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Radiation Exposure in Endovascular Surgery of the Head and Neck

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PURPOSE: To evaluate the radiation risk to the operator and the patient during endovascular surgery of the head and neck. **METHODS:** The dose was measured using thermoluminescence dosimeters attached at the body surface of the operator and the patient during 15 endovascular surgeries (3 for arteriovenous malformation, 8 for dural arteriovenous fistulas, and 4 for other disorders of the head and neck). The dose was measured at seven sites on the operator and at five sites on the patient. **RESULTS:** The mean number of digital subtraction angiography studies and fluoroscopy time were 21 ± 10 and 73 ± 24 minutes, respectively. The equivalent dose range at each site in the operator was 0.12 to 0.88 mSv (glabella), 0.06 to 1.1 and 0 to 0.09 mSv (neck, outside and inside the protector, respectively), 0 to 0.20 mSv (left shoulder, inside the protector), 0.09 to 1.99 mSv (left arm), 0.05 to 3.55 mSv (left hand), and 0 to 0.49 mSv (pubis, inside the protector). Those in the patients were 3.1 to 136 mSv (glabella), 13 to 5441 mSv (right temporal area), 4 to 186 mSv (left temporal area), 0.1 to 51 mSv (neck), and 0 to 0.62 mSv (pubis). **CONCLUSIONS:** The total doses at the operator's eyes and left hand during the course of a year may exceed the dose limits recommended by the International Commission on Radiological Protection. Operators should wear not only body protectors, but also thyroid protectors and lead glass spectacles. The equivalent dose at the right temporal area of the patient may exceed the deterministic dose for transient erythema or alopecia of the skin even in one endovascular procedure.

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

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Although there has been marked improvement of the technology used in interventional neuroradiology, the exposure dose of operators, medical staff, and patients is a matter of concern. Endovascular surgeries of the head and neck take much more time than do routine diagnostic x-ray examinations, which necessarily results in increased risk of radiation exposure of the medical staff and patient. Although the International Commission on Radiological Protection has conducted research to establish international standards for exposure dose and radiologic protection (1), there have been few reports concerning the dose in endovascular surgery. We therefore measured the equivalent doses to the operators and the patients in 15 endovascular surgeries of the head and neck.

Materials and Methods

Fifteen patients, seven male and eight female, ranging from 17 to 71 years of age, were included in the study (Table 1). The endovascular procedures consisted of superselective embolization for brain arteriovenous malformations in three patients, dural arteriovenous fistulas of the cavernous sinus in six, dural arteriovenous fistulas of the posterior fossa in two, and, in one each, traumatic arteriovenous fistula of the face, glomus tumor of the neck, hemangioma of the face, and traumatic aneurysm of the superficial temporal artery. They included nine transarterial and six transvenous procedures. The operator wore a body protector, a thyroid protector, and lead glass spectacles. The x-ray device used was an automatic exposure-controlled fluoroscope (Angioskop, Siemens, Erlangen, Germany) and a digital subtraction angiography system (DPS-4100, Adac Laboratories, Milpitas, Calif). The dis-

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TABLE 1: Fifteen patients undergoing endovascular procedures

Patient	Age/Sex	Diagnosis	Method
1	57/M	AVF of the face	TAE
2	49/F	dural AVF of the cavernous sinus	TAE
3	28/M	brain AVM (grade III)	TAE
4	62/F	dural AVF of the cavernous sinus	TVE
5	58/F	glomus jugulare tumor	TAE
6	38/M	brain AVM (grade II)	TAE
7	49/F	dural AVF of the cavernous sinus	TVE
8	57/F	dural AVF of the cavernous sinus	TVE
9	54/F	hemangioma of the face	TAE
10	49/F	dural AVF of the cavernous sinus	TVE
11	60/M	dural AVF of the posterior fossa	TAE
12	60/M	dural AVF of the posterior fossa	TVE
13	71/F	dural AVF of the cavernous sinus	TVE
14	28/M	brain AVM (grade III)	TAE
15	17/M	traumatic aneurysm of superficial temporal artery	TAE

Note.—AVF indicates arteriovenous fistula; AVM, arteriovenous malformation; TAE, transarterial embolization; and TVE, transvenous embolization.

tance between the x-ray tube and the image intensifier (7, 9, and 13 in variable) was fixed at 90 cm, and the x-ray field was decreased to as small as possible. The fluoroscopic examination was performed in the continuous mode. In a lateral-view examination, the x-ray tube was almost always placed to the right side of the patient because of the design of our x-ray device. Digital subtraction angiography was always performed with manual injection of contrast medium and at the frame rate of 3 frames per second, and at each digital subtraction angiography examination a total of 15 to 25 frames were collected in most cases. The operator performed the endovascular procedure while seated on a chair at the right side of the patient.

The local exposure dose was measured with thermoluminescence dosimeters (Kasei Optonix, Tokyo, Japan) composed of Mg_2SiO_4 (Tb), each covered by a holder with a sensitivity compensation filter (holder F). The detection limits of this thermoluminescence dosimeter system are 0.1 mR and 100 R. The sensitivity of each thermoluminescence dosimeter and the thermoluminescence dosimeter reader were calibrated with a radiation source (radium-226; Kasei Optonix), and residual radiation energy of each thermoluminescence dosimeter was removed by placing it in an annealing oven (Kasei Optinix). Thermoluminescence dosimeters were attached to seven areas on the operator and five areas on the patient. The areas in the operator were glabella outside the spectacles, representing the eye lens, the midline of the neck inside and outside of the thyroid protector, the left shoulder inside the protector, the ulnar aspect of the left upper arm, the back of the left hand, and the pubis. In the patients, thermoluminescence dosimeter were attached to the glabella, the right and left temporal areas (around the pterion), the midline of the neck, and the pubis. Immediately after the operation, each thermoluminescence dosimeter was removed from the Holder-F, avoiding exposure to fluorescent light, and inserted into the thermoluminescence dosimeter reader

TABLE 2: Conversion coefficients from the radiation dose to the 70-μm equivalent dose at each photon energy of X-ray source

Photon Energy, keV	$f_{70\ \mu m}$	$f_{x70\ \mu m}$
10	8.12	0.930
15	8.51	0.0974
20	8.92	1.02
30	10.4	1.19
40	12.0	1.38
50	13.3	1.52

(Kyokko thermoluminescence dosimeter Reader 2500, Kasei Optonix).

The exposure dose was automatically calculated from the luminescent dose of the thermoluminescence dosimeter. The equivalent dose ($H_{70\mu m}$, in millisieverts) of the skin was calculated by the formula: $H_{70\mu m} = f_{70\mu m} \times fx_{70\mu m} \times Px$, where $f_{70\mu m}$ is a conversion factor from the radiation dose to $H_{70\mu m}$; $fx_{70\mu m}$ is a conversion factor from Px to the radiation dose; and Px is the dose measured by the thermoluminescence dosimeter reader for the areas other than the glabella. As shown in Table 2, the coefficients 10.4 and 1.19 were used for $f_{70\mu m}$ and $fx_{70\mu m}$, respectively, because the estimated effective photon energy of our x-ray device is about 30 keV.

The equivalent dose (H_{3mm}, in millisieverts) of the lens (eye) was calculated by the formula: $H_{3mm} = f_{3mm} \times fx_{3mm} \times Px$, where f_{3mm} is a conversion factor from the radiation dose to H_{3mm}; fx_{3mm} is a conversion factor from Px to the radiation dose; and Px is the dose measured by the thermoluminescence dosimeter reader for the glabella. The coefficients of f_{3mm} and fx_{3mm} were those used for $f_{70\mu m}$ and $fx_{70\mu m}$ in the preceding equation.

Doses exceeding 100 R were calibrated according to the dose-characteristic curve for this thermoluminescence dosimeter (Fig 1), because supralineality (overestimation) is observed in this range.

In the comparative study, the equivalent doses were measured by the same method during routine diagnostic four-vessel study (film angiography) by transfemoral cath-

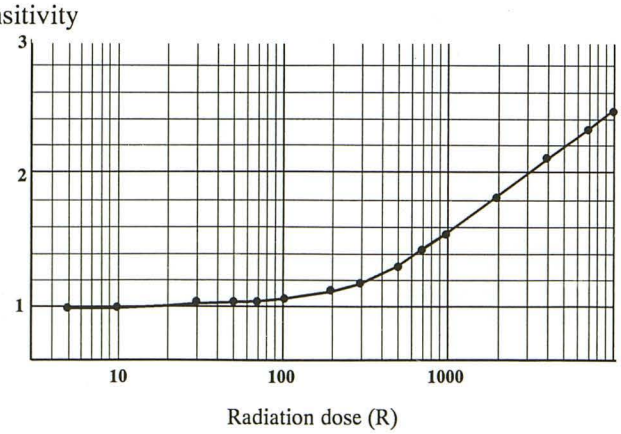

Fig 1. Dose characteristic curve of thermoluminescence dosimeter (Mg_2SiO_4) sensitivity.

TABLE 3: Operator equivalent doses

Patient	Diagnosis	Number of DSA Studies	F-Time, min	Operator Equivalent Dose, mSv						
				Glabella	Neck	Neck*	L Shoulder*	L Arm	L Hand	Pubis*
1	AVF	35	99	0.20	0.18	0.04	0	1.35	0.32	0
2	C-dAVF	44	85	0.49	0.37	0	0.01	0.51	0.44	0.03
3	AVM	23	78	0.25	0.17	0	0	0.60	0.11	0
4	C-dAVF	23	97	0.27	0.15	0.02	0	0.09	0.20	0
5	Glomus tumor	14	93	0.18	0.12	0	0	0.29	0.13	0
6	AVM	16	34	0.02	0.14	0.01	0	0.21	0.13	0
7	C-dAVF	20	74	0.27	0.20	0.01	0.05	0.39	0.15	0
8	C-dAVF	15	63	0.37	0.33	0.01	0.20	0.34	0.59	0
9	Hemangioma	13	70	0.12	0.06	0	0	0.16	0.05	0
10	C-dAVF	12	61	0.35	0.19	0.02	0	0.71	0.12	0.01
11	P-dAVM	26	97	0.88	1.1	0.09	0.02	1.99	3.55	0
12	P-dAVM	10	34	0.39	0.35	0.08	0.01	0.89	0.20	0.02
13	C-dAVF	15	87	0.25	0.51	0	0	0.46	0.29	0.49
14	AVM	35	87	0.80	0.43	0.02	0.02	1.02	0.32	0
15	STA-AN	15	30	0.21	0.16	0.01	0.06	0.19	0.18	0

Note.—Note the dose difference for the neck inside and outside the protector. F-time indicates time of fluoroscopy; AVF, arteriovenous fistula; C-dAVF, dural AVF of the cavernous sinus; AVM, arteriovenous malformation; P-dAVF, dural AFV of the posterior fossa; and STA-AN, aneurysm of the superficial temporal artery.

* Inside the protector.

eterization in a patient with a brain arteriovenous malformation. In this examination, 120 films (40 each in the anteroposterior and lateral views, and 20 each in the right and left anterior oblique views) were obtained with a standard angiographic unit with biplane rapid serial changers. The x-ray tube was always placed to the left side of the patient when the lateral-view films were obtained. The operator was in the room during the fluoroscopic examination but went out of the room during the film angiogram. Digital subtraction angiography was not performed in this patient.

Results

The total time for the endovascular procedure was more than 3 hours in every patient. The number of digital subtraction angiography examinations per patient ranged from 10 to 44 (21.1 ± 10.0, mean ± 1 SD). The fluoroscopic examination time ranged from 30 to 99 minutes (72.6 ± 23.8 minutes).

Operator Equivalent Doses

The operator equivalent doses ranged from 0.02 to 0.88 mSv at the glabella (representing the lens dose), 0.06 to 1.1 mSv at the neck outside the thyroid protector, 0 to 0.09 mSv at the neck inside the protector, 0 to 0.2 mSv at the left shoulder inside the protector, 0.09 to 1.99 mSv at the ulnar aspect of the left upper arm, 0.05 to 3.55 mSv at the back of the left hand, and 0 to 0.49 mSv at the pubis (Table 3). The relationship of the equivalent dose for each area to the fluoroscopy time (Fig 2) and to the number of digital subtraction angiography studies (Fig 3) was examined. Although no significant relationship was found, the doses at the glabella, the neck outside the protector, and the left arm showed some tendency to increase with both the fluoroscopy time and the number of digital subtraction angiography studies. The correlation coefficients for the dose and fluoroscopy time were .35 for the glabella, .30 for the neck outside the protector, and .35 for the arm, and those for the dose and the number of digital subtraction angiography studies were .47, .25, and .40, respectively.

Patient Equivalent Doses

The patient equivalent doses ranged from 3.1 to 136 mSv at the glabella, 13 to 5441 mSv at the right temporal area, 4 to 186 mSv at the left temporal area, 0.1 to 51 mSv at the neck, and 0 to 0.62 mSv at the pubis (Table 4). The dose at the right temporal area was much higher than at the left side in all the patients except one, because the x-ray tube was usually placed to the right side of the patient during the lateral-view examination. Transient alopecia of the right temporal area developed in patients 10 and 14, but the hair grew back out after 2 to 3 months.

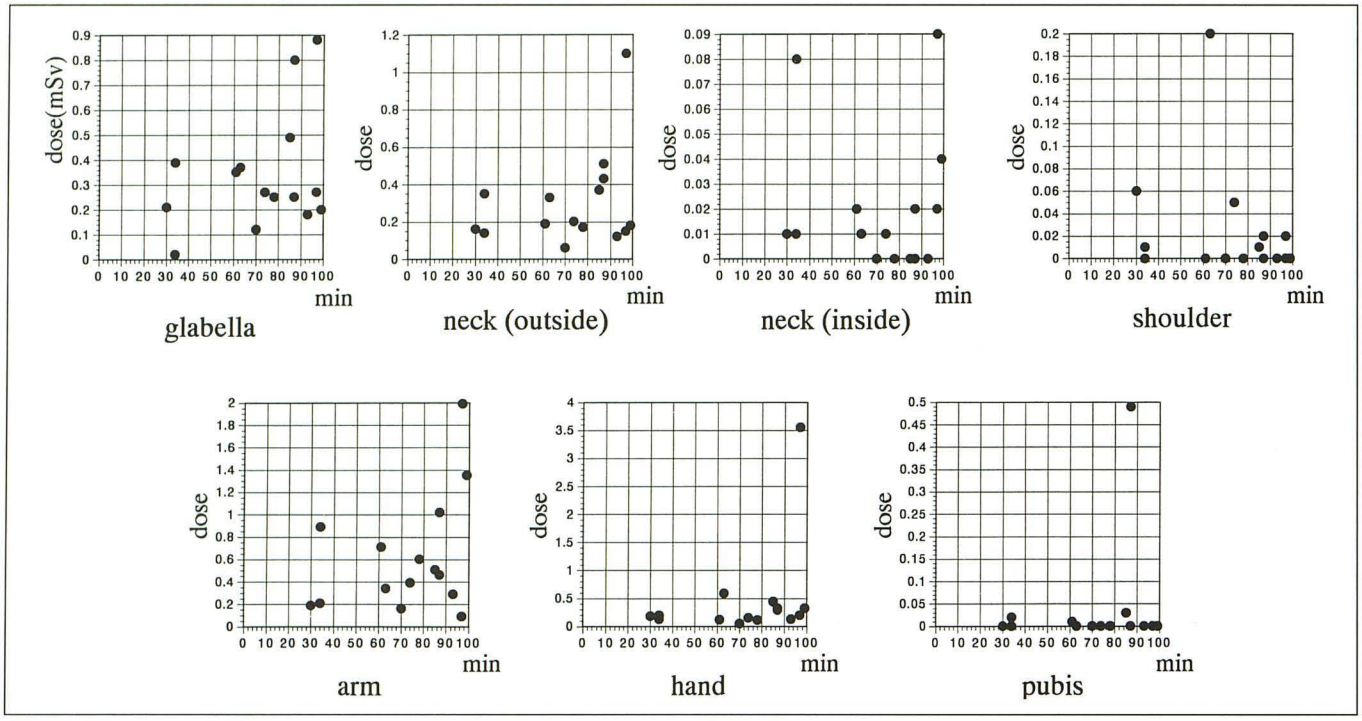

Fig 2. Relationship between the fluoroscopy time and the equivalent dose for each anatomic area of the operator.

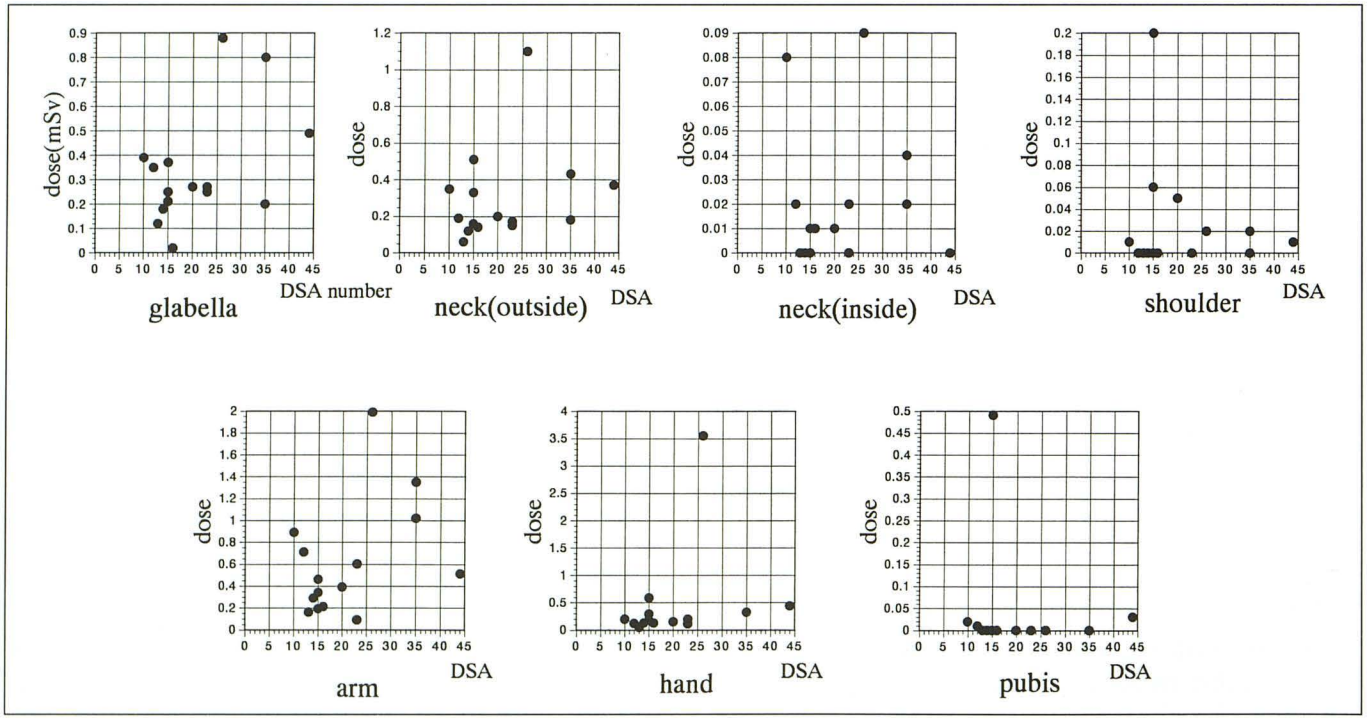

Fig 3. Relationship between the number of digital subtraction angiography studies and equivalent dose for each anatomic area of the operator.

TABLE 4: Patient equivalent doses

Patient	Diagnosis	Number of DSA Studies	F-time, min	Patient Equivalent Dose, mSv				
				Glabella	Temporal Area	Temporal Area	Neck	Pubis
1	AVF	35	99	22	3075	40	25	0.47
2	C-dAVF	44	85	57	867	23	23	0.07
3	AVM	23	78	99	315	85	5	0.12
4	C-dAVF	23	97	136	3688	131	26	0.62
5	Glomus tumor	14	93	67	69	74	51	0.12
6	AVM	16	34	23	329	186	5	0.11
7	C-dAVF	20	74	42	2382	39	14	0.07
8	C-dAVF	15	63	27	3705	43	18	0.13
9	Hemangioma	13	70	3.1	13	4	15	0.07
10	C-dAVF	12	61	35	5441	65	13	0.10
11	P-dAVF	26	97	52	3462	102	0.1	0.09
12	P-dAVF	10	34	55	602	55	25	0.12
13	C-dAVF	15	87	43	4967	148	33	0
14	AVM	35	87	43	4967	148	33	0
15	STA-AN	15	30	56	1848	21	6.3	0.08

Note.—F-time indicates time of fluoroscopy; AVF, arteriovenous fistula; C-dAVF, dural AVF of the cavernous sinus; AVM, arteriovenous malformation; P-dAVF, dural AVF of the posterior fossa; and STA-AN, aneurysm of the superficial temporal artery.

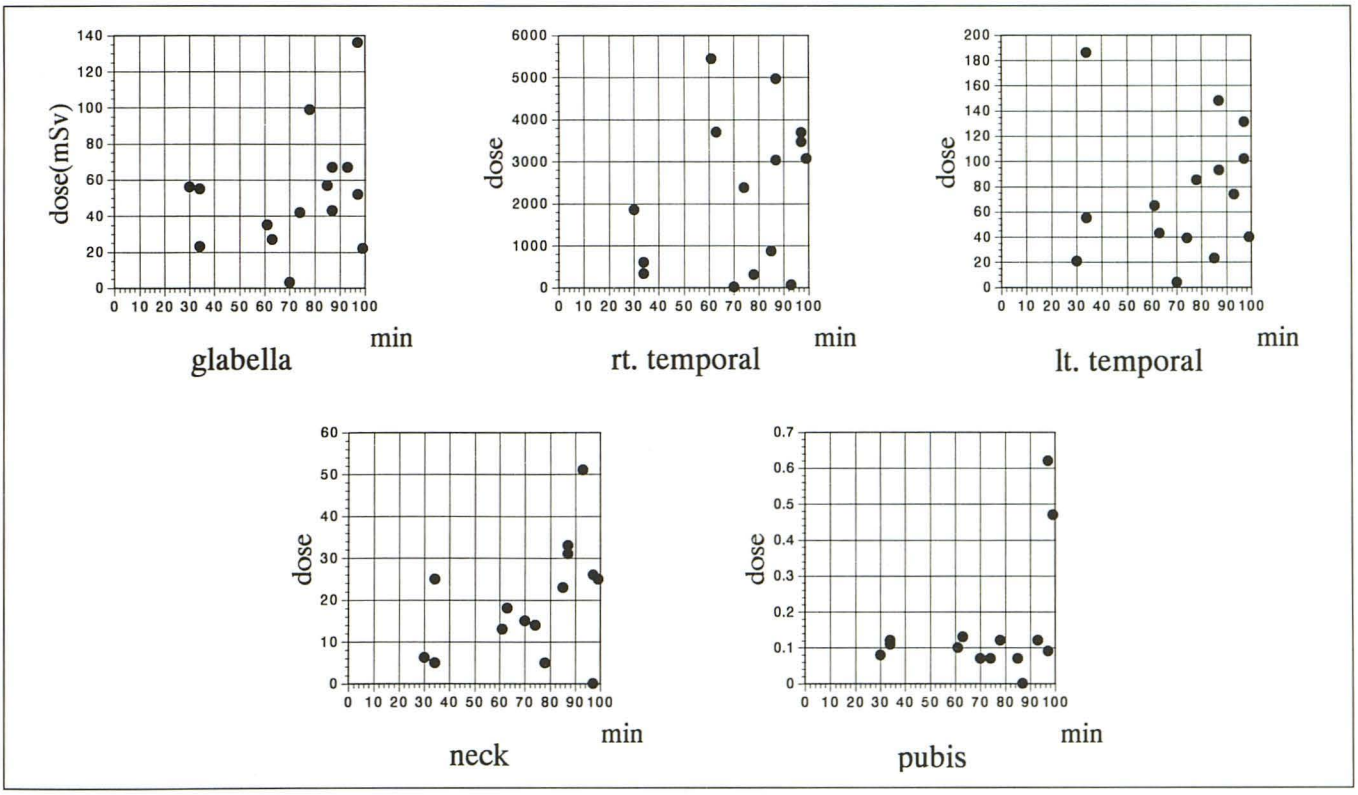

Fig 4. Relationship between the fluoroscopy time and the dose for each anatomic area of the patient.

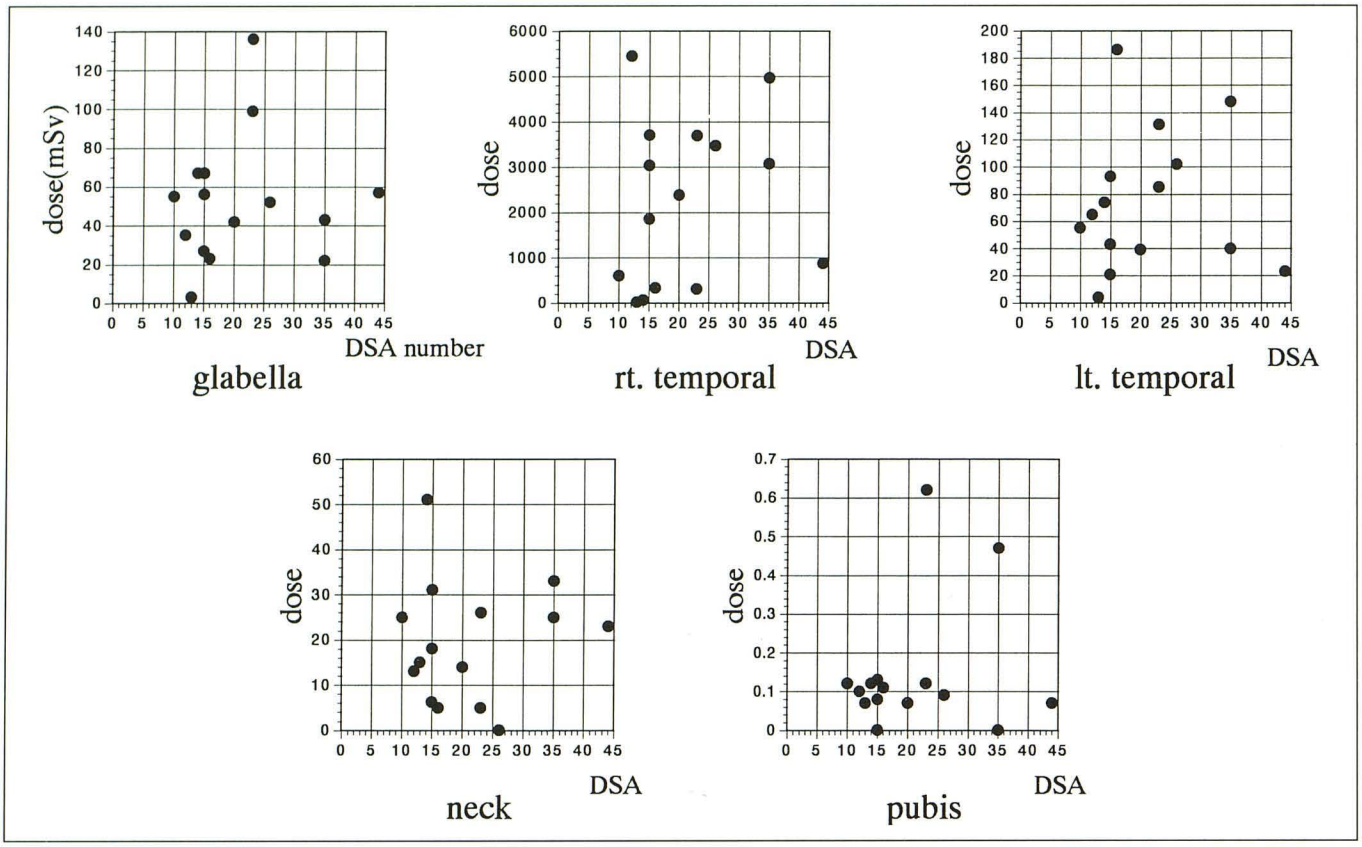

Fig 5. Relationship between the number of digital subtraction angiography studies and the dose for each anatomic area of the patient.

The relationship of the equivalent dose at each area to the fluoroscopy time (Fig 4) and to the number of digital subtraction angiography studies (Fig 5) was examined. Although no significant relationship was observed, the doses at the glabella, the right temporal area, and the neck showed some tendency to increase with the fluoroscopy time. The correlation coefficients for the dose with fluoroscopy time was .31 for the glabella, .29 for the right temporal area, and .41 for the neck.

In the routine diagnostic four-vessel study, the fluoroscopy time (catheter placement) was 6.2 minutes. The operator equivalent doses were 0 mSv at the glabella, 0.01 and 0.03 mSv at the neck inside and outside the protector, 0 mSv at the left shoulder, 0.07 mSv at the ulnar aspect of the left upper arm, 0.01 mSv at the back of the left hand, and 0 mSv at the pubis. Those in the patient were 318 mSv at the glabella, 158 and 202 mSv at the right and left temporal area, respectively, 13 mSv at the neck, and 0.06 mSv at the pubis (Table 5).

Discussion

Recent improvements in x-ray technology have greatly contributed to both the advancement of diagnostic imaging and the reduction of radiation exposure. Although there have been

TABLE 5: Equivalent doses in the routine diagnostic four-vessel study

Patient age, y/sex	Diagnosis	F-Time, min	Number of Films	Equivalent Doses in the Operator, mSv							Equivalent Doses in the Patient, mSv				
				Glabella	Neck	Neck*	L Shoulder*	L Arm	L Hand	Pubis*	Glabella	R Temporal Area	L Temporal Area	Neck	Pubis
28/M	AVM	6.2	120	0	0.03	0.01	0	0.07	0.01	0	318	158	202	13	0.06

Note.—F-time indicates time of fluoroscopy; AVM, arteriovenous malformation.
* Inside the protector.

some reports regarding the radiation doses in diagnostic x-ray examinations (2–5), there are few reports regarding the doses in interventional procedures. The International Commission on Radiological Protection has been investigating various issues in the radiologic protection of not only occupational and medical workers but also the general public since it was established in 1928. In the present study, the radiation exposure in endovascular surgery of the head and neck was assessed according to guidelines of the International Commission on Radiological Protection issued in 1990 (1), and the radiation risk was evaluated. Although the method by which endovascular surgery is conducted varies depending on the techniques and equipment used, the clinical examination used in our study can be used to measure radiation exposure during this complex surgery.

Thermoluminescence dosimeters composed of MG_2 SiO_4 (Tb) are widely used because they are sensitive to x-rays, which allows dose measurement over a wide range with sufficient accuracy. These thermoluminescence dosimeters are appropriate for the measurement of dosage caused by diagnostic x-ray exposure, because they allow measurement in the low-dose range (6). The sensitivity range of the thermoluminescence dosimeters we used is greater than 0.1 mR to 100 R. They require careful calibration in the range above 100 R, however, because of their supralineality. The systematic errors in thermoluminescence dosimeter measurements must be identified by sensitivity factors of each type of detector (6).

Operator Dose

In the present study, no correlation was found between either the fluoroscopy time or the number of digital subtraction angiography studies and the exposure dose, although the exposure doses at the glabella, the neck outside the protector, and the arm showed slight increases with these two factors. Each of the many factors affecting the exposure dose, including exposure time, distance from the x-ray source, x-ray energy, and scattered radiation, must be carefully considered in efforts to reduce the dose. Our findings for the neck inside and outside the protector in the operator clearly indicate that the exposure dose of the operator can be reduced by wearing protective devices.

According to the most recent International Commission on Radiological Protection recommendations regarding radiologic protection (1), the operator dose limit is 150 mSv/y for the lens (H_{3mm}), 500 mSv/y in the skin ($H_{70\mu m}$), and 2 mSv in the abdomen of a pregnant woman operator (H_{1cm}). In the operator who conducted the digital subtraction angiography studies in patient 11, the doses at many sites were far higher than those in the examination of other patients. This patient was the only patient in whom the transcarotid approach rather than the transfemoral approach was used because of tortuosity of the vessels. It is presumed that the short distance between the x-ray source and the operator resulted in the high operator doses.

The highest operator dose at the glabella was 0.88 mSv in this study. A pessimistic calculation indicates that an operator performing 170 (150/0.88) or more endovascular surgeries in a year has a potential risk of exceeding the dose limit for the eye. These results highlight the necessity of wearing protective lead-glass eye wear. The highest operator doses for the left arm and the left hand were 1.99 and 3.55 mSv, respectively. A similar calculation indicates that an operator performing 140 (500/3.55) or more endovascular surgeries in a year has a potential risk of exceeding the dose limit for the skin. Even if the highest dose for the hand (3.55 mSv) was overestimated in our study, the operator dose for the arm exceeded 1 mSv in three procedures in this study, indicating that skin exposure should not be overlooked by operators who perform hundreds of endovascular surgeries in a year. Some consideration is needed for protection of these area. The thyroid and shoulder doses inside the protector found in this study seem to be within an acceptable range. The highest dose for the pubis, 0.49 mSv, was observed for the operator in the examination of patient 13. This dose is far higher than that in the examination of any other patient, and it is thought that the protector above the thermoluminescence dosimeter might have become dislodged when the operator sat on the chair. Thus, pregnant operators should take special care to make sure that the protectors are correctly placed on their abdomens.

Patient Dose

The patient dose showed a wide range according to clinical features and treatment requirements. The doses in patients 5 and 6 were exceptionally low, probably because the thermoluminescence dosimeters at the glabella and temporal area were not near the lesions (the neck in patient 5 and the oral cavity in patient 9).

The clinical threshold for deterministic effect on each organ in acute exposure is 5 Gy (2 to 10 Gy) (equivalent to 6 Sv in this study) for the development of cataracts (7), 5 Gy (6 Sv) for erythema or alopecia of the skin (8), 2.5 to 6 Gy (3 to 7.2 Sv) for sterility (7), and 25 to 30 Gy (30 to 36 Sv) for hypothyroidism (9). In our study, doses at the glabella, neck, and pubis were much smaller than the respective clinical thresholds for the eye, thyroid, and genital organs; however, it is still necessary to ensure that these critical organs are not exposed to the fluoroscopic or angiographic field. The dose at the right temporal area was unexpectedly high, exceeding 1000 mSv (1 Sv) in 9 of 15 patients. Alopecia, although transient, developed in 2 patients, in each of whom the dose at the right temporal area was about 5000 mSv (5 Sv, equivalent to 4.2 Gy). Reports presented by the New York University Medical Center (10–12) indicated that increased incidence of tumors of the head and neck is observed in individuals who were exposed to x-ray therapy for tinea capitis during childhood between 1940 and 1959. The reports also cite high incidence of tumors of the brain, parotid gland, skin, bone, and thyroid and especially high incidence of basal cell carcinoma of the skin. The dose to the scalp estimated in the dosimetric study varied from 4.5 to 8.5 Gy. Although the dose cannot be compared directly with our data, because the effective energy of their x-ray device is not stated, the dose of 5 Sv in our study is not much different from their dose of 4.5 Gy. These data suggest that several patients in our study have increased risk of development of malignant tumors of the skin. These high doses apparently resulted from the performance of the lateral-view fluoroscopy and digital subtraction angiography in only one projection (from right to left). Care must be taken to keep the time in any given projection view as brief as possible.

We conclude based on the results of this study that modern endovascular surgery of the head and neck is not completely safe in terms of radiation exposure, especially at the operator's arm and the x-ray beam entrance site in the patient. Requiring operators to wear protective devices, some mechanical improvement in x-ray equipment, and careful operator attention to the manipulation of the equipment are necessary to decrease the dose.

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Please see the commentary on page 1813 in this issue.