

Personnel Exposure to Radiation at Some Angiographic Procedures¹

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Personnel exposure to radiation was investigated during radiological procedures where x-ray shielding is particularly difficult. Ten percutaneous transhepatic cholangiographies, four percutaneous transhepatic portographies, and four coronary angiographies are included in the study. Exposure to radiation was measured at several anatomical sites for both the radiologist and the assisting nurse. Effective dose equivalents as proposed by the International Commission on Radiological Protection (ICRP) were estimated from the registered absorbed doses.

INDEX TERMS: Diagnostic radiology, radiation dose • Radiations, exposure to personnel

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ANGIOGRAPHIC procedures, including extended periods of fluoroscopy, are among those radiographic procedures resulting in the highest radiation exposure to the personnel performing the examination. Several investigations of dose measurements have been published (1, 7-9, 12-17). Due to the different equipment and techniques used, and depending on what protective measures were taken, the results of these investigations vary considerably.

The main purpose of this study was to estimate the exposure of personnel to radiation from procedures where x-ray shielding is particularly difficult. In our department this happens at percutaneous transhepatic portography (PTP) and percutaneous transhepatic cholangiography (PTC), where no lead rubber drapes can be attached to the x-ray image intensifier in the direction of the radiologist where the radiologist's hands are very close to the x-ray field. When we started this study, no reports on radiation dose measurements to personnel in these x-ray procedures had appeared in the literature.

We also include some measurements on cardiac and coronary angiography where the injection is done by hand, increasing the radiation exposure of the radiologist even though the main part of the body is protected by a lead screen.

MATERIAL AND METHODS

The investigation was carried out during the period January-June 1977 and comprised 10 PTC and 4 PTP examinations, with a total fluoroscopy time of 406 minutes. Our coronary angiographies with a total fluoroscopy time of 72 minutes and a sum of 34 manually injected series were also included. All personnel were outside the room during single and serial radiography except in the few cases when injection was performed manually.

Diagnostic Equipment and Technique

Televised fluoroscopy was performed with undercouch tubes (total filtration 2.5 mm Al) and 25/15-cm image intensifiers. In most cases automatic brightness stabilization with an exposure rate on the input screen of $2.6 \text{ nC kg}^{-1} \text{ s}^{-1}$ ($10 \mu\text{Rs}^{-1}$) to $5.2 \text{ nC kg}^{-1} \text{ s}^{-1}$ ($20 \mu\text{Rs}^{-1}$) was used. Fluoroscopy in the lateral plane was rarely applied. The tube voltage at fluoroscopy varied in most cases between 70 kVp and 90 kVp and the tube current rarely exceeded 1.5 mA.

Filming was done with pulsed 35-mm cineradiography at a frame rate of 75 or 30 frames per second with automatic exposure control (exposure 3.9 nC kg^{-1} [$15 \mu\text{R}$] per frame on the input screen of the image intensifier). The tube voltage varied between 65 kVp and 95 kVp.

Full-scale serial radiography was performed with overhead tubes (total filtration 3.5 mm Al) and Elema-Schonander cut film changer. The exposure to the screen-film system was approximately $0.10 \mu\text{C kg}^{-1}$ (0.4 mR); automatic exposure control was not used. The tube voltage varied between 65 kVp and 100 kVp at coronary angiography and between 65 kVp and 90 kVp at PTP and PTC.

When PTP and PTC were performed, the patient was supine on the table with the intensifier about 10 cm from the abdominal wall. The lead rubber drape on the right side of the patient had to be removed to get access to the puncture site in the right midaxillary line of the patient. During the transhepatic puncture the fluoroscopy collimation had to be large enough to cover a field from the right abdominal wall to the spine. Later during the procedure the field was markedly reduced, covering only about a 100-cm² region of interest. At the end of the procedure three exposures were made in anteroposterior (AP), right posterior oblique (RPO), and left posterior oblique (LPO)

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TABLE I: REGISTERED ABSORBED DOSES

Procedure	Fluoroscopy Time (min.)	Number of Injections by Hand	Absorbed Dose (mGy)*							
			Anatomical Site							
			Chest		Forehead		Neck		Middle Finger	
		Radiologist	Nurse	Radiologist	Nurse	Radiologist	Nurse	Left (Radiologist)	Right (Radiologist)	
PTP	7.8-84	0-5	<0.01-0.03	≤0.01	<0.01-0.41	<0.01-0.06	<0.01-0.21	<0.01-0.06	0.34-8.70	0.11-3.06
PTC	8-17.5	0-3	<0.01	≤0.01	0.01-0.12	<0.01-0.03	0.05-0.09	0.01-0.04	0.78-6.15	0.26-0.98
Cardiac angiography	13-23.5	7-11	≤0.01	<0.01	0.13-0.49	0.01-0.05	0.14-0.36	<0.01-0.03	0.07-0.83	0.05-0.11

* 1 mGy = 100 mrad

positions, respectively, with the overhead tube. During those exposures no personnel stayed in the room.

Coronary angiography was performed via the right femoral artery and included left ventricle biplane cinefluorography and three-view cinefluorography of each coronary artery (RPO, lateral, and LPO) with horizontal beam. One series of full-size radiographs with horizontal beam was obtained of each coronary artery, with four exposures per second for three seconds.

Method of Absorbed Dose Measurement

At each angiographic procedure we measured the absorbed dose to the forehead, neck, and chest (under the 0.25-mm lead equivalent apron) of the radiologist and the assisting nurse, and also to the left and right middle fingers of the radiologist.

The absorbed dose was measured with extruded lithium fluoride thermoluminescent dosimeters (3.2 mm × 3.2 mm × 0.9 mm, manufactured by Harshaw Chemical Co.), read out on a Teledyne Isotopes TLD 7300 reader. The dosimeters were used in groups of 20. Each dosimeter was calibrated separately in a fixed geometry with a ¹³⁷Cs source. Correction for energy dependence was made by calibrating in air at 60 kVp tube voltage with a total filtration of 4 mm Al (approximate half-value layer 2.8 mm Al). Calibration of the ionization chamber is in turn traceable to the National Swedish Radiation Standards Laboratory. To calculate the absorbed dose in soft tissue, a conversion factor of 35.7 Gy per C kg⁻¹ (0.92 rad R⁻¹) was used (6).

The minimum detectable dose, taken as three times the standard deviation of the background, was 0.01 mGy (1 mrad). The precision is described by the coefficient of

variation (relative standard deviation), which was 6.2 percent at 0.11 mGy (11 mrad). Thus, the exposure at the location of the dosimeter can be measured with an overall uncertainty of less than 10 percent. Larger uncertainties, however, arise when estimating the absorbed dose to organs due to the position of the dosimeter relative to the organ studied.

During measurements the dosimeters were enclosed in pairs in plastic bags applied to the skin or the coat. In every patient measurement, two dosimeters were irradiated in the ¹³⁷Cs calibration geometry to control and correct for the variation in sensitivity of the group, and two dosimeters were used for background subtraction.

RESULTS

The ranges of the absorbed doses during the examination at the different measuring points are given in TABLE I. The considerable spread is partly due to the variation in fluoroscopy time but also, especially for the dose to the hands, to variation in examination technique.

The mean fluoroscopy times for the examination studied are given in TABLE II. The estimated average absorbed doses for PTP and PTC procedures given in TABLE II were obtained by dividing the sum of all registered absorbed doses by the total fluoroscopy time, and then multiplying by the mean fluoroscopy time. This corrects for the fact that four of the measurements did not include the total examination.

The doses to the forehead and neck from cardioangiography are related also to the number of manual injections, so the mean values of the doses registered per examination are given. The chest dose to the nurse (at the same procedure) was not measurable (<0.01 mGy {1 mrad}).

TABLE II: ESTIMATED AVERAGE ABSORBED DOSE PER EXAMINATION

Procedure	Mean Fluoroscopy Time (min.)	Absorbed Dose (mGy)*							
		Anatomical Site							
		Chest		Forehead		Neck		Left Hand	Right Hand
		Radiologist	Nurse	Radiologist	Nurse	Radiologist	Nurse	Radiologist	Radiologist
PTP	35	0.01	0.03	0.12	0.03	0.11	0.03	4.0	1.5
PTC	13	<0.01	0.01	0.05	0.01	0.04	0.01	1.5	0.55
Cardiac angiography	18	0.01	0.01	0.21	0.01	0.24	0.01	0.28	0.06

* 1 mGy = 100 mrad

DISCUSSION

Estimated Annual Dose Equivalents

For radiation protection purposes the dose equivalent should be calculated, and for diagnostic x-rays the absorbed dose in gray (1 Gy = 100 rad) gives the dose equivalent in sievert (1 Sv = 100 rem); the quality factor is equal to one. To compare with the annual limits for occupational exposure given by the International Commission on Radiological Protection (ICRP) (3, 5) and the National Council on Radiation Protection (NCRP) (11), we estimated the average and maximum annual dose equivalents to the personnel.

Assisting nurse: The person assisting at most angiographies in our department could serve at 700 angiographic procedures per year (about 25 PTC, 25 PTP, 430 cardioangiographies, and about 220 abdominal angiographies) comprising a total fluoroscopy time of 14,220 minutes (for abdominal angiography we have used a mean of 24 minutes per examination). The radiation protection conditions for the nurse do not vary much for the different procedures; the absorbed dose to the forehead and neck was an average 0.7 μ Gy (0.07 mrad) per minute of fluoroscopy. This means that the head and neck region may receive an average dose equivalent of 10 mSv (1.0 rem) per year. Based on the registered maximum absorbed doses per examination (TABLE I), a yearly dose equivalent of about 35 mSv (3.5 rem) is obtained.

For the part of the body that is protected by the lead apron, the dose equivalent, as registered by film dosimetry, is about 1 mSv (100 mrem) per year.

Radiologist: Calculations have been performed for two situations, supposed to be representative for those radiologists getting the highest doses from the studied angiographic procedures. The dose equivalents are thus estimated from the average (TABLE II) and maximum (TABLE III) absorbed doses per procedure for one radiologist performing 25 PTP and 25 PTC examinations per year, and for the radiologist performing 120 coronary angiographies yearly. The second person may also perform 240 lung biopsies giving about 0.26 mGy (26 mrad) (maximum 1.3 mGy [130 mrad]) to the left hand and 0.13 mGy (13 mrad) (maximum 0.47 mGy [47 mrad]) to the right hand, according to earlier dose measurements.

The estimated average and maximum annual dose equivalents are given in TABLE III.

Comparison with Recommended Dose Equivalent Limits

According to recommendations of the ICRP (3, 5) the following annual dose equivalent limits should be applied to occupationally exposed persons:

Whole body	50 mSv	(5 rem)
Lens	150 mSv	(15 rem)
Other tissues	500 mSv	(50 rem)

In case of nonuniform radiation exposure of the body an

effective dose equivalent could be calculated by application of weighting factors for different tissues representing the stochastic risk for that tissue (3, 4). The weighting factors, as recommended by ICRP, are:

Gonads	0.25
Breast	0.15
Red bone marrow	0.12
Lung	0.12
Thyroid	0.03
Bone surfaces	0.03
Remainder	0.30
(five organs, 0.06 each)	

In the course of the assessment of the effective dose equivalent one could also estimate from which part of the body the greatest contribution comes.

It should be noted that the NCRP (11) recommends a maximum permissible dose equivalent of 50 mSv (5 rem) in a year for whole body, gonads, the lens of the eye, and the red bone marrow. The hands may receive 750 mSv (75 rem) and the forearms 300 mSv (30 rem), while the dose to all other organs and tissues should be less than 150 mSv (15 rem) in any one year.

In the calculation of effective dose equivalents we used the estimated doses with no regard to attenuation in the body. Thus, the dose measured on the chest was applied for gonads, breasts, 87% of the red bone marrow, lungs, 50% of bone surfaces, and three other unspecified tissues. The dose to the neck was applied to the thyroid and the dose to the forehead to 13% of the red bone marrow, 50% of bone surfaces, and to two unspecified organs. This is a rough method that certainly does not underestimate the effective dose equivalents. Wohlni and Strandén (18) calculated effective dose equivalents from organ dose measurements in a phantom. However, the data given in their paper were not detailed enough to be applicable to our study.

According to the ICRP (4), the dose equivalents to the lens of the eye and to the hands should not be included when calculating the effective dose equivalent.

From the average and maximum annual dose equivalents given in TABLE III and the weighting factors given above, the effective dose equivalents in TABLE IV were estimated. The greatest contribution (about 60%) comes in all cases from the radiation exposure of the unshielded head and neck region. The registered dose on the film dosimeter (worn under the lead apron) thus gives an incomplete knowledge of the risk to the personnel due to the radiation.

From TABLES III and IV one could also conclude what part of the body receives the dose equivalent nearest to the dose limit for occupational exposure. For the assisting nurse both the dose to the lens and the effective dose equivalent are less than 10% of the annual limit according to the ICRP (3, 5).

For the radiologists performing PTC and PTP or lung biopsies the dose to the hands is nearest to the annual limit of 500 mSv (50 rem), but even the estimated maximum

TABLE III: ESTIMATED ANNUAL DOSE EQUIVALENTS FOR RADIOLOGISTS

Procedure	Dose Equivalent (mSv)*									
	Anatomical Site									
	Chest		Forehead		Neck		Left Hand		Right Hand	
	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.
PTP + PTC (25 of each)	0.5	1.0	4.3	13	3.8	7.5	140	370	51	100
Cardiac angiography (120)	1.2	1.2	25	59	29	43	34	100	7.2	13
Cardiac angiography + lung biopsies** (120 + 240)		—		—		—	96	410	38	130

* 1 mSv = 100 mrem

** Data for lung biopsy obtained earlier (see text)

doses do not exceed the annual limit. The radiologists performing 50 PTP and PTC examinations may also perform 150 other abdominal angiographies, which, due to better radiation shielding, certainly give a smaller absorbed dose per fluoroscopy time unit than registered in this study. This means that the effective dose equivalent and the dose to the lens of the eye is about 10% or less of the annual dose limit set by the ICRP (3, 5).

In comparison, with the NCRP recommendations (11) the dose to the lens in cardioangiographic procedures may reach 50% of the maximum permissible dose equivalent; the calculated maximum dose exceeds the limit.

The observations show the need for shielding—especially the hands and the head and neck regions. Protective glasses for the lens could be useful if they do not give a false feeling of security leading to increased radiation exposure of the rest of the head and neck regions. It should also be noted that most protective glasses have a limited effect in clinical practice, due to backscatter from the head and lack of lateral eye shielding (10).

Comparison with Earlier Reports

As already mentioned, it is difficult to compare results from different personnel radiation exposure studies, due to the different techniques and shielding used. Recently, Cruikshank *et al.* (2) reported on finger dose measurements at PTC. They registered about three times higher doses than we did at comparable fluoroscopy time. Correspondingly they must limit the number of procedures performed by each radiologist.

Our results for the chest and the head and neck regions during PTP and PTC are comparable with those reported

TABLE IV: ESTIMATED ANNUAL EFFECTIVE DOSE EQUIVALENTS*

Personnel	Average (mSv**)	Maximum (mSv**)
Assisting nurse	2.6	—
Radiologists		
25 PTP + 25 PTC	1.2	3.0
120 cardiac angiographies	5.6	11

* Based on weighting factors according to ICRP (3, 4) applied to measured absorbed doses.

** 1 mSv = 100 mrem

by Santen *et al.* (14) at abdominal angiography. Reports of considerably higher eye lens doses (8, 12) can be explained by a high exposure rate at the image intensifier input screen (8) and manual injection of contrast material during radiography (12). In the present investigation, radiography was as an exception performed with the personnel in the room.

As regards cardiac and coronary angiography, our results are comparable with others reported (1, 8, 13, 15, 17). It is, however, obvious that inadequate shielding of the scattered radiation from the patient may result in excessive personnel doses (9, 16). The measurements performed in our department in 1974 by Kaude and Svahn (7) were done at fluoroscopy with an overtable tube, now replaced by an undertable tube. The dose to the hands of the radiologist was about the same as we recorded at cardiac and coronary angiography. No measurable doses were recorded to the head (lead rubber drapes were applied to the tube).

CONCLUSION

From absorbed dose measurements we calculated the annual dose equivalent to the chest, forehead, neck, and hands of personnel performing angiographic procedures. By applying weighting factors according to the ICRP (3), the effective dose equivalents were estimated. It appears that with our equipment and technique the dose equivalent to the hands of the radiologist is nearest to the annual limit for occupational exposure. Radiation exposure of the head and neck regions give the highest contribution to the effective dose equivalent.

With inadequate shielding of the scattered radiation from the patient, and when manual injection of contrast material is used, the dose to the head and neck regions may be even more significant. It should, however, be noted that shielding of the eye lenses may not significantly reduce the effective dose equivalent and correlated late radiation effects.

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