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V M Feygelman, W Huda and K R Peters

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Effective Dose Equivalents to Patients Undergoing Cerebral Angiography

Vladimir M. Feygelman,[1,2] Walter Huda,[1] and Keith R. Peters[1]

Purpose: To determine values of the effective dose equivalent, H_E, for patients undergoing diagnostic cerebral angiography and compare these values with radiation doses received by patients undergoing other diagnostic examinations of the head. **Methods:** The radiographic techniques for ten patients undergoing cerebral angiography were recorded and used to obtain the product of the entrance skin dose and the x-ray beam cross-sectional area. These measured dose-area product data were converted into effective dose equivalents employing published conversion factors which take into account the part of the patient anatomy irradiated and the radiographic technique factors employed. **Results:** The average patient H_E value was 10.6 mSv, with a range of 2.7–23.4 mSv. Fluoroscopy contributed approximately 67% of the total H_E, with cut films and digital subtraction angiography contributing 26% and 7%, respectively. **Conclusions:** The radiation doses (H_E) to patients undergoing diagnostic cerebral angiography are comparable to the patient doses in nuclear medicine brain studies where the typical H_E is approximately 10 mSv. In CT, the patient dose is approximately 2 mSv, whereas in plain skull x-ray examinations, the patient dose is much lower at approximately 0.15 mSv.

Index terms: Cerebral angiography; Radiation, exposure in diagnostic procedures

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Patients undergoing cerebral angiography are exposed to ionizing radiation from three distinct components of the typical diagnostic x-ray procedure: fluoroscopy, cut film radiography, and digital subtraction angiography (DSA). The traditional parameter for describing patient "radiation doses" in most radiologic examinations, including neuroradiology, has been the entrance skin exposure (ESE) (1, 2). Although the ESE has an advantage in being easily measured or calculated, it suffers from three serious drawbacks when applied to quantifying patient radiation doses in cerebral angiography. The ESE does not provide a direct estimate of the patient radiation risk; the ESE components (ie, fluoroscopy, cut film, and DSA), which make up a typical cerebral angiogram, are not additive; and the resultant ESE values cannot be compared (directly) with radiation doses that patients may receive in other diagnostic radiologic examinations, such as planar skull x-rays, computed tomography (CT) head examinations, or nuclear medicine brain flow studies.

All three limitations associated with specifying the ESE as the patient radiation doses parameter may be overcome by employing the effective dose equivalent, H_E (3). The International Commission on Radiological Protection (ICRP) originally introduced the H_E in 1977, to account for nonuniform irradiation in radiation protection practice (4). Since this time, however, the H_E has also been used by national and international bodies in all areas of diagnostic radiology and is presently deemed to be the best available parameter for specifying patient radiation doses (5–7).

In this paper, values of the H_E to 10 randomly selected patients undergoing cerebral angiography were determined, including the separate contributions of fluoroscopy, cut film, and DSA. The resultant doses are compared with H_E values associated with other neurologic diagnostic procedures that use ionizing radiations, including

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[1] Department of Radiology, 100374, JHMHC, University of Florida College of Medicine, Gainesville, FL 32610-0374. Address reprint requests to Walter Huda, PhD.

[2] Current address: Department of Medical Physics, Manitoba Cancer Foundation, 100 Olivia Street, Winnipeg, Manitoba, Canada R3E OV9.

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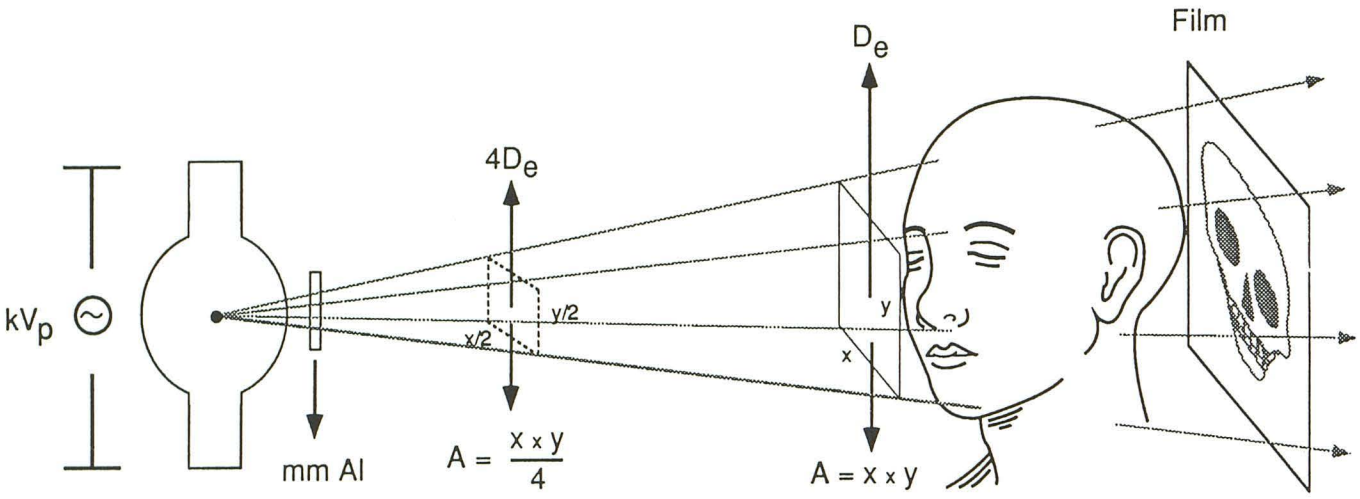

Fig. 1. Schematic arrangement of an x-ray examination of a head, with the entrance skin dose given by D_e. Note that if the focus-to-skin distance is halved, the dose-area product (ie, $D_e \cdot A \equiv D_e \cdot x \cdot y$) retains the same value, since the increased skin dose (×4) is offset by a reduced x-ray beam area (×¼).

plain film skull x-rays, CT examinations, and nuclear medicine brain studies.

Methods

Ten randomly selected cases involving the use of diagnostic cerebral angiography were chosen for detailed analysis and subsequent patient dose estimation. All angiograms were obtained for diagnostic purposes and not in conjunction with neurointerventional procedures. The studies were performed on a Philips super M-100 x-ray unit (Philips Medical System, Shelton CT) with a fixed anteroposterior (AP) image intensifier with 9-inch and 6-inch modes, and biplane film changers. All studies were performed by residents and fellows, under the supervision of attending neuroradiologists.

Figure 1 depicts a head being irradiated by an incident x-ray beam which may be characterized by the kV_p and the beam filtration. The entrance (skin) dose* (D_e mGy) is obtained from the ESE and the exposure to absorbed dose conversion factor (f_{med}) and is given by the equation

$$D_e = ESE \times f_{med} \text{ mGy} \quad (A)$$

where the ESE is expressed in Roentgen (R) (1 R = 2.58 × 10^{-4} C kg^{-1}) and f_{med} is expressed in mGy/R. The x-ray beam cross-sectional area is A cm^2, which results in a "dose-area" product of $D_e \times A$ mGy − cm^2. With this irradiation geometry and resultant (three-dimensional) dose *distribution* in the patient, there will be a corresponding mean dose, D_i, (and thus a corresponding risk) to each irradiated organ (i). The effective dose equivalent, H_E, is a weighted sum of the mean doses to all irradiated organs or

$$H_E = \Sigma_i D_i \times w_i \text{ mSv} \quad (B)$$

where the summation is over all i irradiated organs, and where w_i are the organ-weighting factors specified by the ICRP (4). The effective dose equivalent (H_E) is thus a measure of the total risk to the patient undergoing the x-ray examination and may be computed from a knowledge of the mean doses to all irradiated organs in any x-ray examination.

For each patient examination, the effective dose equivalent, H_E, was determined using a two-step process. The first step involved the estimation of the product of the entrance (skin) absorbed dose (mGy) and the x-ray field size (cm^2). In the second step, this dose-area product was converted directly into H_E values using published conversion factors, which takes into account both the part of the patient anatomy irradiated in each x-ray projection view and the specific technique factors used (ie, kV_p and x-ray beam filtration in mm Al); these are based on calculated organ-dose per unit dose-area product obtained with Monte Carlo dosimetry techniques (8).

In each patient examination, the total fluoroscopy time and technique factors were recorded for each body part in the beam. The patient dimensions were recorded and the resultant irradiated area was determined taking into account focus-to-skin distance and collimator setting. Based on the recorded technique factors and distances, entrance skin doses under backscatter conditions were (subsequently) measured utilizing an MDH (Radcal Corporation, Monrovia, CA) radiation probe and a 20-cm thick acrylic phantom. Exposure readings (including backscatter by virtue of the experimental set-up) were converted into absorbed dose (soft tissue) using an f_{med} conversion factor of 8.7 mGy/R (9). The area-dose products were then calculated and the corresponding values of the H_E obtained

* The dose equivalent (milli-Sievert − mSv) is equal to the product of the absorbed dose (milli-Gray − mGy) and the radiation quality factor Q; since Q = 1 for radiations used in diagnostic radiology, absorbed dose in mGy and dose equivalent in mSv are numerically equal and are used interchangeably in this paper.

using the published conversion factors (8). For the cut film changer and DSA operating modes, the number of exposures and technique factors were also recorded, and subsequently used to make measurements of the patient entrance (skin) absorbed doses. The resultant patient H_E values were then determined in the same manner as in the case of fluoroscopy.

Angiography was performed via right femoral arterial catheterization and standard sterile and procedural techniques. Selective common carotid or vertebral catheterizations were performed using Bentson 1 or Bentson 2 catheters (Mallinckrodt Medical, St. Louis, MO). For each patient the total number of studies was also recorded. A study was defined as the injection of contrast through a selectively placed catheter for evaluation of a specific area. Thus, an injection of contrast material through a catheter in the common carotid artery for evaluation of the carotid bifurcation and cervical carotid artery constitutes a separate study from the evaluation of the cerebral portion of the same vessel. Additionally, all film changer and DSA examinations of the same region, without change in catheter position, represent portions of the same study.

Results

Table 1 summarizes the mean values (+ ranges) of all technique factors that were employed in the determination of the H_E values received by the patients investigated in this study. The parameters presented in Table 1 generally correspond to simple averages. Of note, however, the fluoroscopic kV_p values were weighted relative to the fluoroscopy time prior to being averaged. Entrance skin doses associated with the AP cut films were higher than the corresponding doses associated with lateral cut films because of the requirement for x-ray table penetration in the AP projection and also an increase in tissue thickness in the AP projection. DSA was performed in a single plane per injection and technique factors were comparable to those employed in lateral cut film procedures. Rate of cut film acquisition was varied to allow for preferential evaluation of arterial, capillary, or venous phases. All DSA examinations were performed at a filming rate of three frames per second in a 512 × 512 matrix. An average of 28 cut films were obtained per patient and this represented approximately half of the average number of frames obtained per patient with DSA. Ninety percent of all patients undergoing cerebral angiography underwent cut film evaluation, and 70% had DSA procedures.

Table 2 shows the resultant H_E values obtained for all 10 patients undergoing cerebral angiography. The average patient H_E was determined to be 10.6 mSv, with two thirds of this dose being due to fluoroscopy. The mean number of studies performed per patient was 4.3 with a range of one to eight studies per examination.

TABLE 1: Mean technique factors and parameters required to estimate the H_E values to patients undergoing cerebral angiographys (all x-ray beam filtration values were 2.5 mm Al)

Exposure Mode	Parameter	Mean Value	(Range)[a]
Fluoroscopy	kV_p	80	(65–110)
	Exposure time	10.4 min	(3.1–38)
	x-ray beam area	204 cm^2	(140–252)
	Entrance skin dose	271 mGy	(69–745)
Cut film (AP)	kV_p	80	(73–85)
	mAs/film	26	(25–32)
	No. films/patient	28	(0–87)
	x-ray beam area	364 cm^2	(280–439)
	Entrance skin dose	88 mGy	(0–253)
Cut film (lateral)	kV_p	78	(75–80)
	mAs/film	3.5	(3.2–4.0)
	No. films/patient	28	(0–87)
	x-ray beam area	432 cm^2	(296–540)
	Entrance skin dose	18 mGy	(0–48)
DSA	kV_p	68	(58–80)
	mAs/frame	4	(1.3–10)
	No. frames/patient	53	(0–207)
	x-ray beam area	259 cm^2	(48–445)
	Entrance skin dose	25 mGy	(0–53)

[a] Corresponding ranges for each parameter.

TABLE 2: Values of the effective dose equivalent, H_E, for the 10 patients undergoing (diagnostic) cerebral angiography[a]

Patient No. (No. of studies)	Fluoroscopy	Cut Film	DSA	Total
1 (7)	2.2	2.0	3.4	7.6
2 (3)	6.4	3.6	0	10.0
3 (2)	5.7	2.6	0	8.3
4 (1)	3.0	1.3	0	4.3
5 (2)	4.7	1.7	0.7	7.1
6 (3)	1.7	0	1.0	2.7
7 (5)	20.2	2.6	0.6	23.4
8 (7)	14.0	9.0	0.2	23.2
9 (8)	7.7	1.2	1.1	10.0
10 (5)	5.6	3.8	0.3	9.7
Average (4.3)	7.1	2.8	0.7	10.6
(Percentage of total H_E)	(67%)	(26%)	(7%)	

[a] All radiation doses (H_E) are expressed in mSv.

Discussion

Radiation risks may be classified as being stochastic or nonstochastic (deterministic). Stochastic effects have no threshold and the severity of the effect is independent of the radiation dose (ie, carcinogenesis and genetic effects). Nonstochas-

tic effects are associated with a threshold dose below which the detrimental effect will not occur, and where the severity of the effect is generally dependent on the radiation dose. The skin doses associated with the diagnostic procedures (Table 1) are *all* below the *acute* radiation dose thresholds for both eye lens opacification (2,000 mGy) (10) and skin reactions (5,000 mGy) (11). With entrance skin doses below the thresholds for nonstochastic effects, the *only* risk to the patients undergoing x-ray examinations is from the stochastic processes of carcinogenesis and genetic effects. The magnitude of these stochastic risks is given by the effective dose equivalent H_E, and not by parameters such as the entrance skin dose. Since the H_E parameter explicitly estimates the (stochastic) risk from nonuniform irradiation, it is suited for estimation of the radiation risk from any given x-ray (or nuclear medicine) examination *relative* to the corresponding radiation risk from any other radiologic examination. The derivation of an *absolute* risk would involve the use of risk coefficients such as the detriment value of 7.3×10^{-5} cancers and genetic abnormalities per mSv radiation dose adopted by the ICRP in 1991 (12). The generation of absolute risks, however, is much more difficult because of uncertainties about radiation risks at the low levels of exposures encountered in diagnostic radiology (5) and also because demographic features of the exposed population must be taken into account (13, 14).

The mean entrance skin doses for fluoroscopy (271 mGy), AP cut film (88 mGy), lateral cut film (18 mGy), and DSA (25 mGy) *cannot* be added to generate an overall "patient dose." For each of these four components, however, the resultant effective dose equivalent may be readily obtained using published conversion factors of dose-area product to effective dose equivalent (8). In general, values of the effective dose equivalent will be directly proportional to the dose-area product, and will also depend on the x-ray technique factors (ie, kV_p and beam filtration in mm Al) and on the region of the body being irradiated. For the fluoroscopy component, the mean entrance skin dose was 271 mGy, but the resultant mean effective dose equivalent only 7.1 mSv. This latter value is a realistic (and comprehensible) indicator of the patient risk, and may also be added to the H_E values from cut film and DSA procedures to generate an overall patient dose. For fluoroscopy, cut film studies and DSA portions of the angiographic examinations, the magnitude of the effective dose equivalent is only about 3% of the magnitude of the entrance skin dose. This is understandable given the small region of the patient being irradiated, and the rapid fall off in dose along the primary x-ray beam. It does, however, indicate that use of the entrance skin dose would seriously overestimate the patient risk if it were (erroneously) taken to be a uniform whole body dose.

The data presented in Table 2 suggest steps that may be adopted to reduce the patient radiation dose (ie, H_E) and corresponding patient radiation risk. The major contribution (67%) to the patient dose is from fluoroscopy. For a given kVp and image intensifer input exposure rate, ways of achieving reductions in fluoroscopy patient dose are by limiting the total fluoroscopy time (ie, entrance dose) *and/or* by the use of smaller fields of view (ie, x-ray beam area). In this respect, it is worth noting that any reduction in the patient skin-to-focal distance will have no impact on the patient H_E, and thus on the resultant patient radiation risk, assuming the whole x-ray beam intercepts the patient and that there is no change in x-ray beam collimation. This is because the dose-area product remains a constant when the patient-to-focus distance is reduced, since the increased skin dose is exactly counterbalanced by the reduced cross-sectional area (Fig. 1).

The radiation doses associated with cerebral angiography may be compared with other diagnostic neurologic studies that employ ionizing radiation. In nuclear medicine, for example, a brain scan results in an average H_E of about 10 mSv when 1,000 MBq of Tc-99m gluconate is used or 9.5 mSv when 1,500 MBq of Tc-99m DTPA is used (15). Radiation doses from modern CT scanners, such as the GE 9800 or the Siemens DRH, may be taken to be about 2 mSv (16). The average doses associated with typical plain film examinations of the skull are generally much lower than those associated with special procedures, nuclear medicine, and CT. In England (1983), a random survey of 229 adult skull examinations indicated that on average, three films per patient were used, and that the mean H_E per patient was 0.15 mSv (17). Thus, cerebral angiography appears to have a patient exposure comparable with those in nuclear medicine, but a factor of five higher than CT and about two orders of magnitude higher than those associated with plain film studies of the skull.

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