Tanzania Journal of Science 45(1): 18-31, 2019 ISSN 0856-1761, e-ISSN 2507-7961

Determination of Radiation Doses to Patients Undergoing Fluoroscopically Guided Orthopaedic Procedures at Muhimbili Orthopaedic Institute in Tanzania

Jacob Busumabu[1,2], Ismael N. Makundi[2*] and Justin E. Ngaile[3]

[1]*Department of General Studies, Arusha Technical College, P. O. Box 296, Arusha, Tanzania*
[2]*Department of Physics, University of Dar es Salaam, P. O. Box 35063, Dar es Salaam, Tanzania*
[3]*Radiation Control Directorate, Tanzania Atomic Energy Commission, P. O. Box 743, Arusha, Tanzania*
[*]*Corresponding author e-mail address: ismakundi@udsm.ac.tz*

Abstract

The aim of the present study was to determine the magnitude of radiation doses delivered to patients undergoing Fluoroscopically Guided Orthopaedic Procedures (FGOP's) in Tanzania. The air Kerma Area Product (KAP), fluoroscopy time, organ dose and effective dose to patients undergoing FGOP's were obtained from Muhimbili Orthopaedic Institute. A total of 72 adult patients from selected three FGOPs namely Lumbar Spine (LS), Dynamic Hip Screw (DHS) and Thoracic Spine (TS) procedures were investigated using C-arm fluoroscopy machine. The knowledge of patient demographic data, radiographic data, KAP and Monte Carlo-based PCXMC software were used to obtain the magnitude of organ doses (OD) and effective doses (ED) of the patients. The median values of KAP for the LS, DHS and TS were 2.569, 2.410 and 0.770 Gy cm^2, respectively. The mean values of ED for the LS, DHS, and TS procedures were 0.27, 0.47 and 2.70 mSv, respectively. The observed wide variations of KAP, organ dose, effective and exposure protocols within the hospital under study and relative high dose in this study compared to reported values from the literature call for standardization of procedural protocols and optimize fluoroscopically guided orthopaedic procedures.

Keywords: Kerma-area-product, organ dose, effective dose, C-arm fluoroscopy machine, orthopaedic procedures.

Introduction

In developing countries like Tanzania, the use of X-ray fluoroscopy machines such as mobile C-arm machine has been increased in radiology departments and operation theatres for examination and treatment of orthopaedic trauma. The popularity of X-ray fluoroscopy over plan X-ray modalities is largely due to its ability of providing both real–time X-ray images and still X-ray images on television screen. The X-ray fluoroscopy modalities are used in operation theatres to view bone fractures, joint dislocations and to guide orthopaedists during operation or treatments (UNSCEAR 2008, ICRP 2010). Furthermore, the uses of X-ray fluoroscopy machines for guidance of the surgeons' manipulations have made the orthopaedists and surgeons to execute the surgeries more easily, in short time and with the least possible traumatizing of the patient tissues. In addition, the results of the operation can be assured and filed by obtaining X-ray fluoroscopic images before the patient leaves the operation theatre (Tsalafoutas et al. 2008, Osman et al. 2012, Tsapaki et al. 2016).

The aforementioned significant contribution of X-ray fluoroscopy machines however, comes with negative impacts as the use of X-ray modalities involve the definite radiation risks to the patients undergoing the

fluoroscopically guided orthopaedic procedures (FGOPs) including stochastic effects. The radiation doses imparted to the patients result to radiation health risks that may originate from various factors including the dynamic nature of the imaging procedures (multiple fluoroscopy projection and prolonged fluoroscopic time), the level of complexity of the orthopaedic procedures, the diverse experience and skills among the orthopaedists and C-arm fluoroscopy machine operators and wide range of examination protocols among the personnel and number of images per procedures (Crawley and Roger 2000, ICRP 2010, Osman et al. 2012). Furthermore, the high radiation dose to the patients undergoing these FGOPs are expected to be more prominent in developing countries including Tanzania due to several reasons such as irregular equipment maintenance, insufficient of formal training in radiation protection, insufficiency of quality assurance and written protocols for manual selection of exposure parameters (IAEA 2007, ICRP 2010).

In light of these radiological risks and the extensive use of X-ray fluoroscopy modalities in operation theatres, it is important to assess the magnitude of radiation dose imparted to patients undergoing FGOPs. Understanding the level of radiation dose can secure individual patients and the entire population from radiation health risks through standardization of exposure and or optimizing when necessary. Thus, the aim of this study was to assess magnitude of radiation dose delivered to patients in three commonly performed FGOPs namely, Dynamic Hip Screw (DHS), Lumbar Spine (LS) and Thoracic Spine (TS) at Muhimbili Orthopaedic Institute (MOI) in Tanzania and compare the results to other radiation doses reported in the literatures.

Materials and Methods

Data acquisition and collection procedure

The current study was conducted at Muhimbili Orthopaedic Institute (MOI) where a mobile fluoroscopic machine (C-arm machine) (718074, ON: 01J0FJ280, SN: 001550 Philips Medical Systems, The Netherlands) with 38 cm diameter image intensifier was used for FGOPs. The focus to image intensifier distance was 98.0 cm and the unit employed a maximum voltage of 110 kV. The anode angle was 12 degrees and the total radiation beam filtration at 75 kV including contribution from the transmission ionization chamber gives to 3.0 mm Al equivalent as inherent. Also the addition filtration was 1.0 mm Al equivalent plus 0.1 mm Cu and the half value layer of the C-arm fluoroscopy machine was 4.41 mm Al at 75 kV. The data in this study were from patient characteristics including date of birth, gender, weight (kg), height (cm), thickness (mm) and diagnostic purpose of examination and patient radiographic details including fluoroscopy time, projection type, kV, mA and number of radiographic images. These data were collected from patients undergoing FGOPs (LS, DHS and TS) for four months from March to July, 2017. The data were recorded using the prepared patient clinical survey forms while observing the clinical and patient ethics as directed by Ethical Clearance Committee of the University of Dar es Salaam (Ref: 2017-01-09/UDSM REC/03). The patients' demographic data were obtained directly from patients' clinical files and the patients' radiographic data were recorded directly from the C-arm fluoroscopy machine during on-going procedure after each exposure.

Number of patients investigated under C-arm machine

A total of 72 adult patients (43 males and 29 females) from orthopaedic procedures under C-arm machine were investigated. For DHS, 20 adult patients (65% males, 35% females) were assessed during the operation while for the spine procedures, 32 adult patients from LS (44% males, 56% females) and 20 adult patients from TS (80% males,

20% females) were also examined during operation.

Patients' dose measurements

Prior to dose measurements, the performance test of the C-arm fluoroscopy machine was done to comply with international standards (IPEM 2005) such as voltage output (kV), dose, dose rate and timer reproducibility and accuracy. All these tests and measurements were carried out using an Unfors Xi multimeter or ionization chamber (IC) (Unfors Xi, type No. 8201013-C Xi Base, Ser. No. 190017, Unfors. Inc., Bill dal, Sweden) with a solid state detector (Unfors Xi, type No. 8202031-HXi, Ser. No. 181017) which was originally calibrated from Sweden National Testing and Research Institute according to the technique explained in TRS 457 (IAEA 2007). The overall accuracy of the IC measurements was approximated to be 5% as validated by International Electrotechnical Commission. The operational mode of the C-arm fluoroscopy machine was in pulsed fluoroscopy and automatic exposure control.

In order to assess the patient dose in terms of OD and ED from FGOPs using Monte Carlo (MC)-simulation the knowledge of air KAP was needed. In the current study, the air KAP was measured automatically by the calibrated KAP meter built within the C-arm fluoroscopy machine. In the same way, the exposure parameters from C-arm fluoroscopy machine were manually documented in the patient clinical survey forms.

Patients' organs and effective doses computation

The computation of patients' organs and effective doses using MC simulation was achieved by utilizing the measured air KAP values. In this study, a PC-X-ray based MC (PC-XMC) version 2.0.11 Rotation dosimetry software package supplied by the Finnish Centre for Radiation and Nuclear Safety, STUK was used for computing the patients' organs and effective doses of each type of the examination performed (Tapiovaara and Siiskonen 2008). This program uses hermaphrodite phantom models of Eckerman et al. (1996) to represent patient of different ages, which are flexible to imitate the geometry of the patients. Furthermore, Table 1 shows the common key parameters used during PCXMC dose computation. For all procedures the Total Filtration (TF) was 4.0 mm Al +0.1 mm Cu, maximum energy was 150 keV and the number of photons was 200,000.

The patient's details such height (in cm) and weight (in kg), were fed first into the MC system to start simulation and immediately the mathematical phantom was generated to represent the patient. The X-ray beam dimensions at the patient's surface were obtained by feeding the image field size (31 cm × 31 cm), focus –image distance 98 cm and the distance between focal spot and reference point (80 cm) into MC system. The number of photons used in simulation for every projection was 200,000 so as to minimize relative statistical errors (Tapiovaara and Siiskonen 2008). The radiographic data such as X-ray tube voltage (55 to 110 kV), tube anode angle, X-ray filtration and KAP (in mGy cm^2) were entered into simulated details for OD and ED computation. In order to simulate the real clinical exercise for computations of the patient doses, the patient's arms were removed from the phantom model and in order to implement the risk assessment the program needed to specify the origin of the patient, thus the Euro-American statistics was assumed to be equivalent to Africans statistics (Mantebea 2015). The risk assessment was based on the equivalent doses of sensitive organs such as breast, colon, lung, active bone marrow, liver, ovaries, prostate gland, stomach, thyroid gland, uterus, urinary bladder and weighted remainder. For each projection the estimated dose for all the 29 organs and tissues in PCXMC phantom were observed. The patient

doses were recorded in Excel files from the report drawn after the MC calculations. In addition, the ED for every projection was calculated based on the values of organ doses and the ICRP 103 tissue weighting factors (ICRP 2007). The total ED per individual procedure was obtained by summing the ED from each individual projection.

Table 1: A summary of common key parameters used during PCXMC for first five patients

Procedure	Examination data			Patient	MC parameters			Compute dose	Risk assessment	
LS	BW	BH	FSD		kV	TF	AA		Gender	Statistics
	22.55	22.55	42.94	1	110	4.0 mm Al +0.1 mm Cu	12º	Maximum energy was 150 keV and number of photons was 200,000	F	Euro American was used.
	22.55	22.55	42.30	2	102		12º		F	
	22.55	22.55	68.48	3	96		12º		M	
	22.55	22.55	46.11	4	99.8		12º		F	
	22.55	22.55	79.20	5	110		12º		F	
DHS	22.55	22.55	65.91	1	81	4.0 mm Al +0.1m m Cu	12º	Maximum energy was 150 keV and number of photons was 200,000	F	Euro American was used.
	22.55	22.55	66.42	2	77		12º		M	
	22.55	22.55	79.36	3	65		12º		F	
	22.55	22.55	62.73	4	70		12º		M	
	22.55	22.55	58.60	5	83		12º		M	
TS	22.55	22.55	62.80	1	97	4.0 mm Al +0.1 mm Cu	12º	Maximum energy was 150 keV and number of photons was 200,000	M	Euro American was used.
	15.27	15.27	70	2	70		12º		F	
	22.55	22.55	62.80	3	73		12º		M	
	22.55	22.55	62.80	4	90		12º		M	
	22.55	22.55	70	5	83		12º		M	

TF = Total Filtration, AA = Anode Angle, BW = Beam Width and FSD = Field-Size Distance

Comparison of tube outputs

In order to be sure with the method of the PCXMC simulation, the tube output obtained experimentally from calibrated Ionization Chamber (IC) was compared to the tube output of PCXMC simulation (Wielandts et al. 2010). The IC was placed at a distance of 81.0 cm from the radiation source (tube focus of the C-arm fluoroscopy machine). The IC measured the exposure parameters including the total dose (mGy), potential (kV), dose rate (mGy/s) and half value layer. At each specific potential of the C- arm fluoroscopy machine (60 kV, 70 kV, 80 kV, 90 kV and 100 kV) three corresponding readings of kV, dose (mGy), dose rate (mGy/s), exposure time (ms) and half value layer from the IC were obtained after each exposure and the average of each parameter was computed. The potentials (kV) 60, 70, 80, 90 and 100 and the current (mA) of 1.24, 2.74, 2.87 and 2.94, respectively were manually set from the C-arm fluoroscopy machine. The measured tube outputs due to the C-arm were calculated using the following equation:

$$Tube\ \ output = \frac{Dose\,rate\ (mGy/s)}{Current\ \ (mA)}$$

In PCXMC simulation, the same settings of kV as that of C-arm fluoroscopy machine were used and the PCXMC assumed a certain dose (in mGy) and mAs when calculated KAP (mGy cm^2) from the C-arm machine was used as input parameter. The tube output due to PCXMC simulation was also calculated using the above equation. The comparisons of the two outputs for the five various kV are presented in the Table 2.

Table 2: Comparison of the experimental and PCXMC tube output (mGy/mAs)

Tube voltage setting (kV)	Tube output (mGy/mAs at 81 cm)		
	Measured	PCXMC	Difference
60	0.017	0.016	0.001 (6%)
70	0.025	0.022	0.003 (12%)
80	0.038	0.036	0.002 (6%)
90	0.053	0.049	0.004 (8%)
100	0.071	0.061	0.010 (14%)

Statistical analysis

The Microsoft office excel 2007and R-statistical software packages (version 3.4.2, 2017-06-30; R Foundation for Statistical Computing, Vienna, Austria) were used to obtain averages, medians, 3rdquartile and ranges of the patient demographic parameters (i.e., weight, height, age) and patient doses (KAP, effective and organ dose) for each type of the examination assessed. In addition, a linear regression from R-statistical software packages was used to describe the correlation between the KAP and ED obtained from the PCXMC in order to investigate the influence of KAP on ED. The Pearson's correlation coefficient was described as follows: 0.00-0.19 for very weak correlation; 0.20-0.39 for weak correlation; 0.40-0.69 for moderate correlation; 0.70-0.89 for strong correlation and 0.90-1.0 for very strong correlation (Streiner et al. 2015). A 95% as the confidence interval was employed throughout the statistical manipulations. Thus, parameters with p - values of < 0.05were considered to be statistically significant.

Results and Discussions

Particulars of patients

Table 3 summarizes the number of patients per examination, the mean and range of patient weight, height, thickness and age. From Table 3, LS was the most performed FGOPs while DHS and TS procedures had equal average of number of operations in the present study.

Table 3: Summary of sample size, mean (range) of patient details for fluoroscopically guided procedures

Operation procedure	Number of patients	Patient age (years)	Weight of patients (kg)	Height of patients (cm)	Thickness of patients (mm)	BMI (kgm^{-2})
DHS	20	34 (17-64)	69 (48-84)	163 (125-178)	243 (160-326)	26.21
LS	32	50 (18-64)	80.67 (58-130)	170 (155-242)	306.25 (213-524)	28.51
TS	20	32.55 (17-54)	68.25 (54-83)	162 (150-181)	291.95 (218-453)	26.11

BMI = Body Mass Index

Measurement of KAP per fluoroscopy procedure

The mean values of KAP for the three fluoroscopy procedures (LS, DHS and TS) within the Institute are presented in Table 4. It can be observed from the table that there is a significant variation of KAP values within the Institute. For example, the mean values of KAP varied by a factor of 656.14 (i.e., from 17.10 to 11220 mGy cm^2), 81 (from 71.40 to

5783 mGy cm^2) and 52.58 (from 72 to 3786 mGy cm^2) for DHS, LS and TS, respectively. The variation of KAP values for the three procedures were mostly attributed to the complexity of the procedures, nature of the pathology, the diversity levels of the skills and experience among the radiographic technologists and surgeons, the patient's body size and the variation of exposure parameters such as kV, mA, fluoroscopic time and number of radiographic images.

Table 4: The Kerma-Area-Product (KAP) (in $mGycm^2$) data of the three fluoroscopy guided orthopaedic procedures

Operation procedure	Patient number	Mean KAP ($mGycm^2$)	Range KAP ($mGycm^2$)	Third quartile KAP ($mGycm^2$)	Median KAP ($mGycm^2$)
DHS	20	2929.13	17.10-11220	3627	2410
LS	32	1613.97	71.40-5783	2569.2	1624.5
TS	20	985.83	72-3786	1176	769.5

Estimated mean patient organ dose and effective dose for individual procedure

The results of mean patient OD and ED for individual procedures in different fluoroscopy procedures of DHS, LS and TS are presented in Table 5. It is observed from Table 5 that there is a large variation of OD and ED per individual procedure. For example, TS had the highest mean organ dose of 1.42 mGy and effective dose of 2.7 mSv among the three procedures. This observation is attributed to the highest tissue weighting factors employed in computation of the effective doses in this procedure. For instance the thoracolumber region was beamed during the operation of TS procedure; thus, sensitive organs with high tissue weighting factors such as the breast (0.12), lung (0.12), bone marrow (0.12) and stomach (0.12) were also exposed to X-ray radiation. In addition, the exposure parameters might also be attributed to the high ED in this procedure.

Table 5: Summary of the mean, range and third quartile of KAP values, organ dose and effective dose per individual procedure

Procedure	KAP (mGy cm^2)			Organ dose (mGy) per procedure			Effective dose (mSv) (ICRP 103)		
	Mean	Range	3rd Quartile	Mean	Range	3rd Quartile	Mean	Range	3rd Quartile
LS	1614	71.40-5783	2569.2	0.15	0.0-0.90	0.12	0.27	0.00-1.29	0.85
DHS	2929	17.10-11220	3627	0.54	0.07-2.91	0.66	0.47	0.04-2.03	0.45
TS	986	72-3786	1176	1.42	0.07-9.48	1.32	2.70	0.16-21.08	2.70

Figures1, 2 and 3 present the linear regression between the KAP values and ED for TS, LS and DHS procedures, respectively. It is evident from Figure 1 that there is very strong positive correlation between KAP and ED ($r = 0.92$, $p < 0.0001$) for TS with the KAP contributing up to 85% of the ED variations. A strong positive correlation between KAP and ED was observed from Figure 2 ($r = 0.76$, $p < 0.0001$) for LS with the KAP accounting up to 57% of the ED variations. A moderate correlation between KAP and ED ($r = 0.69$, $p < 0.0001$) for DHS with KAP accounting up to 47% of the ED variations was also observed from Figure 3. The positive relation between KAP and ED is mainly attributed to the factors such as number of radiographic images, number of

projections and exposure parameters (kV, mA, Fluoroscopic Time (FT)). It was observed that there was a strong correlation between KAP and ED and there is an assumption of linearity between ED and stochastic health risk (Streiner et al. 2015, Ngaile et al. 2016). Thus, KAP variation is considerably related to occurrence of radiation health risks to patients undergoing the FGOPs.

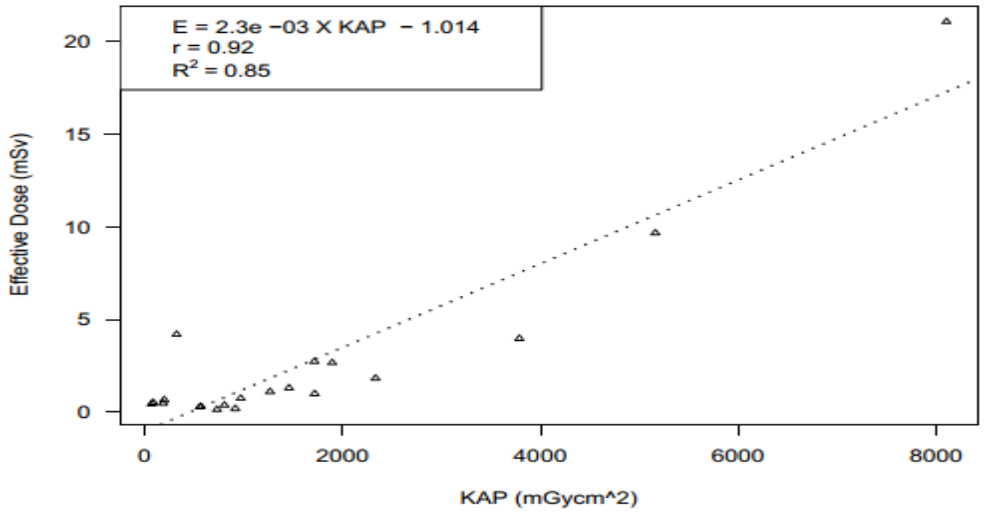


Figure 1: The correlation between the ED and KAP per individual projections for TS.

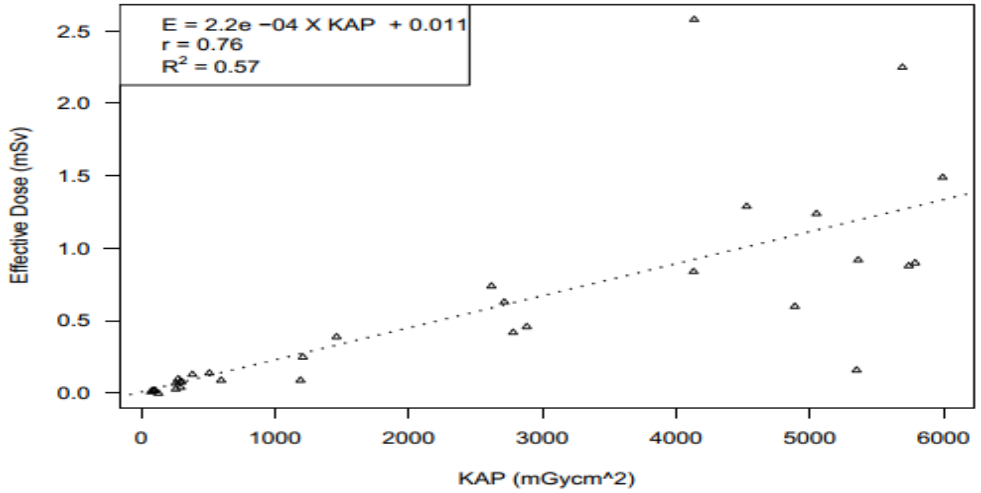


Figure 2: The correlation between the ED and KAP per individual projections for LS.

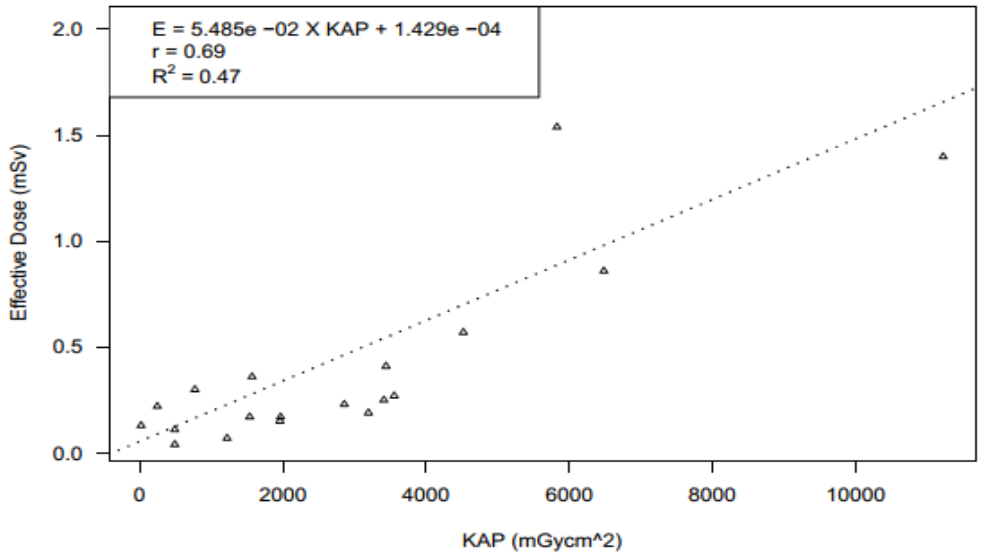


Figure 3: The correlation between the ED and KAP per individual projections for DHS.

Estimated mean patient organ dose for selected organs

The mean and median patient organ doses for selected organs were obtained by means of the PCXMC along with Microsoft office excel 2007 in three different procedures namely; DHS, LS and TS. The computations of these doses based on current tissue weighting factors of ICRP Publication 103 (ICRP 2007). The radiation weighting factor considered in these calculations was 1 for photons. The mean patient organ doses were evaluated from MC files and presented in the Table 6 for DHS, LS and TS. In addition the mean absorbed dose and selected organs for each operational procedure were presented in the histogram as show in Appendices A, B and C.

From the results presented in Table 6 and Appendix A, the upper leg bones received the highest radiation dose of 7.48 mGy among the selected organs for DHS followed by pelvis recording the organ dose of 4.40 mGy. The prostate and testicles as the sensitive organs received the radiation dose of 4.02 and 2.63 mGy, respectively. The rest organs had considerably small amounts of radiation doses in the DHS procedure. This might be as a consequence of the procedure being carried out in the hip region of the patient's body; thus some of the organs were not beamed directly and low tissue weighting factor employed in the computation for the selected organs. It should be noted that, male patients undergoing this operation are of great concern because of the sensitive organs such as prostate and testicles. Furthermore, from Table 6 and Appendix B, the pelvis received relatively higher radiation dose of 1.31 mGy than the rest of the organs for the LS procedure. The spleen received the highest soft tissue organ dose of 1.02 mGy and lower large intestine recording the considerably high radiation dose of 0.86 mGy. The breast and lungs as the sensitive organs account for 0.05 and 0.08 mGy. This was due to the positioning of the X-ray tube, projection and designated part of the patient body during the exercise; as a result, the breast and lungs were not directly beamed. In addition, from Table 6 and Appendix C, it can be observed that ribs as bony organs accounted for the highest radiation dose of 12.30 mGy for TS procedure. For the sensitive organs, the breast received the highest radiation dose of 7.55 mGy followed by the lungs with radiation

dose of 4.60 mGy. This was due to the positioning of the X-ray tube, projection, designated part of the patient body during the exercise; as a result, the breast and lungs were directly beamed and they assumed high tissue weighting factors (0.12) in computation of doses for the sensitive organs (ICRP 2007). The thyroid accounted for the least radiation dose of 0.40 mGy among the sensitive organs, and this might be due to the low tissue weighting factors (0.04) applied in computing the dose by PCXMC. For the soft organs, the heart, scapulae, stomach and spleen absorbed radiation doses (mGy) of 6.26, 4.98, 4.96 and 4.78, respectively. With these observations, the rest soft organs for the TS had relatively lower radiation doses.

Table 6: Mean patient organ dose for DHS, LS and TS procedures

Selected organs	Procedure and Organ dose (mGy)		
	DHS	LS	TS
Active bone marrow	0.60	0.22	1.15
Adrenals	NA	0.14	1.64
Breasts	NA	0.05	7.55
Clavicles	NA	NA	2.03
Colon	1.04	0.52	NA
Gall bladder	0.02	0.13	1.72
Heart	NA	0.11	6.26
Kidney	0.01	0.19	0.73
Liver	NA	0.06	1.93
Lower larger intestine	2.24	0.86	NA
Lower spine	NA	NA	0.34
Lungs	NA	0.08	4.60
Lymph nodes	NA	0.25	1.75
Muscles	1.28	0.24	1.06
Oesophagus	NA	0.11	2.82
Ovary	0.63	0.41	NA
Pancreas	NA	0.46	3.88
Pelvis	4.40	1.31	NA
Prostate gland	4.02	NA	NA
Ribs	NA	0.43	12.30
Scapulae	NA	NA	4.98
Skeleton	1.44	0.18	1.72
Skin	1.02	0.16	NA
Skull	NA	NA	0.08
Spleen	NA	1.02	4.78
Stomach	NA	0.84	4.96
Testicles	2.63	NA	NA
Thymus	NA	NA	3.36
Thyroid	NA	NA	0.40
Upper leg bones	7.48	NA	NA
Urinary bladder	2.06	0.24	NA
Uterus	0.83	0.27	NA

NA = Not Available

Generally, it was observed that there was a wide range of variations of the absorbed organ doses that existed within the Institute for the three procedures. For example, the mean organ dose for the selected organs in DHS, LS and TS varied from 0.01 mGy to 7.48 mGy, from 0.05 mGy to 1.31 mGy and from 0.08 mGy to 12.30 mGy, respectively. Among the selected organs, upper leg bone, pelvis and ribs for DHS, LS and TS received the maximum organ doses of 7.48 mGy, 1.31 mGy and 12.30 mGy, respectively. The detected broad range of variations of the organ doses in Table 6 for all the three procedures indicates that exposure parameters contribute significantly to organ dose variations. The results from the current study relate to others in the literatures.

It can be observed from Table 7 that the mean values of KAP for the LS, DHS and TS procedures in the current study were slightly lower than the mean values reported by Crawley and Roger (2000) for the UK, Osman et al. (2012) for Sudan and Tsapaki et al. (2016) for Greece.

Table 7: The mean values of KAP, effective dose, fluoroscopy time (FT) and number of radiographic images (n) of the current study relative to other studies

Author (Location)	Number of patients	n	FT (min)	KAP ($Gycm^2$)	Effective dose (mSv)	Procedure under C-arm
This Study (Tanzania)	32	12	0.18	1.614	0.27	LS
	20	17	0.85	2.929	0.47	DHS
	20	12	0.22	0.986	2.70	TS
Tsapaki et al. (2016) (Greece)	101	21	2.1	6.3 ($Gycm^{-2}$)	NA	IMN of IP fractures
	28	22	2.2	6.3 ($Gycm^{-2}$)	NA	IMN of shaft of femur/tibia
Osman et al. (2012) (Sudan)	37	6	0.60	NA	1.21	DHS and DCS
Hart et al. 2012 (UK)	174	3		5.0		LS
	1713			4.0		Hips
	1238			3.0		TS
Mantebea (2015) (Ghana)	50	46	NA	NA	6.88 ± 1.22	Orthopaedics
Malek et al. (2007) (UK)	389	NA	0.7	1.96	0.3 ± 0.2	DHS
	85	NA	1.1	3.56	0.6 ± 0.6	CHS
Crawley and Roger (2000) (UK)	2	NA	0.85	3.51 (3^{rd} QT)	0.370	TS
	43	NA	0.90	3.74 (3^{rd} QT)	0.720	DHS
	52	NA	2.30	6.068 (3^{rd}QT)	0.435	LS

NA = Not Available, IMN = Intra Medullary Nailing, IP = Intertrochanteric or Peritrochanteric, n = number of radiographic images, DCS = Dynamic Cannulated Screw, CHS = Cannulated Hip Screw

The observed lower values of KAP in Tanzania compared to Greece, Sudan and the UK might be caused by differences in practices and the patients' sizes. It is also noted from Table 7 that the average values of the effective doses in the current study for LS, DHS and TS were comparable and slightly higher than those reported by Crawley and Roger (2000) and Malek et al. (2007) for the UK. For instance, the mean values of the effective doses in this study for LS, DHS and TS were 0.27, 0.47 and 2.7

mSv, respectively, while for the UK the mean effective doses were 0.435, 0.720 and 0.370 mSv for LS, DHS and TS, respectively. Furthermore, the mean value for DHS reported by Malek et al. *(*2007) for the UK was 0.3 mSv which is lower than 0.47 mSv for DHS in the present study. Conversely, the mean values of the effective doses in the current study were relatively lower than those described by Mantebea (2015) for Ghana and Osman et al. (2012) for Sudan. For example, the mean values of the effective doses for all the procedures in the current study were lower than that of Ghana by the numerical factor of 8.49 and the mean value of the effective dose in Sudan for orthopaedic procedures (DHS and CHS) was 1.21 mSv which is higher than 0.47 mSv for the DHS in the present study. The observed high variations of the mean values of the effective doses in the current study and those reported from Sudan, Ghana and the UK might be mainly attributed to the large numbers of radiographic images, complexity of the procedures, anatomical size and targeted regions of the patient and diversity of the skills and experience of the surgeons.

Conclusions

The information on assessment of radiation dose imparted to patients from the FGOPs at Muhimbili Orthopaedic Institute has been reported. Substantial variations of patient doses within the Institute were observed. For each fluoroscopically guided procedure (LS, DHS and TS), there were variations of the EDs and KAP within the Institute. For example, the range of KAP values (in mGy cm^2) for LS, DHS and TS procedures were 17.10–1122, 71.40–5783 and 72–3786, respectively, while the range of EDs (in mSv) for the LS, DHS and TS procedures were 0.00–1.29, 0.04–2.03 and 0.16–21.08, respectively. These variations were mainly caused by the different number of radiographic images for every procedure, the level of complexity of the procedure, the anatomical region of the patient exposed to radiation, fluoroscopy time, general lack of written standard examination protocols for reference of the examination X-ray parameters, level of skills and experience among the radiographers and surgeons. The observed variations in the radiation doses for the non-optimized procedures call for optimization of fluoroscopically guided procedures. This can be accomplished through establishment of written standard exposure protocols and formal training of personnel on optimal use of fluoroscopy machines and optimal choice of technical exposure parameters focused on anatomical region being investigated and patient body size. Furthermore, extensive studies on evaluation of patient radiation dose during plan X-ray radiograph before surgical operation, assessment of radiation dose level to paediatric patients during fluoroscopically orthopaedic procedures and estimation of radiation dose to medical staff in the operational theatres should be conducted.

Acknowledgements

The authors would like to express their acknowledgements to the Arusha Technical College for financial support, Tanzania Atomic Energy Commission for equipment support and Muhimbili Orthopaedic Institute (MOI) management for granting permission to use the C-arm fluoroscopy facility during data collection. They would further like to sincerely thank Dr. M. Mango, Mr. J. Kulinga, Mr. B. Adam, Mr. R. Juma, Mr. E. Mlelwa and Mr. P. Tarimo for their technical support at the X-ray fluoroscopy unit.

References

Crawley MT and Roger AT 2000 Dose–area-product measurements in a range of common orthopaedic procedures and their possible use in establishing local diagnostic reference levels. *Brit. J. Radiol*. 73: 740-744.

Eckerman, KF, Cristy M, Ryman JC 1996 The ORNL Mathematical Phantom Series, Oak Ridge, TN, Oak Ridge

National laboratory, http://ats.ronl.gov/documents/mird2.pdf

Hart D, Hillier, M and Wall BF 2012 Doses to Patients from Medical X-ray Examinations in the UK-2010 Review. National Radiological Protection Board. Chilton, England ISBN 978-0-85951-716-4.

IAEA (International Atomic Energy Agency) 2007 Dosimetry in Diagnostic Radiology. An International Code of Practice. *Tech. Rep. Ser*. No. 457.

ICRP (International Commission on Radiological Protection) 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. *Ann. ICRP* 37(2–4): 2.

ICRP (International Commission on Radiological Protection) 2010 Radiological protection in fluoroscopically guide procedures performed outside the Imaging department. ICRP Publication 117. *Ann. ICRP* 40 (6).

IPEM (Institute of Physics and Engineering in Medicine) 2005 Recommended standard for the routine performance testing of diagnostic X-ray imaging systems. Report No.77. York.

Malek S, Davies, Malek IA Rawal A, Singh A and Harvey RA 2007 Trauma surgery and risk of radiation injury to patients. *Eur. J. Orthop. Surg. Traumatol.* 17: 23-28.

Mantebea H 2015 *Determination of doses and cancer risk to paediatric and young adult patients undergoing plain radiographic and fluoroscopic guided surgical procedures*. A Master of Philosophy degree thesis, University of Ghana.

Ngaile JE, Msaki PK and Kazema RR 2016 Survey of effective doses to patients undergoing contrast-based X-ray fluoroscopy procedures in Tanzania. *Radiat. Prot. Dosim.* 173(1-3): 203-211.

Osman H, Elzaki A, Sam AK and Sulieman A 2012 Evaluation of patient radiation dose during orthopaedic surgery. Proceedings of the Eleventh Radiation Physics and Protection Conference, Egyptian Atomic Energy Authority (EAEA) (Egypt); National Network of Radiation Physics (NNRP) (Egypt), p. 404.

Streiner DL, Norman GR and Caimery J 2015 Health Measurement Scales: A Practical Guide to their Development and Use. 4th Edition. Oxford University Press, USA.

Tapiovaara M and Siiskonen T 2008 PCXMC: A Monte Carlo Program for Calculating Patient Doses in Medical X-ray Examinations, 2nd Edition. Helsinki, Finland: Finnish Centre for Radiation and Nuclear Safety.

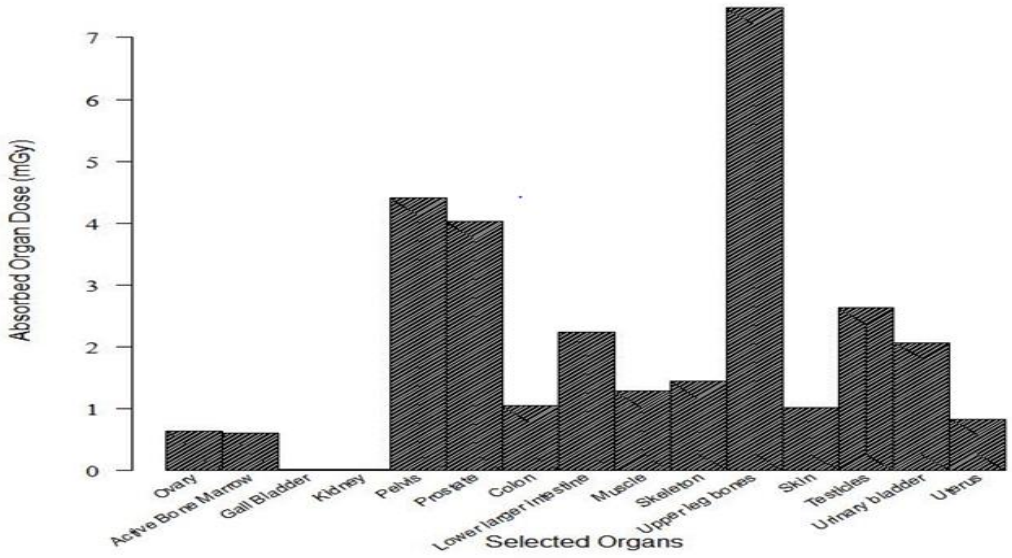
Tsalafoutas IA, Tsapaki V, Kaliakmanis A, Pneumaticos S, Tsoronis F, Koulentianos ED and Papachristou G 2008 Estimation of radiation doses to patients and surgeons from various fluoroscopically guided orthopaedic surgeries. *Radiat. Prot. Dosim.* 128 (1): 112-119.

Tsapaki V, Tsalafoutas IA, Fagkrezos D, Lazaretos I, Nikolaou VS and Efstathopoulos N 2016 Patient radiation doses in various fluoroscopically guided orthopaedic procedures. *Radiat. Prot. Dosim.* 168 (1): 72-75.

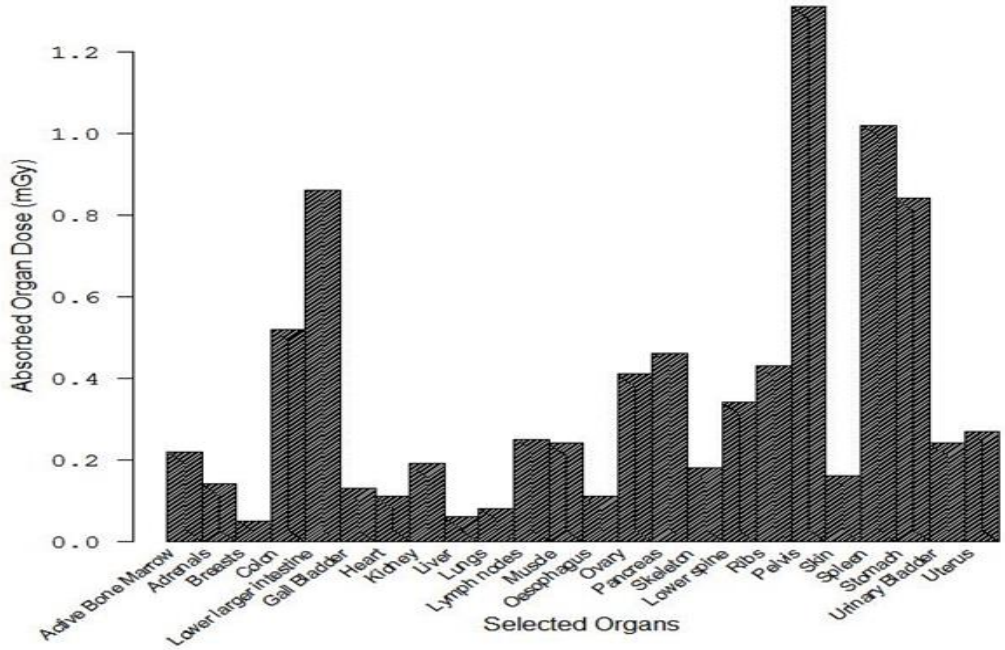
UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) 2008 Sources and Effects of Ionizing Radiation. *Report to the General Assembly with Scientific Annexes*, vol. I. New York: UNSCEAR.

Wielandts JY, Smans K, Etor J, De Buck S, Heidbuchel H and Bosmans H 2010 Effective dose analysis of three-dimensional rotational angiography during catheter ablation procedures. *Phys. Med. Biol*. 55: 563-579.

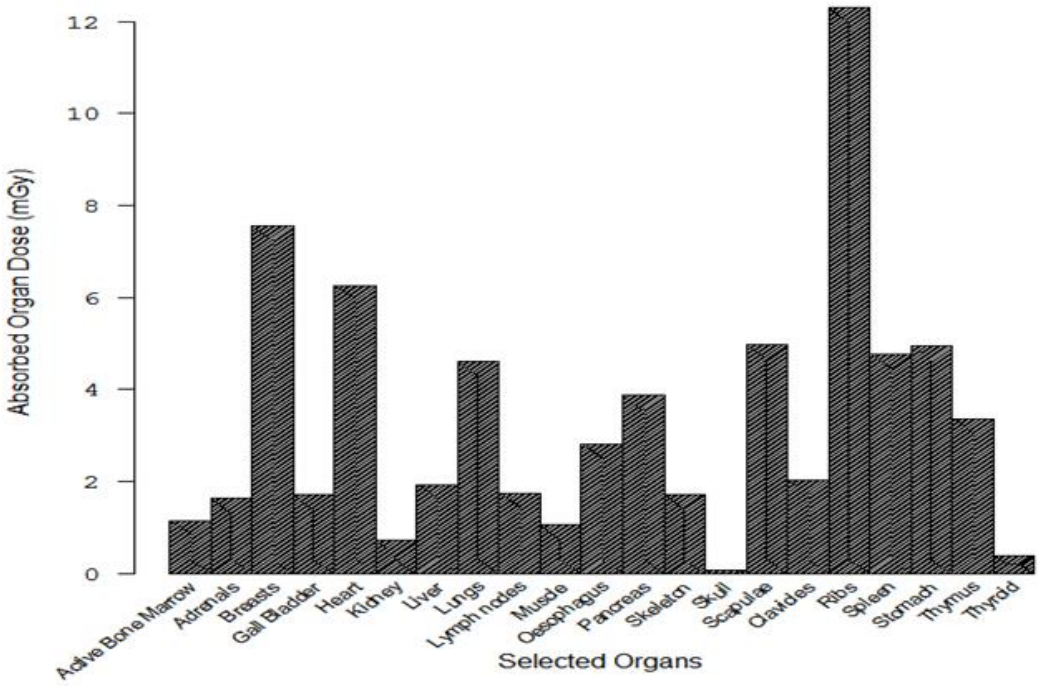
Appendices: Histograms of absorbed organ doses distribution for the procedures



Appendix A: Histogram of absorbed organ dose distribution for DHS procedure and selected organs.



Appendix B: Histogram of absorbed organ dose distribution for LS procedure and selected organs.



Appendix C: Histogram of absorbed organ dose distribution for TSP procedure and selected organs.