PATIENT EXPOSURE AROUND AN X-RAY DIAGNOSTIC MACHINE-A CASE STUDY

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Abstract

Sources of extraneous exposure to patients undergoing radiological examinations include human and machine errors and the application of substandard procedures that may not be detected until quality control measurements have been carried out. This implies elevated individual and population health risks. This paper reports findings from a study of a diagnostic x-ray machine in one diagnostic centre. The exposure times, tube voltage and exposures were studied. The tube voltage were more than 100% higher than the set voltage while the exposure times were up to 60% higher than the set exposure times. These led to higher exposures than envisaged. The implication on the health risks and methodologies for exposure reduction in this and other diagnostic centers are discussed.

Keywords: *Exposure rate, output, tube peak voltage, target angle, filtration*

Introduction

Potential sources of extraneous exposures to patients undergoing radiological examinations span the whole of the various levels of activities involved in the radiological process. In particular the IAEA (1994) noted some aspects of the process that require handling in order to minimize unwanted or extraneous exposures. These are (i) the area, e.g., the beam size dictated by the chest, skull, extremities, etc. of the patient to be examined, the number and size of views per examination (number of films) and the time per examination (ii) collimation of the primary x-ray beam in order to minimize the volume of the tissue to be exposed and also to improve the diagnostic quality (iii) appropriate values of the tube voltage (V), tube current (I), exposure time (t) and filtration (F) in units of kilovolt peak (kVp), milliAmpere (mA), second (s) and mm Al respectively, the measurements of which constitute an integral part of the process of optimization of protection. Their values may be influenced by human-machine interactions and every decision taken has the potential for reducing or adding extraneous exposure to a patient's burden.

The IAEA (1994) recommended Guidance level of dose for diagnostic radiography for typical adult in terms of the entrance surface dose (ESD). The Commission of European Communities (CEC 1990) also published examples of image quality criteria and good radiographic technique that includes ESD levels, focus-to-detector distance (fdd), t, V range and F among others. The ESD is important because it can be used to either calculate the organ doses or directly measure the radiation risk and hence the effective and the population dose. But the ESD depends on the exposure measured in air or tissue. The former option is often preferred because it is relatively easier to measure and the ESD is directly proportional to the exposure. This implies that the exposure is a good indicator of the radiation risk. In this exercise the exposure in air has been used as a measure of the risk to the patient. However, while parts of the recommendations above can be easily implemented by the radiologists and radiographers, exposure measurement is often outside the scope of their duties.

The objective of this paper is to report measurements of t, V and estimates of the potential exposures for a typical adult patient undergoing radiological examination at a diagnostic x-ray facility. The exposures measured in air using radiographic quantities that were used for typical adult patients were about ten times higher than expected. Generally, potential for improvement exists. Suggestions for minimizing the patient exposure in similar circumstances are offered. In order to extrapolate from one tube voltage to another and also estimate the exposures at those voltages, simple mathematical formulae were used with results that were in good agreement with results of another method found in the literature.

Methodology

The exposure measurements were carried out on a single-phase X-ray machine with a tungsten anode at the out-patient department of the University College Hospital (UCH), Ibadan, Nigeria. The machine is a GEC Medical Apollo, Roentgen 501 with an X-ray tube made by Machlett at target angle of 16^{o}. The fsd was fixed at 100 cm, the beam size was 43 cm x 35 cm and typical V setting of 50 – 80 kVp used for adult patient in common diagnostic processes were employed. The inherent filtration of the tube was 0.7 mm Al and the tube current was 300 mA. Typical exposure times, t(s) for an average size patient were chosen for the operations. Each exposure was made by a radiographer.

For the measurements, an experimental arrangement similar to the one described in the AAPM protocol (Ma et al 2001) was followed with a little modification (the absorbers were tapped to the tube window). The experimental setup is shown in Fig. 1.

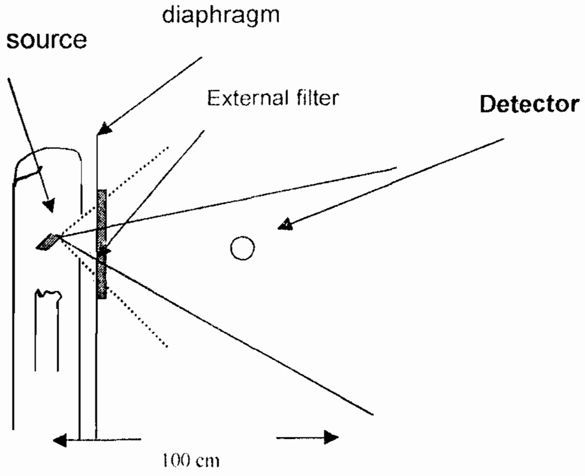

Fig. 1: The experimental setup for exposure measurement (Adapted from Ma et al, 2001)

The aluminium filters used had a purity of 99% and were obtained from the Secondary Standards Dosimetry Laboratory (SSDL) set up at the Department of Physics in the University of Ibadan with technical support from the IAEA. In the, experiment, the thickness of the aluminium filter was varied and for each thickness the exposure was measured with a detector placed 1 m from the source such that scatter radiations effect is negligible and the beam can be considered narrow. The detector used for exposure measurements is the Victoreen X-ray test device (Model 4000M+). This device measures mean, effective and the maximum peak tube voltage, power phase, exposure and exposure time. It was factory calibrated for x-ray tubes with tungsten target/aluminium filtration anode (W/Al) against a beam at 3 mm Al filtration and molybdenum filtered molybdenum (Mo/Mo) anode. The system determines the tube voltage with an accuracy of ± 2% (Victoreen 1995). The internal ionization chamber that measures exposure has a volume of 36 cm^{3}. The time is measured to an accuracy of ± 2%. In order to eliminate measurement error due to the 'heel effect', the detector was positioned such that its front-to-rear panel axis was always parallel to the anode-cathode axis of the tube as recommended by the manufacturer (Victoreen 1995).

Results and Discussion

Table 1 presents the set/expected tube voltage (Col. 1), the corresponding measured tube voltage (col. 2) and the measured exposure rates in (Col. 3). It can be observed that the exposure increases with increasing voltage. The variation between the measured tube voltage, V_m, and the expected voltage V_e is also plotted graphically in Figure 2. It can be seen that V_m was more than twice V_e in the range employed in this facility as illustrated. This implies that the patient exposure may be unexpectedly elevated due to faulty machines.

Table1 Variationn of measured exposure rate with measured tube voltage

Expected Voltage (kVp)	Measured V (kVp)	Measured Exposure Rate, ERm (mGy/s)	Calculated Exposure Rate, ERc (mGy/s)Eq. 2.	Ratio ERm/ERc
50	116.6	2.61	2.48	1.05
60	121.2	2.68	2.72	0.98

70	127.5	2.93	3.06	0.96
80	138.8	3.87	3.73	1.04

Using the generic curve fitting method of EXCEL 2000 computer software and Pentium IV PC, V_m was found to increase exponentially with V_e at the total filtration of 2.7 mm Al. The relationship between the measured and expected tube voltages was determined to be of the form in equation (1) below:

$$V_m = 86.515e^{0.00575V_e} \qquad (1)$$

where V_m is the measured voltage and V_e is the set or expected tube voltage. Equation (1) reproduced V_m accurately to within ±1% at all input voltage V_e and was used to extrapolate V_m for values of V_e from 90 to 120 kVp in order to cover the range of V most commonly employed in diagnostic radiology. The data of the extrapolated V_m is shown on the curve.

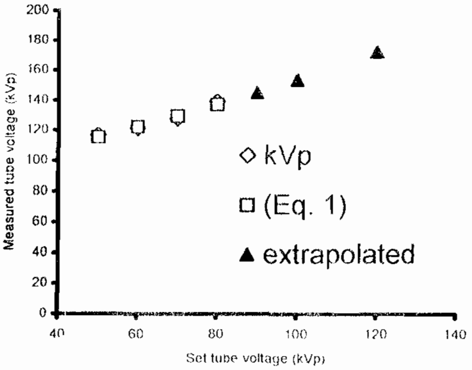

Fig. 2: Variation of the measured tube voltage with set tube voltage at 2.7 mm Al total filtration.

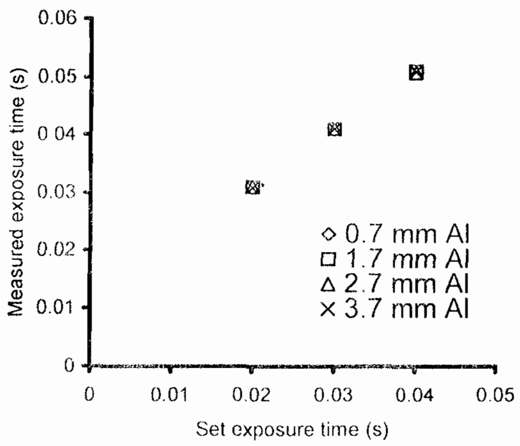

Fig. 3: Variation of measured exposure time with set/expected exposure time

Figure 3 shows the measured exposure time T(s) compared with the set/expected exposure time t(s). T(s) was 60% higher than t(s) at t(s) of 0.02 s and 30% higher at 0.04 s but, as can be seen, the discrepancy in timing is independent of the filtration. The implication of the wrong timing is that since integrated exposures vary directly with the time of exposure, the patient exposure will increase beyond expectation and is an unnecessary burden. However a later investigation showed that the discrepancies in timing were due to both the machine and operator errors. Firstly, the time setting knob on the control panel was not operating properly. It stopped before getting to its normal position. Secondly, the operator failed to notice the error. This problem was later pointed out to the operator who made necessary adjustments in subsequent exposures but the error was not completely removed. This is a machine related error and it requires to be constantly monitored.

The measurement of exposure rate at V_e of 50 kVp, I of 300 mA, fdd of 100 cm and T that ranged from 0.03 to 0 05s is illustrated in Fig.4. The curve shows that the exposure rates are independent of the exposure time for each total filtration but decayed exponentially with the total filtration. Thus the addition of external filtration reduces the patient dose. The machine was being used with the inherent filtration of 0.7 mm Al.

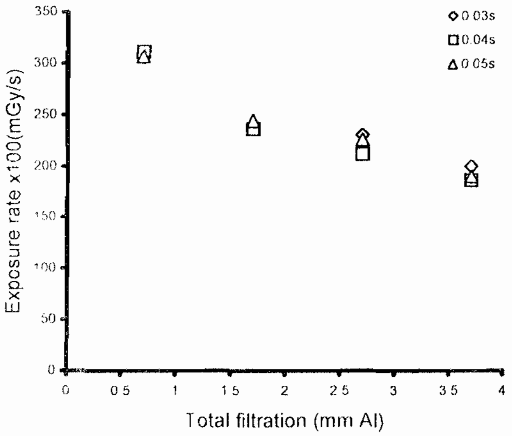

Fig. 4: Variation of exposure rate with exposure time and total filtration at set V of 50 kVp, current of 300 mA, and fdd of 100 cm.

Figure 5 shows the integrated exposure at corresponding times and total filtrations. The trend with the total filtration is similar but the exposures increase with increase in the exposure time. The absence of overlap among the curves indicates that the detector functioned properly.

The variation between the measured exposure rate ER_m in units of mGy/s and V_m was modeled using the Microsoft EXCEL Software 2000 and Pentium IV PC. The relationship was fitted to a power function of the measured voltage V_m resulting in equation (2) below:

$$ER_m = a\,V_m^{\ b} \qquad (2)$$

where $a=3.82\times10^{-5}$ and $b=2.32874$ for data at a total filtration 2.7 mm Al. The equation reproduces ER_m accurately to much better than ±1% as suggested by the ratios of ER_m to the calculated rate ER_c (column 5 of table 1). Also using Equation (1) and Equation (2) the values of ER at the most commonly used voltages were predicted and entered in column 2 of Table 2.

Table 2: Comparison between measured exposure rate and exposure rate predicted at expected tube voltage.

Expected Voltage (KVp)	Calculated Expected Exposure Rate ER_c(mGy/s)	Measured Voltage (kVp)	Measured Exposure Rate ER_m(mGy/s)	Ratio (ER_m/ ER_c)
50	0.34	116.6	2.60	7.55
60	0.53	121.2	2.68	5.06
70	0.76	127.5	2.93	3.87
80	1.03	138.8	3.87	3.75
90	1.35	-	-	-
100	1.74	-	-	-
120	2.65	-		-

The results represented in figure 6, variation of exposure rate with voltage, indicate that the dose rate expected by the use of voltages from 50 to 80 kVp has been far exceeded by a mechanism that elevated V. This implies a large excess exposure to the patient. A form of equation (2) has been used by Robson (2001) to predict radiation output for x-rays used in mammography and showed that the exposure increases with the tube voltage. In addition, the x-ray exposure calculated at the similar voltage of 120 kVp by the method of Chaney and Batchelor (1981) for x-ray beams at 2.5 mm Al was 2.80 mGy/s. This value compares very well with the value of 2.65 mGy/s predicted by Equation (2) in this work at 2.7 mm Al. Therefore the values in table 2, also plotted in figure 6, accurately predicted the exposure rates from the x-ray tube showing the potential exposure to which a typical patient may be exposed, (ER_c), and what he actually takes, (ER_m). Column 5 shows that a typical patient would, potentially, receive up to about 10 times more exposure than necessary from this machine. It can also be seen that the exposure situation gets worse as the tube voltage gets lower when the discrepancy between the actual, i.e. measured, exposure and the expected exposure gets larger. The reason for the large discrepancies between the expected and measured tube voltages are difficult to explain immediately but it is suspected that the tube voltage was adjusted upwards during an earlier repair/maintenance operation after the x-ray system failed to produce high quality radiographs.

These results showed that the x-ray system ought to have been recalibrated or checked for exposure output following the repair/maintenance operation. The IAEA (1994) recommendation for after-maintenance monitoring of the x-ray system is thus further buttressed.

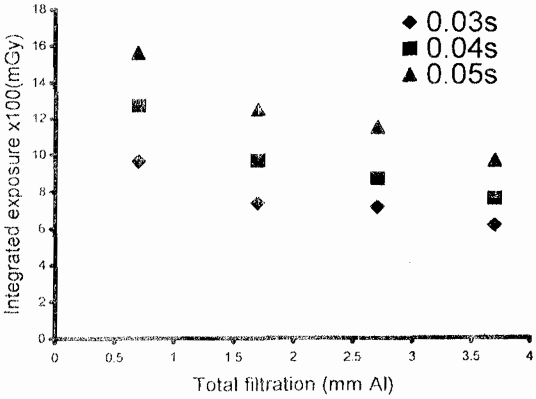

Fig. 5: Variation of integrated exposure with exposure time and total filtration at set V of 50 kVp, current of 300 mA, and fdd of 100cm.

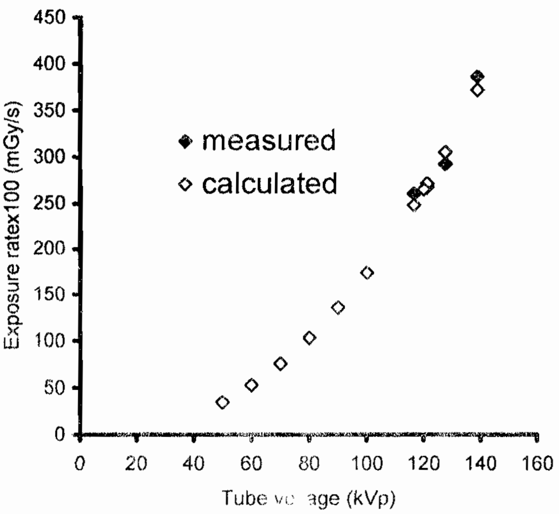

Fig. 6: Variation of the exposure rates with voltage at 2.7 mm Al total filtration

Besides, there were no obvious provisions in the facility for special radiation shields for patients undergoing radiography of body parts that may expose sensitive organs such as the gonads and, again, this is contrary to the IAEA (1994) recommendation.

It should be noted that although other calculational methods using empirical, semi empirical and Monte Carlo methods exist for modeling the exposure as a function of V (Ay et al 2004), they are either too cumbersome and require more information and facility than we can provide for their use or they are not easily procurable. The method above was considered simple and adequate for this exercise.

Conclusion

This study shows that a combination of machine and human errors could contribute to the extraneous exposure to the patient. Particularly, there is a need to periodically check the radiographic parameters and eliminate any faults that are likely to contribute to unnecessary exposures. Areas to watch include the correct working of the various control meters and actually measure, in regular Q/A programs, the tube voltage, exposure times and the exposure output from the machine making necessary corrections when required. The expression used in the calculation of the exposure rate is valid for a single-phase machine with tungsten anode at target angle in the range of 16° to 18° only. In order to be valid for three-phase machines and machines at target angles outside this range appropriate corrections have to be made which is outside the scope of this work. A dosimeter that is capable of simultaneously indicating the exposure time, machine phase, the voltage and exposure is best for these measurements. In order to minimize patient exposure from this machine, it is recommended that (i) an external filtration of at least 2 mm Al be added to this machine. (ii) radiation shielding should be provided for sensitive body parts such as the gonads, lens of the eye, breast and the thyroid when necessary. (iii) at all times, minimum exposure should be delivered to the abdomen and pelvis of women reproductive capacity in order to minimize exposure to any embryo or foetus that may be present. Besides, the IAEA guidelines should be consulted for exposure/dose reduction methods.

There are unascertained number of diagnostic x-ray machines that operate with the inherent filters in this country. The Nigerian Nuclear Regulatory Authority (NNRA) should take steps to rectify these anomalies by making it mandatory for diagnostic facilities to add external filters from 2 mm Al to 3 mm Al thickness to their machines and also carry out regular Q/A projects on their facilities to enhance patient exposure reduction.

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