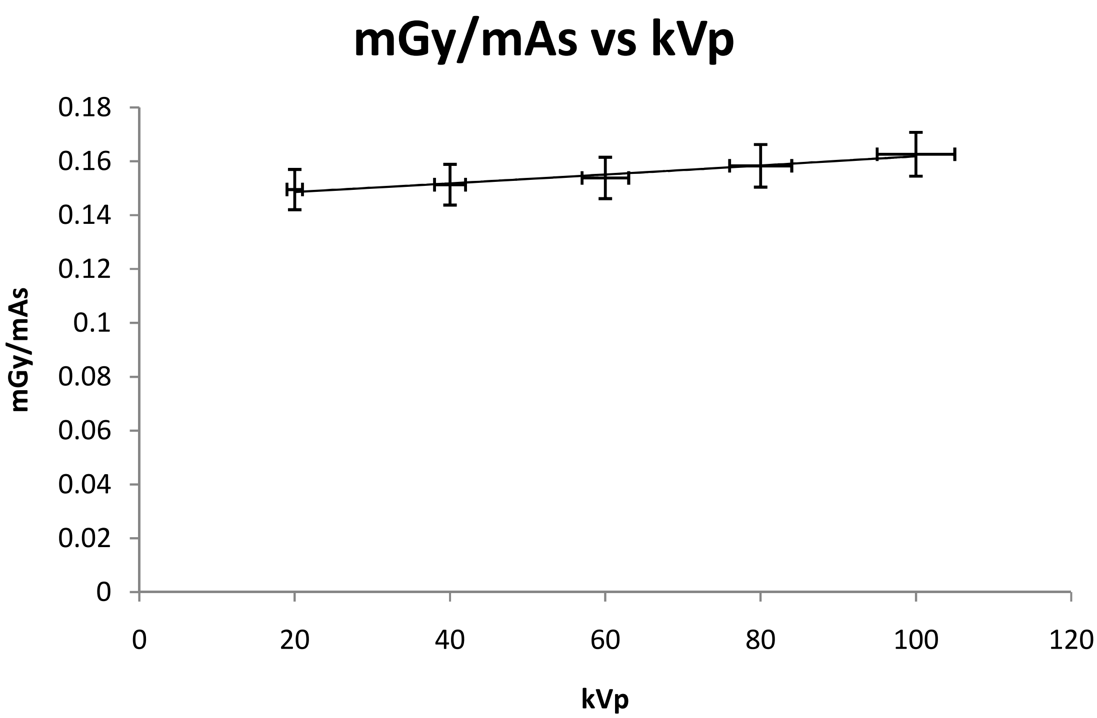

Figure 1. Plot of exposure (mGy/mAs) versus tube voltage (kVp) with standard error bar.

procedures carried out at OSTSC, are shown in Table 2.

Left acetabular reconstruction and total hip reconstruction had the highest peak kilovoltage value of 90 kV while surgery of the thorax had the lowest peak kilovoltage value which is 50 kV. Total hip replacement had the highest value of milliampere-secondswhile closed manipulation of distal right humerus fracture and casting had the lowest value of 3 mAs.

Table 2. Mean Values of Exposure Parameters for Common Interventional Procedures/Examinations at OSTSC

Interventional/Procedure Examination	Mean Milliampere-Second	Mean Kilovolt
Abdominopelvic surgery	37	60
Acetabular reconstruction	71	79
Barium enema	21	57
Contrast sonography	48	78
Conventional/CT myelogram	69	78
Ext. fixation/ORIF/IM of the Tibia	90	64
Extremities	30	56
HSG	38	71
Humeral surgery/ext. fixation	16	65
Implant removal/ORIF	58	66
Esophagogram	11	47
ORIF with screw and plate	55	65
Others	92	64
Reduction of shoulder bone dislocation	11	62
Spinal canal decompression/fixation	81	75
Spinal surgery	22	80
Thoracic	30	50
Total hip replacement	161	65
Venography	38	46
Wound debridgement/ORIF/ext. fixation	49	67

Calculated Dap (mGy.cm²)

The DAP calculated using equation 4 for each fluoroscopy examination carried out at the center at the time of this study ranged from 275 to 22,536 mGy.cm² with a mean of 4,399 mGy.cm².

Effective Dose (mSv)

The effective dose to patients ranged from 0.001 mSv to 3.253 mSv. The mean effective dose was 0.360 mSv. The mean effective dose to ages 0–15 years was 0.704 mSv, ages 16–30 was 0.029 mSv,ages 31–45 was 0.359 mSv, ages 46–60 was 0.423 mSv, and ages above 60 was 0.569 mSv. The total, mean, maximum, and minimum effective doses are illustrated in Figure 2. The effective dose in terms of age (adolescents and adults of varying age groups) is illustrated in Figure 3.

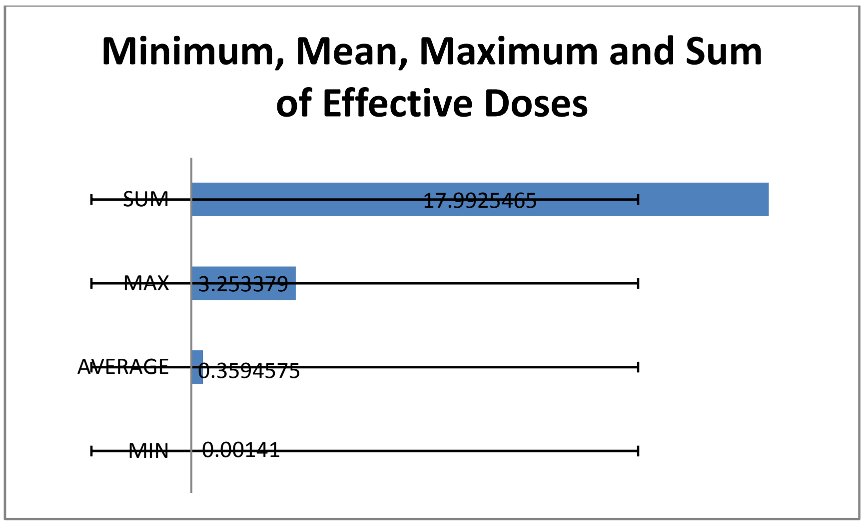

Figure 2. Effective dose (minimum, mean, maximum, and sum).

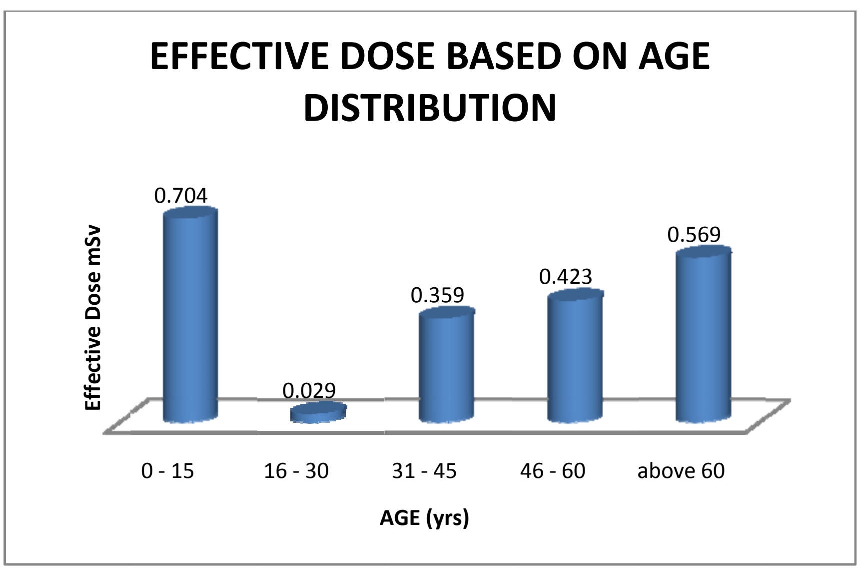

Figure 3. Effective dose based on patients'age distribution..

Table 3. Effective Dose (Minimum, Mean, Maximum, and Sum)

Effective Dose (ICRP103)	
Max.	3.253379
Min.	0.00141
Mean	0.3594575
Sum	14.378300

Table 4. Estimated Risk of Radiation-Induced Cancer Based on Age Distribution

Tissues	Age (years)						Mean
	0–15	16–30	31–45	46–60	61–75	76–90	
Active bone marrow	0.781	0.118	0.124	0.437	0.453	0.067	0.251
Breasts (women)		0.051	0.004	0.004	0.004	0.001	0.01
Colon (Large intestine)	2.742	0.542	0.266	0.588	0.481	0.356	0.613
Liver	2.827	0.039	0.153	0.14	0.067	0.002	0.386
Lungs	2.141	0.046	0.149	0.046	0.015	0.001	0.306
Ovaries	0.928	0.016	0.902	0.954	0.992	0.328	0.825
Prostate (men)	7.777	4.918	1.797	4.298	3.814	0.291	3.82
Stomach	3.083	0.037	0.031	0.091	0.113	0.006	0.373
Thyroid	0.589	0.06	3.74	0.01	0.001		1.466
Urinary bladder	0.596	0.01	2.643	1.904	1.798	1.015	1.829
Uterus	9.78	6.232	3.095	4.514	2.178	1.458	4.486
Weighted remainder	1.777	0.323	0.496	0.311	0.268	0.19	0.493

Estimated Risk of Fatal Cancer from Fluoroscopy Examination of Patients (Per Million Patients)

The estimated risk of fatal cancer associated with exposure to radiation at Ondo State Trauma and Surgical Centre (per million patients) is 235 ± 2.

Table 5 shows the estimated risk of radiation-induced cancer associated with the various age groups.

The results of radiation detriment (broken down into its constituents' organs) associated with different fluoroscopy examination carried out on patients during this study is illustrated in Figure 4.

Table 6 shows the risk estimate for various organs and tissues. The comparison of the risk of cancer estimated from the summation of detriments to various organs at the center and those from other studies are presented in Table 6.

Table 5. Estimated Risk of Radiation-Induced Cancer Based on Age Distribution

Tissue/Organs	Estimated Risk to Tissue/Organ	Sum
Active bone marrow	0.235562059	8.244672059
Breasts (women)	0.01141337	0.31957437
Colon (large intestine)	0.367587853	12.86557485
Liver	0.055648667	1.725108667
Lungs	0.025780739	0.618737739
Ovaries	0.7542152	19.6095952
Prostate (men)	0	0
Stomach	0.047524148	1.330676148
Thyroid	1.9838886333	13.88720433
Urinary bladder	1.793218935	57.38300594
Uterus	3.271461656	107.9582347
Weighted remainder	0.300936158	11.73651016
Sum of estimated risk	8.847235119	235.6788941

Table 6. Risk of Fatal Cancer Estimated From the Summation of Detriments to Various Organs/Tissues

	Risk of Fatal Cancer
Present study	235 ± 2
Perisinakis et al., 2001	650* 480†
Calkins et al.,1991	1,000
Lindsay et al.,1992	1,500
Rosenthal et al.,1998	2,300
Kovoor et al.,1998	300

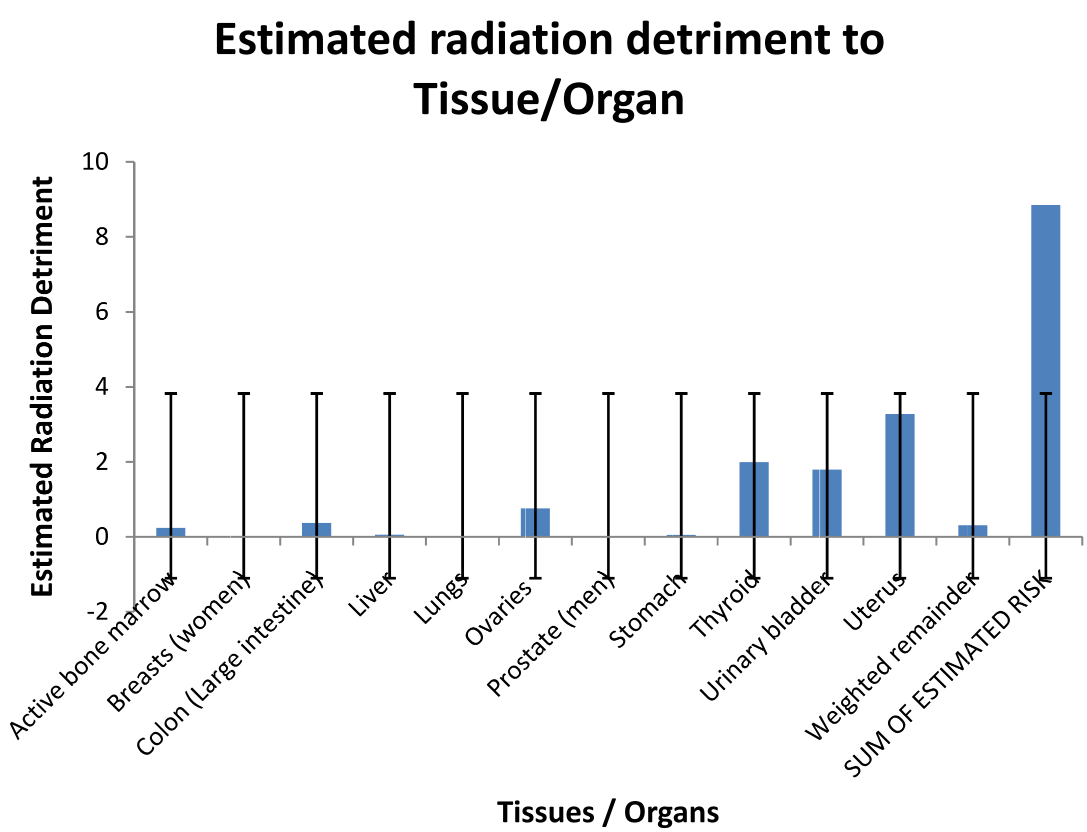

Figure 4. Estimated risk of cancer to patients (female).

DISCUSSION

The procedures and examinations carried out at the center were broadly categorized into 20 groups.

From the categorization, the most common procedure at the hospital during the period of this study was open reduction internal fixation (ORIF)/implant of the femur and tibia. This procedure was carried out on about 24% of the total patients considered. This procedure is probably the most common at the center since OSTSC is a reference center for orthopedic patients.

The most basic and yet very important x-ray exposure parameters are the applied tube voltage (kV), the tube current (mA), and the time of exposure (s). The highest values of peak kilovoltage and milliampere-second were obtained for both left ace tabular reconstruction and total hip reconstruction in this study, as seen in Table 2. These high values can be traced to the complex nature of both procedures. This complexity led to the need for multiple imaging during each phase of the procedures. The procedures with low exposure values are relatively uncomplicated procedures. For instance, reduction of shoulder bone dislocation is not a complex procedure; therefore, there was no need for long fluoroscopy time or high milliampere-second values.

The tube voltage (kV) determines the energy of x-ray photons produced and how much of such photons are absorbed (attenuated) by the patient and how much reaches the detector (screen). This to a great extent is one of the factors that determine the absorbed dose of the patient. To achieve optimal radiation protection of patients, an operator is expected to combine high peak kilovoltage values with low milliampere-second values or low peak kilovoltage and high milliampere-second values. If the operator selects high values for both peak kilovoltage and milliampere-second, the patient will be exposed to high radiation dose with a resultant high probability for radiation-induced detriments.

As can be observed from Table 2 at OSTSC, the radiographers employed low peak kilovoltage values in most cases depending on the particular procedure. Low peak kilovoltage values combined with high milliampere-second values were favored over high peak kilovoltage values in combination with low milliampere-second values because most fluoroscopy procedures are associated with high milliampere-second values.

It is also important to state that the value of exposures used in an examination was not just based on the radiographers but also on the experience and expertise of the surgeon.

This study has computed doses for patients that cut across all age groups. Most of the patients considered in this study were in the active reproductive age range of 22–45 years. ICRP and other radiation protection bodies have recommended that patients within this crucial age range should be protected from radiation exposure that could lead to genetic effects. Doses to these patients at OSTSC are within recommended limits;therefore, it can be inferred that the center has taken appropriate measures to protect such patients.

Another very important group of patients that must be carefully protected during any radiation examination are the adolescents. It has been recommended that extra radiation protection be employed when adolescents are involved in any procedure involving radiation. This is because adolescents have an estimated longer life span, which could lead to increased likelihood of cancer induction at a later time.

Information obtained from the effective dose to this group of patients as illustrated in Figure 3 showed that the mean effective dose is within the recommended limit; as such, there is low likelihood of some of the adolescents developing cancer at a later age. Even when present, this is a stochastic risk that tends to be more academic.

The mean DAP value (4399 mGy.cm^2) obtained in this study was higher than 2.80 Gy.cm^2 obtained in the study by Kim et al. (2009). The difference in the values can be attributed to difference in exposure duration between the procedures carried out in both studies. The estimated time for lumbar epidural steroid injection was 40.7s (Kim et al., 2009),which is lower than the time involved in most of the procedures carried out in this study. This high value of DAP is indicative of the probability for skin erythema or radio-dermatitis.

It is also worthy of note that some of the DAP values obtained in this study are within the range for deterministic effect. Of particular interest is the highest DAP value (22,536 mGy.cm^2), which could be traced to high exposure parameters (67 kVp and 410 mAs). Doses above 2 Gy are able to cause deterministic effects in irradiated individuals. The doses which fall within this deterministic effect range in this present study are not whole body irradiation but localized;therefore, there is no certainty that affected individuals would show symptoms.

The organ dose using PCXMC was computed for 25 organs/tissues of the body. Organ dose when multiplied with the radiation weighting factor for each organ gives an estimate of the risk to that organ/tissue of the patient.

Table 3 showsa typical organ and effective dose computed using PCXMC. From the values of organ dose obtained, it was observed that exposure parameter, patient age, sex, and weight as well as the area of the body imaged are some of the factors that contributed to the individual patient doses.

The wide difference between the maximum and minimum effective doses for patients as observed from Table 4 and illustrated in Figure 2 could be explained by taking into consideration the fact that this study computed doses for patients of different ages. Effective dose varies considerably for different age groups and sex. It is pertinent to note that patients on the higher end of the effective dose range are predisposed to high radiation risk while there is a possibility of losing image information for those on the lower end. Hence, optimum values are the recommended target during imaging.

The mean effective dose (0.359 mSv) obtained in this study is within the recommended limit advised by both ICRP and NCRP and agrees in general with the study by Kim et al.(2009) as shown in Table 7. The slight difference may have resulted from the use of different equipment and the fact that the effective dose in this study is computed for different fluoroscopy procedures beyond just the lumbar epidural steroid injection considered in the aforementioned study.

Figure 3 shows that the adolescents (0–15 years)had the highest value of effective dose of 0.704 mSv. This high value of effective dose predisposes these adolescents to stochastic risk. One reason for this high dose can be traced to the use of anti-scatter grid during examinations involving adolescents, as the fluoroscopy machine used has a permanent anti-scatter grid. Many radiation protection bodies have published recommendations discouraging the use of anti-scatter grid in the examination of adolescents, as it increases dose to patients (Aborisade et al.,2015).

Table 6 shows that the organs most at risk are the uterus, urinary bladder, and thyroid. The high risk associated with these organs maybe because most of the procedures involved irradiation of organs adjacent to these organs,such as the hips, the thigh, abdomen, etc. The high risk observed in these organs would raise red flags for the induction of genetic effects in the offspring of the patients with the observed high risk to the gonads.

The result of risk in this study is higher than the level recommended by the International Commission on Radiation Protection (ICRP), which has recommended that if one million patients receive a whole body irradiation of 1 Sv, the number of patients likely to develop cancer in their lifetime should not exceed 35. This is represented as (International Commission on Radiological Protection, 1991; Mahadevappa, 2001;United Nations Scientific Committee on the Effects of Atomic Radiation, 2008). The result of this study is however lower when compared to those obtained by Perisinakis et al. (2001),who reported 650 for the U.S. population and 480 for the U.K. population, and Kovoor et al. (1998), who reported 300. It is also lower than the values of 1,000, 1,500, and 2,300 reported by Calkins and associates (1991),Lindsay et al.(1992),and Rosenthal et al. (1998),respectively.

The estimate of the risk of fatal cancer from this study shows that the group with the highest risk of cancer isthose within the age group of 0–16 years. This increased risk can be traced to the high effective dose value. The reason for this could also be because of the size of the adolescents, which makes the amount of radiation that passes through their body cut through many radiosensitive organs. Also, the progenitor cells of children and adolescents are more radiosensitive than those of the other age groups.

CONCLUSION

This study has shown that the risk of radiation-induced cancer at this center is above expected dose reference levels (RL),expected levels especially for pediatric patients. Furthermore, the dose to some patients approached that for deterministic effects. As such, there is an urgent need for standardization of procedures in fluoroscopy examinations at the center. This can be achieved by employing comprehensive quality control and assurance program, training of technicians, and x-ray equipment calibration at the center.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

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