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A Study on Effective Dose to Patients and Workers During Diagnostic X-ray Procedure in UTHM Health Centre

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Abstract: Effective dose is used as a reference limit to measure the total health risk from the radiation exposure to the body. Over exceeding the limit of effective dose could result in a high possibility of developing radiation-induced cancer. The aim of this research is to measure the effective dose to patients and workers during the diagnostic X-ray procedure in UTHM Health Centre. Effective dose to radiation workers is estimated by calculating the radiation dose in the controlled and supervised area. Pen dosimeter is used for dose measurement. The pen was placed at numerous spots inside the radiation facility to study the effective dose with respect to distance and shielding materials present. An ANSI patient-equivalent phantom was developed to simulate the real patient absorption and scattering during X-ray diagnostic examination for extremity, chest, skull, and lumbar. Results show that the lowest annual effective dose is measured by the door leaf which is 3.83 mSv per year while the highest is on the erect bucky stand that is 48.10 mSv per year. The annual effective dose in the supervised area and the ESE values of ANSI patient-equivalent phantoms (in mR per projection) is found to be under the reference dose limit. This finding suggested that the radiation protection principles are obeyed, with the effective dose to the radiation workers as well as patients is in the range of reference dose limit.

Keyword: Effective dose, diagnostic X-ray, ANSI patient-equivalent phantom, pen dosimeter

1. Introduction

Effective dose (EfD) was recommended in 1991 by the International Commission on Radiological Protection (ICRP) and acts as a reference dose limit for radiation received by patients during diagnostic radiology [1]. The effective dose, which takes into consideration the type of radiation and the sensitivity of the organ, is the best parameter to assess the health risk from ionizing radiation [2].

For the purpose of assessing radiation exposure and the associated risk of biological damage, the effective dose limiting system was introduced [3,4]. Separate limits are set for three categories of exposed individuals: patient, workers and members of the public, which known as medical, occupational and public exposures, respectively [5]. Patients are the most vulnerable to the radiation dose compared to the radiation workers and members of the public. This is because they receive direct primary radiation exposure as well as indirectly secondary scattered radiation. The safety of clinical staffs or radiation workers also needs to be taken into measures as they are exposed to radiation more frequent than patients. The public is a vast majority group of people who are not associated with man-made radiation. Hence, they receive the less radiation dose [6]. Radiation exposure should always be kept ALARA to minimise the probability of any potential damage to people.

The annual effective dose limit varies with these different groups of people, based on how frequent they deal with the radiation source. The annual effective dose for members of the public is limited to 1 mSv per year at most while for anyone who regularly deals with radiation sources their effective dose must not exceed 20 mSv per year [1,4]. If the dose level exceeds the limit, it will increase the probability of cancer risk and other abnormalities. In contrast to the previous groups of people, the amount of radiation received by a patient may be indicated in terms of entrance skin exposure (ESE) and glandular dose, bone marrow dose and gonadal dose [3,4].

Dose measurements for the public and radiation worker groups may be implemented

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by placing radiation gauges (i.e. OSL badges) in areas designated for the two groups concerned at a specified period [8]. However, the dose to the radiographic examination from a different part of the patient body can be estimated either directly or indirectly, by placing the radiation meter (i.e. TLD) on the surface of the patient's skin or by replacing the real patient with the patient-equivalent phantom (PEP), respectively. Acrylic and aluminium phantoms have been developed by the American National Standards Institute (ANSI) and the Centre for Devices and Radiological Health (CDRH) for estimating effective dose to the patient during X-ray diagnostic exposure [9]. This type of phantom will be used throughout this work.

The radiology facility in any health centre can be classified into the controlled and supervised area [1,8]. The controlled area shall be the X-ray rooms where the diagnostic X-ray machine is located. The supervised area includes the area where the radiologist works, the control panel area and any other part that is not the public area. X-ray beam must be constricted to the outside of X-ray room with the use of a shielding material [5]. While clinical staff and members of the public are protected by the wall of the building made of concrete, patients are protected from X-rays by the excellent installation and carefully graduation of X-ray machines [3-7]. The use of newer equipment of medical imaging as well as proper use of radiological parameter can also help in decreasing of the absorbed dose by patients [3-5]. Basic parameters involved are source to skin distance (SSD), tube potential (kVp), and tube current (mAs).

This study focused on measuring the effective dose to the patients and workers during the diagnostic X-ray procedure in the UTHM Health Centre. Effective dose to radiation workers is determined by calculating the radiation dose in the controlled and supervised area, while the ESE exposure per projection (in mR) to a specific part of the patient body is estimated using the ANSI patient-equivalent phantom.

2. Materials and Methods

The X-ray tube used was Toshiba DRX-1603B, supported with a floor-to-ceiling X-ray tube stand (Toshiba DS-TA-5A). The radiation dose was merely measured using pen dosimeters Model 13.8 which had been calibrated by the Malaysian Nuclear Agency with each pen having different calibrating factor [10].

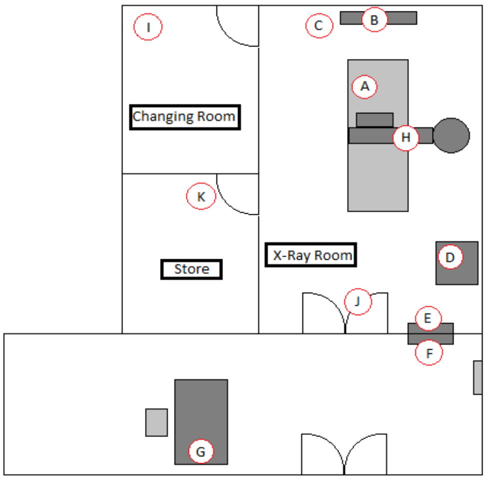

Fig. 1 Position of pen dosimeter in radiation facility of UTHM Health Centre.

Table 1 Representation position of pen dosimeter.

Position of Pen Dosimeter	Representation
On the couch	A
On top of erect bucky stand	B
Beside erect bucky stand	C
On top of steel cabinet	D
By the window (inside)	E
By the window (outside)	F
On the desk	G
X-Ray tube gantry	H
Changing room	I
Door leaf (inside)	J
Store	K

The established methodology was adapted to perform the dose measurement in the controlled and supervised area of radiation facility in UTHM Health Centre [11-14]. The pen dosimeters were left in its respective places for 3 to 4 days to measure the effective dose in the area. Table 1 and Fig. 1 both show the placement of pen dosimeter at 11 different spots inside the radiation facility of UTHM Health Centre.

The measurements of the dose were performed at daytime during normal working hours which is from 8 am to 5 pm on Sunday to Wednesday, and 8 am to 3 pm on Thursday. No measurements were performed during weekends and public holiday. The X-ray machine was operated with energy ranging from 42 to 95 kVp and intensity ranging from 0.011 to 0.070 mAs. These parameters represent the exposures for diagnostic imaging of body parts such as chest, abdomen, extremities, skull, and spinal vertebra. The number of diagnostic X-ray procedure conducted was inconsistency. It depends on the availability of patient on the very day. The actual dose was calculated from the measured dose using formula;

$$D = B \times CF \tag{1}$$

where D is the actual dose (μSv), B is the dose measured from dosimeter (mR), and CF is calibration factor (μSv/mR) of individual pen dosimeters. The effective dose was calculated by using the equation;

$$E = W_T D_T \tag{2}$$

where E is the effective dose (μSv), W_T is the tissue weighting factor, and D_T is the mean actual dose to tissue.

The effective dose in human organs was measured with the assist of ANSI phantoms. The phantom was developed from a clear acrylic piece of 30.5 cm×30.5 cm×2.54 cm and aluminium sheet of various thickness, based on the body parts the phantom represent [8]. The extremity phantom consists of 30.5 cm×30.5 cm×1.0 mm aluminium sheet sandwiched between the two acrylic planes. Chest phantom consists of two aluminium sheets with thickness 1 mm and 2 mm, respectively. Both aluminium sheets were sandwiched between two transparent acrylic pieces. An air gap of 5.08 cm was made to represent the lung cavity. Skull phantom consists of 6 pieces of acrylic and two aluminium sheets of 1 mm and 2 mm thickness, respectively. The lumbar spine phantom consists of 7 pieces of acrylic and aluminium of 7 cm×30.5 cm×4.5 mm placed on top of it. Aluminium with a thickness of 4.5 mm was used to give additional attenuation in the spinal region [9]. Fig. 2 shows the design of the four phantoms used in this study. Darker square (or darker rectangle) represents the sandwiched aluminium sheet.

Two acrylic pieces were fabricated hole to provide an inner insertion slot for a pen dosimeter with respect to skin depth (acrylic surface). The exposure (mR) per projection was measured by placing the pen dosimeter at the front and back of phantom. For chest phantom, the exposure was also measured at the air gap. For each exposure, five measurements were recorded to reduce the statistical error and to calculate the standard deviation.

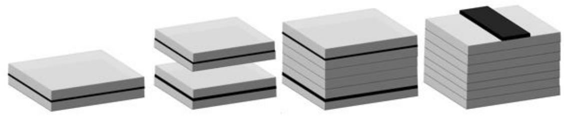

Fig. 2 Extremity phantom, chest phantom, skull phantom and lumbar spine phantom (left to right) [9].

3. Results and Discussions

All measured dose in radiation facility is with background radiation which is approximately 1 mR. The annual dose limit for radiation workers is 20 mSv per year [1,8]. By using simple mathematic calculation, the effective dose calculated for every position is converted into mSv per year for better comparison with the reference dose limit [1,8]. Table 2 shows the annual effective dose in mSv per year with respect to the different position in the radiation facility.

Table 2 Annual effective dose at a different position inside the radiology facility.

Position of Pen Dosimeter	Annual Effective Dose (mSv/yr)
On the couch (A)	10.39
Erect bucky stand (upper) (B)	4.82
Erect bucky stand (lower) (B)	48.10
Beside erect bucky stand (C)	5.43
On steel cabinet (D)	4.32
By the window (inside) (E)	6.56
By the window (outside) (F)	8.04
On the desk (G)	9.87
X-Ray tube gantry (H)	5.47
Changing room (I)	5.43
Door leaf (inside) (J)	3.83
Store (K)	4.82

Based on Table 2, the highest annual effective dose is around the area of erect bucky stand (point B) and the second highest is on the couch (point A). This high reading is expected due to it being exposed to X-ray beam the most during the diagnostic procedure. Although this value had exceeded the dose limit, it is not a concern as it was in the controlled area. With proper shielding, the workers can be protected from excess exposure. It is shown that other areas in the facility have an effective dose lower than the reference dose. The annual effective dose measured around the radiologist desk is 9.87 mSv per year. This finding shows that the workers are protected from excess radiation exposure and are working in a radiologically safe environment. Overall, it can be said that the effective dose to the controlled and supervised area of UTHM Health Centre is under the reference dose limit. Comparing the results obtained from this study with previous studies is considered to be difficult due to the significant difference in the method of dosimetry as well as other factors that may affect the actual dose [15,16,17,18].

For the measurement of effective dose to ANSI patient-equivalent phantoms, the background radiation is excluded. Based on Table 3, it shows that the dose is higher as the distance between the source and the pen dosimeter is shorter, due to attenuation of X-ray beam when penetrating the acrylic and aluminium materials of the phantom.

Table 3 The dose at the front and back of the phantoms and its comparison with the permissible ESE (mR per projection).

Phantom	Position of Pen Dosimeter	Measured Dose (mR)	Permissible Skin Entrance Exposure (ESE in mR per Projection)
Extremity	Front	19.0 ± 1.4	10-330 [3]
	Back	4.6 ± 2.1	
Chest	Front	18.2 ± 1.8	10-25 (PA) [3]
	Air gap	4.0 ± 0.4	
	Back	3.0 ± 1.2	
Skull	Front	200.6 ± 24.6	105-240 (LAT) [3]
	Back	4.2 ± 0.4	
Lumbar Spine	Front	185.2 ± 38.8	570-1710 (AP) [4]
	Back	3.8 ± 0.4	

Factors of attenuation may include absorption and scattering. The measured exposure from the table is the exposure of phantom that represents a different part of the real patient body.

The average measured entrance skin exposure (ESE), in mR per projection, to the patient during X-ray diagnostic for extremity, chest, skull, and lumbar spine are 19.0±1.4, 18.2±1.8, 200.6±24.6, and 185.2±38.8, respectively. The measured dose (mR) to all four body parts of patient studied in this research are in the range of the permissible patient ESEs.

4. Conclusion

The annual effective dose in the radiation facility of UTHM Health Centre is successfully measured. The results show that the lowest effective dose is measured by the door leaf which is 3.83 mSv/yr while the highest is on the erect bucky stand that is 48.10 mSv/yr. The effective dose in the supervised area (point G and F) of radiation facility is found to be under the reference dose limit. Although there is a highly effective dose measured inside the X-ray room, however, the exposure rate to the radiation workers is minimised by the shielding materials in the said room. Optimization of procedure protocols as well as implementing the general use of protective shield during X-ray diagnostic procedure can reduce the occupational doses to the radiation workers.

The low dose measured shows an excellent radiographic technique practised by the workers of UTHM Health Centre. In conclusion, it was found that the radiation protection principles are obeyed in UTHM Health Centre, with the effective dose to the radiation workers as well as patients is in the range of reference dose limit.

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