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Radiation Doses to Patients in Neurointerventional Procedures

Pierre Bergeron, Raymond Carrier, Daniel Roy, Noël Blais, and Jean Raymond

PURPOSE: To evaluate stochastic and deterministic risks associated with neurointerventional procedures for the patient. **METHODS:** Eight neurovascular interventional procedures were evaluated to determine the entrance skin dose and effective dose for the patient. Dosimetry was done with thermoluminescence dosimeters. The highest dose on the patient's head was recorded as the maximum entrance skin dose. The equivalent dose was obtained by conversion of the dose-area product using published conversion tables. **RESULTS:** The maximum entrance skin dose varied from 129 to 1335 mGy. The mean effective dose was 1.67 mSv with a range of 0.44 to 3.44 mSv. No deterministic effect has been encountered. Stochastic risk linked to the highest effective dose value was approximately one death by fatal cancer for every 6000 procedures, according to the new International Commission on Radiological Protection coefficient. **CONCLUSIONS:** Because no deterministic effect has been detected, and stochastic risks were very low, radiation hazard to the patient is a minor consideration in deciding whether to undertake a neurointerventional procedure.

Index terms: Radiation, dose; Radiation, exposure in diagnostic procedures; Interventional neuroradiology, complications of; Iatrogenic disease or disorder

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Interventional radiologic techniques have been increasingly used to treat various neurovascular anomalies, either alone or with surgery (1). Because these procedures are long and complex, they raise questions about radiation safety for the patient and the personnel involved. For instance, cases of patients' hair loss have been reported (Norbash AM et al, "Evaluation and Reduction of Patient Skin Dose in Interventional Neuroradiology Procedures," presented at the American Society of Interventional and Therapeutic Neuroradiology/World Federation of Interventional and Therapeutic Neuroradiology Congress, Vancouver, Canada, May 14–16, 1993).

Radiation effects can be deterministic or stochastic (2). In the former, the severity of the effects is a function of the dose, and a threshold is generally present. Radiation dermatitis and epilation are two examples of deterministic effects. In stochastic effects, only the probability of occurrence of the effect (not the severity) is a function of the dose. It is assumed that there is no threshold of radiation dose with reference to stochastic effects. Cancer induction and genetic hazards are two examples of stochastic effects.

The effective dose equivalent concept was introduced by the International Commission on Radiological Protection in 1977 as an improved indicator of the relative risk associated with low-dose irradiation (3). Specific application of the effective dose equivalent concept to diagnostic radiology has been described (4, 5). However, the evaluation of effective dose equivalents is problematic (6). Recently, the continuous evaluation of additional data regarding radiation effects in exposed populations (7) has resulted in a refined method with more accurately determined weighting factors. Applying these modifications, the International Commission on Radiological Protection replaced the effective dose equivalent with the effective dose (8). The entrance skin dose is no longer used as a risk indicator, except for some de-

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TABLE 1: Patients' diagnoses and angiographic parameters

Case	Age, y	Sex	Diagnosis	Treatment	Fluoroscopic Time, min	Runs	Frames
1	48	M	Aneurysm	GDC	37	29	451
2	38	M	AVM	Embolization	37	19	346
3	55	M	Meningioma	Embolization	45	14	399
4	50	F	Aneurysm	GDC	31	24	286
5	58	F	Aneurysm	GDC	74	23	321
6	52	M	Meningioma	Embolization	35	28	345
7	51	F	AVM	Embolization	52	24	532
8	58	F	Aneurysm	GDC	35	16	205

Note.—AVM indicates arteriovenous malformation; GDC, Guglielmi detachable coils.
* The arteriovenous malformation was in the cervicospinal location.

terministic effect involving the skin and superficial organs.

The purpose of this study is to determine the stochastic and deterministic risks for patients undergoing neurointerventionnal radiologic procedures.

Methods

Dosimetry was performed for eight procedures between January and April 1993 (Table 1). Four aneurysms, two arteriovenous malformations, and two meningiomas were treated. All procedures were performed conjointly by the same two neuroradiologists (D.R. and J.R.).

Angiogram Technique

The right femoral artery approach was used in every case, with the radiologists and personnel standing on the patient's right side. Angiograms were performed on a Picker (Cleveland, Oh) DAS-211 single-plane system with an undercouch tube. Total filtration was constant and equivalent to 4.5 mm Al. The half-value layer has been measured at 4.1 mm and 80 kV on a triphased potential generator. All lateral views were obtained with the tube on patient's left side. All acquisitions were made on a digital substraction angiography unit with a variable filming rate (1 to 3 per second) and a 512 × 512 matrix. The 15-cm (of a 15, 22, 30-cm) image intensifier was exclusively used with a circular collimation of the same size or slightly smaller. Magnification was kept minimal, with the image intensifier as close as possible and the x-ray tube as far as possible from the patient's head. Fluoroscopic times, number of runs, and frames were recorded (Table 1).

Dosimetry Technique

Thermoluminescence Dosimeter Selection. The first step was to ascertain the quality and stability of the thermoluminescence dosimeter. Fifteen of 75 lithium fluoride, rod-type (6 × 1 × 1-mm) thermoluminescence dosimeters (model 100; Harshaw Chemical, Solon, Ohio) were selected using the following criteria: 2 SD/mean < 10%. To obtain the standard deviation and mean, thermoluminescence dosimeters were exposed five times to the same spectrum of radiation that was used during the procedures. A Keithley electrometer (model 35050 A; Keithley, Cleveland, Ohio) connected to a PRM 15-mL ionizing chamber (PRM, Nashville, Tenn) monitored the exposures in addition to the thermoluminescence dosimeters. A calibration factor was established for each thermoluminescence dosimeter chip. Two additional control irradiations were performed between the interventional procedures to confirm thermoluminescence dosimeter quality.

Procedures. Ten thermoluminescence dosimeter chips were disposed on a plastic band around the patient's head during the procedures. Thermoluminescence dosimeters were placed at equal distance one from the other, forming an axial line around the head.

Three thermoluminescence dosimeters were exposed separately immediately after each procedure, using the same method described in the "Thermoluminescence Dosimeter Selection" section above. Two thermoluminescence dosimeters remained unexposed but were also read on the Harshaw Thermoluminescence Dosimeter System 4000 to determine background levels. Measured exposures (R) were converted to absorbed dose (in centigrays) using the following *f* factor: 0.88 cGy R^{-1} (9).

The highest dose on the patient's head was recorded as the maximum entrance skin dose. The dose-area product (DAP) (9) was obtained by the equation:

$$DAP = d \times h \times f \times \sum_{n=1}^{10} e_n,$$

where *e* is the entrance exposure read on the thermoluminescence dosimeter (R); *n* is the thermoluminescence dosimeter number (1 to 10); *d* is the distance between two adjacent thermoluminescence dosimeters (in centimeters); *h* is the diameter covered by the x-ray beam at the patient plane; and *f* is the conversion factor between exposure and dose. The diameter (h) was considered constant (10 cm), because little collimation was used with the small field of view of the image intensifier.

TABLE 2: Dosimetry results

Patient	Maximum ESD, mGy	DAP, mGy/cm^2	H_E[3], mSv	E, mSv
1	281	95 726	5.06	1.41
2	317	39 974	1.95	0.59
3	946	175 288	9.26	2.54
4	129	29 343	1.51	0.44
5	469	91 264	4.80	1.31
6	1259	213 187	11.54	2.97
7	1335	243 229	13.14	3.44
8	187	43 442	2.23	0.64
Mean	615	116 432	6.19	1.67

Note.—ESD indicates entrance skin dose (entrance skin exposure × conversion factor [mGy R^{-1}]); DAP, dose-area product; H_E, effective equivalent dose; and E, effective dose.

X-ray transmission through the head was calculated to be less than 2% and was considered negligible with regard to the total exposure. Each thermoluminescence dosimeter value was considered as a separate field of irradiation. The effective dose equivalent could then be derived from a published conversion factor (10). A corrective factor was then applied to obtain the effective dose value (11).

Results

The results of the maximum entrance skin dose, dose-area product, and effective dose values for patients are presented in Table 2. The maximum entrance skin dose varied between 129 and 1335 mGy and the effective dose from 0.44 to 3.44 mSv.

Discussion

The maximum entrance skin dose noted (1335 mGy in case 7) is well below the dose known to cause temporary epilation (3 Gy) or local erythema (6 Gy) (12). We have not observed these complications. However, if procedures get more lengthy and complicated, such effects can occur. Different methods of dose reduction in interventional procedures have been discussed by others: region of interest fluoroscopy (13), alternation of skin entry between opposing sides, and proper additional filtration (Norbash et al, cited above).

The highest effective dose value of 3.44 mSv is comparable to 1 year of natural background in North America. Stochastic risks with this dose are low. Using the 5×10^{-5} mSv^{-1} fatal cancer coefficient reported by the International Commission on Radiological Protection in 1991 (2), 3.44 mSv would result in one fatal cancer for every 5814 procedures. This is surely far less than the risk associated with diseases for which patients undergo neurointerventional procedures.

Interestingly, this is almost the same risk that could be calculated with the older coefficient (International Commission on Radiological Protection, 1977) of 1.25×10^{-5} mSv^{-1} and the highest effective dose equivalent of 13.14 mSv (one fatal cancer for every 6090 procedures). This simply illustrates the fact that, for cerebral procedures, the fourfold increased in risk has been counterbalanced by a near-proportional reduction of the effective dose.

It should be noted, however, that neither effective dose equivalent nor effective dose included the risks related to irradiation of other parts of the body during fluoroscopy. Thus, the risk is slightly underestimated. Less than 5% of the fluoroscopic time is spent out of the head area.

We found few articles in the literature with which to compare our results. In the past, most interest has been directed to the doses absorbed by the eye's lens (14). With the use of an undercouch tube, this has become less of a problem.

Among studies reporting the doses related to specific diagnostic procedures, Chopp et al (15) have reported entrance dose of 159 ± 45 mSv to the patient's head. Plunkett et al (16) reported a median exposure area product of 3198 R × cm^2 in their diagnostic neuroangiography group. In comparison, we obtained a mean value of 11 643 cGy × cm^2.

Feygelman et al (17) reported an average effective dose equivalent of 10.6 mSv, greater than that for our therapeutic procedures (mean, 6.19 mSv). Both studies used a dose-area product method for calculation of the dose. The same conversion factors to the effective dose equivalent were also used. However, Feygelman et al (17) measured the entrance skin dose with a radiation probe and an acrylic phantom, taking into account focus-to-skin distance and collimator setting. The 22-cm (of a 15, 22-cm) image intensifier was used for an unmentioned duration. In comparison, we measured the entrance skin dose with thermoluminescence dosimeters directly on patients' heads, and the 15-cm image intensifier was exclusively used. These two factors, plus the difference in the x-ray equipment, could explain the variation in the results.

Two studies evaluated the doses during therapeutic procedures. Berthelson and Cederblad (18) reported a group of five patients who underwent embolization of cerebral arteriovenous malformations. Their estimated effective dose equivalent varied beetween 6 and 43 mSv, compared with 2 and 13 mSv in our study. Norbash et al (cited above) reported a maximum skin dose of 270 cGy in 12 patients during interventional procedures. This is twice as high as our highest value of 134 cGy.

Many factors can explain these differences in results. Different procedures were evaluated, using different x-ray equipment, generating different doses on different field sizes. Moreover, different dosimetry techniques (thermoluminescence dosimeter versus ionizing chamber) and calculation methods of the dose (energy-imparted versus dose-surface product) were used.

Conclusion

Our study was conducted on a small but representative group. It is a valuable estimation of the radiation risks associated with interventional neuroradiologic procedures in the head at our institution. Because no deterministic effect was encountered, and the stochastic risks were low, we believe that the radiation hazards of these therapeutic techniques are of minor significance and contribute minimally to the overall risk of the procedures.

However, we should still keep in mind that, according to the "as low as reasonably achievable" principle, every link of the angiographic system and every radiographic protection means should be scrutinized to minimize the exposure to both patients and personnel.

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