Iran. J. Radiat. Res., 2005; 2 (4): 185-190

Estimation of the effective dose to the radiologists during fluoroscopy or angiography of abdominal viscera

M. Hajizadeh Saffar*, S. Nekoee, M.H. Bahrayni-Toosi, A. Sedghi

Department of Medical Physics, Mashhad University of Medical Sciences, Mashhad, Iran

ABSTRACT

Background: The radiation effective dose received by the radiologists during procedures such as fluoroscopy or different angiographies are usually evaluated using TL dosimeter. This method is a time-consuming procedure; therefore, radiologists are usually worried and unaware of their exact radiation dose received during each fluoroscopy or angiography. In this study, a new trend for quick estimation of effective dose based on measuring air-absorbed dose of the scattered radiations at body surface of the radiologists has been introduced.
Materials and Methods: Scattered radiations of abdominal viscera were simulated by a fluoroscopy unit (Shimatsu, model SF5010MD), and a water phantom (spherical plastic bag 27 cm in diameter filled with water up to 22.5 cm height). Radiation field was 20 × 20 cm on the bed and X-ray tube had 1.5 and 2 mm of Aluminum as an internal and external filtration respectively. A calibrated survey meter model RDS-110 was used to measure the scattered radiation horizontally and vertically around the phantom at different angles and distances, in front and behind of an apron.
Results: The scattered dose rate at 1 m from the phantom, during fluoroscopy at 83 kVp and 1.7 mA, was 451 μGy/h. This value reduced to 4.45 μGy/h by passing through lead ribbons of serigraph and to 1.2 μSv/h behind an apron. The scattered dose rate at different angles above the bed was constant and varied by distance from the center of the radiation field. The effective dose received by the radiologist is estimated to be about 174μGy/h, while wearing an apron and staying 50 cm away from the patient during fluoroscopy or angiography of abdominal viscera.
Conclusion: The radiologist can estimate his/her effective dose following a fluoroscopy or different angiographies of abdominal viscera, by determining scatter radiation dose at their body surface and applying factor 0.87 for shielding effect of the body. Equivalent organ dose can also be calculated from dose rate in air after applying factor 0.87 for deep organs or 1.1 (the mass energy absorption coefficient ratio of water/tissue to air) for organs near the surface. *Iran. J. Radiat. Res., 2005; 2 (4): 185-190*

Keywords: *Effective dose, radiologist, fluoroscopy, angiography, phantom.*

INTRODUCTION

Increasing diagnostic and therapeutic applications of X-ray in medicine will potentially enhance the radiation dose received by the radiologists; this is of more importance when they perform especial procedures. Although the tube collimator will prevent the exposure of radiologists from primary radiation beam, the scattered radiation from the patient's body will constitute a potential source of exposure of the staff around the patient.

***Corresponding author:**
Dr. M. Hajizadeh Saffar, Department of Medical Physics, Mashhad University of Medical Sciences, Daneshgah St., Mashhad, Iran.
Fax: +98 511 8517505
E-mail: hajizadeh@mums.ac.ir

The effective dose received by the radiologists during procedures such as fluoroscopy or different angiographies are usually evaluated using dose area product (DAP) or entrance surface dose

(ESD) measurements and applying conversion factors between measured quantities and effective dose (Cruces *et al.* 1998). For obtaining conversion factors, Marshall *et al.* 1995 have proposed the simulation of the procedure using an anthropomorphic phantom loaded with TL dosimeter located at radiosensitive organs and then calculating the effective dose simultaneously. These methods are time consuming procedures, therefore the radiologists are usually worried and unaware of their exact radiation absorbed dose. There are other methods for quick estimation of effective dose used for estimating effective dose from background radiation (Spiers 1981) or to estimate the effective dose of aircrews by simply measuring the ambient dose equivalent (Bartlett 2004). In these methods, a conversion coefficient is needed to relate the measured values to effective dose. Aircraft crews in flights, similar to radiologists, are exposed to high background radiation at high altitude. Bartlett (2004) suggested an approach for the assessments of effective dose of aircrew by calculating the effective dose per unite time (μSv/h) from the measurable operational quantity of the ambient dose equivalent rates. Spiers *et al.* in 1981 reported that the effective dose from background radiation can be estimated by measuring radiation dose at the skin surface and considering shielding effect of the body (i.e. the deeper the organ the lower the absorbed dose). Therefore, in a similar way using Bartlett or Spiers' method, by evaluation of the scattered radiation around the patient during a fluoroscopy procedure, one can estimate the radiation dose received to the radiologist and calculate the effective dose using duration he/she attends at any position around the patient.

Scattered radiation dose around the patient will depend on several factors, including the distance of the radiologists from patient and the exposure conditions that differ depending on the patient size, units and the techniques being used. In this study, it is aimed to estimate the effective dose of the radiologists, by measuring the scattered radiation dose around the patient and recording duration that radiologist attends at different distances from the patient during fluoroscopy or angiography.

MATERIALS AND METHODS

In this study, a Shimatsu fluoroscopy unit model SF5010MD was used to produce the scattered radiation around a water phantom. The unit has a 230 × 70 cm mobile bed at 86 cm from the ground level. Its tube was located 45 cm below the bed. The diaphragm dimension was such that its radiation field size was 20 × 20 cm on the bed. The X-ray tube had 1.5 and 2 mm of aluminum as an internal and external filters respectively. Above the bed, there is a serigraph for inserting the radiography film or the image intensifier tube. To minimize the scattered radiation reaching the physicians during fluoroscopy there are lead ribbons (45 cm wide and 0.55 mm thick Pb). As the Compton scattering is independent of the atomic number of the media (Greening 1985, 1992), the scattered radiation of the body organs such as head, abdomen, etc. can be simulated by a water phantom of the same size. To produce the scattered radiation in this study, a spherical plastic bag 27 cm in diameter filled with water up to 22.5 cm height and was used as an abdomen phantom. The phantom was placed at the center of the radiation field on the fluoroscopy bed and set the serigraph at 30 cm above its surface (similar to most of the abdominal angiography setting).

The X-ray unit sets the exposure conditions automatically according to the patient thickness and field size. Using this phantom, the exposure condition was automatically set at 83 kVp and 1.7 mA for fluoroscopy, which was similar to most of the abdominal angiography setting; therefore, the scattered radiation was assumed similar to those produced in the abdomen of an adult patient, especially in the transverse direction.

A survey meter model RDS-110 was used to measure the scattered radiation. The instrument was calibrated for X and gamma rays in the range of 50 kV to 1.25 MV by RADOS Technology OY. This meter can measure the radiation dose in the range of 0.001 to 1 mSv, and the dose rate from 0.05 µSv/h to 100 mSv/h. To measure the scattered radiation, the survey meter was fixed on a camera stand and moved around the fluoroscopy bed at different distances and heights from the center of the radiation field. The phantom was exposed for a short duration and the scattered radiation dose rates (µSv/h) were recorded at each position directly from the dosimeter display.

To evaluate the scattered radiation all around the phantom the measurements were made at two perpendicular directions as following:

1. Horizontally: at the bed height and different longitudinal angles around the phantom as shown in Figure 1a. These measurements can show the variation of the scattered radiation around the phantom in front of the lead ribbons of serigraph. Since the measurements for the spherical phantom and the cylindrical body of the patient are not similar for angles less than 42 degree, they were measured for angles of 42.5 to 90 degree at one meter away from the center of the phantom.

   To evaluate the effect of the distance on the scattered radiation the measurements were also performed at different distances from the center of the phantom at 42.5 degree.

2. Vertically: at 42.5 degree and different azimuth angle around the phantom as shown in Figure 1b. These measurements can show the variation of the scattered radiation around the phantom at different heights. The measurements were made at 1 m away from the phantom and the results are shown in table 3. In these measurements, the maximum and minimum angles are such that the scattered radiation field covers the whole body of the person standing at 1 m away from the phantom.

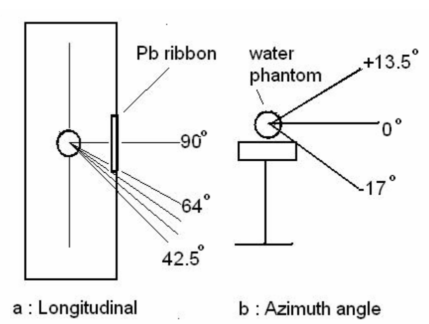

Figure 1. Directions of scattered radiation measured around the phantom.

RESULTS

Variation of the scattered radiation dose rates at bed height, around and away from the phantom in front of the lead ribbons of serigraph are shown in tables 1 and 2. The best-fitted curve through the measured dose

Table 1. Dose rates at different longitudinal angles around the phantom (At the bed height and 1 m away from the phantom center).

Longitudinal angles (degree)	Dose rate (µGy/h)
42.5	451
53.5	400
57.5	235
64	9.45
90	With 0.45 mm Pb apron 12 With 0.55 mm Pb S.ribon 4.45 + 0.45 mm Pb apron 1.2

Table 2. Dose rates at different distances from the phantom center (At the bed height and 42.5°).

Distance (cm)	Dose rate (µGy/h)
15	39500
20	19100
30	7290
40	3500
70	1040
100	451
150	187
200	98
250	47
300	37
350	25

rates in air (vs. distances from the scattering center) is presented in Figure 2. Vertically variation of scattered dose rate at 1 m away from the phantom is shown in table 3. These data at fixed distances from the phantom is nearly constant for all angles over the bed.

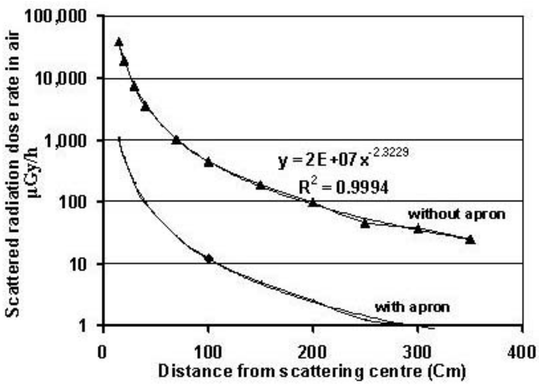

Figure 2. Variation of scattered radiation dose rate in air vs. distance from scattering center.

Table 3. Dose rates at different azimuth angle around the phantom (At 42.5° and 1 m away from the phantom center).

Azimuth angle (degree)	Dose rate (µGy/h)
+13.5	451
+6.7	451
0	451
-6.7	131
-13.5	25
-17	15.1

DISCUSSION

Table 1 shows that the scattered radiation dose rate of 451 µGy/h is decreased to 4.45 µGy/h by passing radiation through the 0.55 mm lead ribbons of serigraph. This will decrease to 12 µGy/h behind the 0.45 mm lead equivalent apron and to 1.2 µGy/h behind one mm lead protection (apron plus ribbons of serigraph). It means that the scattered radiation can be attenuated almost 100 folds by staying in the radiation safe region behind the lead ribbons of serigraph or wearing apron. This factor has been reported to be 70 - 270 (mean of 200) by Kicken and Bos (1995) for 0.5 mm lead apron, 70 folds by Giblin *et al.* (1996) or approximately 50 folds drop by Kuon *et al.* (2002) for 0.5 mm lead equivalent. These values verify the fact that the scattered radiation is a soft ray and using any protective means such as apron will dramatically decrease the absorbed dose.

Table 2 shows that the absorbed dose rate decreases by power -2.3 with distance (nearly following the inverse square law) as shown in figure 2. This result is in agreement with the comparative report of Hayashi *et al.* (1998) on exposure of the operator at different distances during the digital subtraction angiography. Absorbed dose in water or tissue (organ dose) can be calculated by measuring the absorbed dose of the air at skin surface and using the mass energy absorption coefficient ratio of water to air. This ratio is 1.04 -1.10 in the range of diagnostic radiology 50-100 keV (Greening 1992). Scattered radiation is a soft ray and absorbs superficially, therefore, the absorbed dose of deeper organs will decrease. This is called the “shielding effect” of the body and it causes the effective dose of an adult to be estimated 0.87 fold of the absorbed dose of the air at skin surface (Spiers *et al.* 1981). Spiers and coworkers (1981) introduced the factor 0.87 for shielding effect of the body from background radiations, but Bartlett (2004) used no shielding effect for determination of effective dose of aircraft crew from cosmic radiation exposure. However, using that for soft scattered radiation of the fluoroscopy may overestimate the effective dose, but will make sense for percussion in the radiation protection. Table 4 shows the scattered radiation dose rate in air and tissue or water in the presence and absence of the protecting material (apron) calculated from the measured data at 25, 50 and 100 cm from the center of the phantom. Based on these data and shielding effect of the body, the effective dose of an adult, while staying at these imaginary distances from the phantom centre was calculated and shown in table 4.

Table 4. Scattered radiation dose rate in air, water or tissue and effective dose of radiologist at different distance from the phantom center.

Distance cm	Dose Rate in air µGy/h		Dose Rate in water or tissue µGy/h		Effective Dose With shielding effect µSv/h	
	Without apron	With apron	Without apron	With apron	Without apron	With apron
25	11314	301	12445	331.1	9843	261.9
50	2261	60	2487	66.2	1967	52.2
100	452	12	497	13.2	393	10.4

As the entire body cannot be exactly placed at one of the above distances, one can practically assume the hands to be at 25 cm unshielded, head and neck at 50 cm also unshielded, and the rest of the body at 50 cm while wearing an apron. In this situation, the effective dose of the radiologist, using dose rate of all organs at their appropriate distances and weighting factors, will be 174 µSv/h. The effective dose will dramatically decrease, if he/she stays within the radiation safe region behind the lead ribbons of the serigraph.

The calculated value of 11000 µSv/h at 15 cm from the patient reported by Giblin *et al.* (1996) is in agreement with the value given in table 4 for a radiologist being unshielded and very close (>10 cm) to the phantom surface (or>23.5 cm from the phantom center).

Damilakis *et al.* (1995) measured the radiation exposure to the hands of the operator during several conventional angiographic procedures by using TL dosimeters, which were enclosed in plastic bands, and attaching it to each operator's index finger. He reported the mean dose of 9.02 and 5.03 mSv/h for the left and right hand respectively, during an abdominal angiography procedure. These figures almost agree with this study for unshielded fingers assumed to be mostly in positions at 3 cm (left finger) and 8 cm (right finger) from phantom's surface (or +13.5 cm from phantom center).

Cruces *et al.* (1998) reported effective dose rate of 0.8 mSv/min for abdominal angiography with 86 kVp and 5.4 mA, which is not in agreement with this study. They have compared their findings with Thwaites *et al.* (1996) who reported a value of 0.15 mSv/min and concluded that the difference could partly be due to different imaging equipments. The result of Thwaites (9 mSv/h) agree with data shown in table 4 if the radiologist assumed to be very close to the patient (25 cm) and not wearing apron.

Pecher *et al.* (1998) studied the doses received by the physicians in 1208 cases of arterial intervention procedure and reported the average value of 7 µSv. This finding also agrees with this study, if each procedure takes 16 minutes in duration and the radiologist assumed to be protected by apron and stays at 50 cm away from the patient. Nishizawa *et al.* (1994) reported the effective dose of a radiologist to be at 8-9 mSv/y while wearing lead apron and exceeding the annual dose limit for those not wearing it. This finding cannot be compared with the current study since there is not enough information about the standard working daily time of radiologist. Nevertheless, this study shows that, the annual dose limit (20 mSv) allows the specialists to spend 112 hours in a year by being at 50 cm away from a patient during fluoroscopy or angiographic procedures while wearing lead apron. This time duration will reduce if the exposure levels increase or the radiologist necessarily stays closer to the patient and his/her head and hands are exposed to primary radiation.

In conclusion radiologists can estimate their effective dose in fluoroscopy or different angiographies of abdominal viscera, from recording duration being in the scattered radiation field, distances from the radiation scattering center and situation of their protection: using data in table 4 or extrapolating for other distances. Equivalent organ dose $H_{i(d)}$ can also be calculated from dose rate in air (figure 2) after applying factor 0.87 (the shielding effect) for deep organs or 1.1 (the mass energy absorption coefficient ratio of water/tissue to air) for organs near the surface.

ACKNOWLEDGMENT

we would like to thank Dr. Shamsa the research vice-chancellor of Mashhad University of Medical Sciences (MUMS) for providing the financial support needed for this study and the staff of the radiology department at Emdad hospital for their kindly cooperation.

REFERENCES

Bartlett D.T. (2004). Radiation protection aspects of the cosmic radiation exposure of aircraft crew. *Radiation protection dosimetry,* ***109:*** *349-355*

Cruces R.R., Garcia-Granados J., Diaz Romero F. J., Armas J. H. (1998). Estimation of effective dose in some digital angiographic and interventional procedures. *The Br. J. Radiol.,* ***71:*** *42-47.*

Damilakis J., Koukourakis M., Hatjidakis A., Karabekios S., Gourtsoyiannis N. (1995). Radiation exposure to hands of operators during angiographic procedures. *Eur. J. Radil.,* ***21:*** *72-5.*

Giblin J.G., Rubenstein J., Taylor A., Pahira J. (1996). Radiation risk to the urologist during endourologic procedures, and new shield that reduces exposure. *Urology,* ***48:*** *624-7.*

Greening J.R. (1985). Fundamentals of radiation Dosimetry, 2nd edition, reprinted with minor correction 1992. *The Bath Press Avon, UK.*

Greening J.R. (1992). Fundamentals of radiation dosimetry, second edition, published by IOP publishing Ltd, Bristol, Reprinted by the Bath Press, Avon.

Hayashi N., Sakai T., Kitagawa M., Inagaki R., Yamamoto T., Fukushima T., Ishii Y (1998). Radiation exposure to interventional radiologists during manual injection digital subtraction angiography, Cardiovasc. *Intervent. Radiol**.,*** ***21:*** *240-3.*

ICRP (1990). Recommendation of the commission on radiological protection, 1991, ICRP publication 60, Ann, ICRP 21, (1-3), Edited by Smith H., Oxford, Pergamom Press.

Kicken P.J. and Bos A.J. (1995). Effectiveness of lead apron in vascular radiology: Results of clinical measurements. *Radiology,* ***197:*** *473-8.*

Kuon E., Schmitt M., Dahm J.B. (2002). Significant reduction of radiation exposure to operator and staff during cardiac interventions by analysis of radiation leakage and improved lead shielding. *American J. of Cardiology,* ***89:*** *44-49.*

Marshall N.W., Noble J., Faulkner K. (1995). Patient and staff dosimetry in neuroradiology. *Br. J. Radiol.,* ***68:*** *495-501.*

Nishizawa K., Maruyama T., Takayama M., Dono S., Furuya Y.(1994). Effective dose evaluation of angiography staff. *Nippon Igaku Hoshasen Gakkai.* ***54:*** *661-9.*

Pecher G., Koenig H., Pecher S., Gosch D., Voigt P., Schulz H.G. (1998). Reduction of radiation exposure for patient and investigators in interventional radiography. *Rofo. Fortscher. Geb. Rontgenstr Neuen Bildgeb. Verfahr.,* ***169:*** *505-9.*

Spiers F.W., Gibson J.A.B., Thompson I.M.G. (1981). A guide to the measurement of environmental gamma ray dose rate, BCRU.

Thwaites J.H., Rafferty M.W., Gray N., Black J., Stock B. (1996). A patient dose survey for femoral arteriogram diagnostic radiographic examination using a dose-area product meter. *Phys. Med. Biol.,* ***41:*** *899-907.*