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Techniques for Reducing Interventional Neuroradiologic Skin Dose: Tube Position Rotation and Supplemental Beam Filtration

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PURPOSE: To limit the side effects of interventional neuroradiologic radiation, such as epilation, by applying a technique involving tube position rotation and by adding a supplemental inexpensive primary beam filter; and to show the dose effect of modifying technical factors. **METHODS:** Combined skin dose from fluoroscopy and digital subtraction angiography was measured with an array of 16 thermoluminescent dosimeters during interventional neuroradiologic procedures in 12 control subjects, in 18 patients whose procedures included addition of an inexpensive primary beam filter (0.5 mm aluminum/0.076 mm copper), and in 10 patients in whom the tube position was rotated, additional primary beam filtration was used, and close attention was paid to technique. **RESULTS:** Maximum thermoluminescent dosimetric measurements obtained with existing machine filtration ranged from 0.31 to 2.70 Gy in the control group (mean, 1.51 ± 0.88); 0.25 to 2.42 Gy in the group with additional filtration alone (mean 0.96 ± 0.64; average dose reduction, 36%); and 0.13 to 1.23 Gy in the group with additional filtration, tube position rotation, and close attention to technique (mean, 0.58 ± 0.34; average dose reduction, 63%). Differences were statistically significant. **CONCLUSIONS:** Greater than 50% skin dose reductions were documented during interventional neuroradiologic procedures by combining tube position rotation, supplemental primary beam filtration, and technical modifications.

Index terms: Interventional instruments; Interventional neuroradiology; Radiation, dose

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The Food and Drug Administration has recently directed its attention to the radiation-induced skin injuries patients can receive during the course of interventional radiologic procedures (1, 2). Doses high enough to result in erythema, desquamation, and temporary and permanent hair loss have been documented (3–10). Recent attention has been directed to radiation doses seen in neuroangiographic and neurointerventional procedures (10–13). Many methods are available by which the radiation dose received during interventional neuroradiologic procedures can be reduced. Such techniques as close collimation, decreased tube-source air gap, maximization of road mapping, and use of supplemental primary beam filtration have been known for a long time; however, these procedures have not been formally evaluated for interventional radiologic or neuroradiologic application. We sought to document the amount of dose reduction obtained with the use of some of these techniques and to apply a dose-reducing technique of tube position rotation.

General dose-reduction measures include regulating maximum entrance exposure rate, minimizing high-level fluoroscopy, altering beam hardness by using supplemental beam filtration, and using machine accessories such as pulse-progressive fluoroscopy and image hold features (3, 10, 11, 14–16). Additional modifiable variables include grid manipulation and video chain modifications (3, 14). Supplemental beam filtration has been discussed as a general method to decrease radiation dose, although it has not been previously investigated for specific interventional radiologic applications (15, 16). Despite the lack of specific sci-

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entific literature supporting interventional radiologic applications, commercially available machines are being marketed with increasing amounts of available primary beam filtration.

Operator-dependent variables have been discussed as an important means of minimizing dose; examples include conscious reduction of fluoroscopic time, modification of beam geometry and scattered radiation achieved by closely collimating the field and placing the image intensifier close to the imaged object, and careful minimization of biplane fluoroscopic overlap (3, 17). However, there has been little in vivo documentation of the dose reductions that these techniques produce with interventional radiologic applications.

Interventional neuroradiologic procedures are used to treat surgically inaccessible lesions, to improve traditional treatment methods through decreased morbidity and mortality, or to improve the chance for cure with traditional treatment. Nine (10%) of 87 patients treated in a 2-year period at our institution had temporary or long-standing scalp epilation, presumably as a result of skin doses accrued during interventional neuroradiologic procedures. We are not aware of any large-scale studies that have explored the prevalence of temporary or permanent scalp epilation resulting from interventional neuroradiologic procedures, and therefore we are unable to compare our findings with a documented or accepted mean.

We believe that the radiation dose received by patients during interventional neuroradiologic procedures should be significantly decreased. To this end, we evaluated the maximum radiation-induced skin doses delivered in our practice during interventional neuroradiologic procedures and documented decreases in skin dose attained with the use of a previously undescribed method of tube rotation, inexpensive supplemental primary beam filtration, and attention to other technical parameters.

Materials and Methods

The clinical portion of this study was performed in three parts. In the first part, 12 patients were studied for skin dose levels and dose distributions; in the second part, 18 patients were studied for dose reductions after supplemental filtration, and in the third part, 10 patients were studied for dose reductions after supplemental filtration and technique modifications were made on a General Electric DF 5000 LU unit (GE Systems, Milwaukee, Wis). In each of the groups of patients, a variety of interventional neuroradiologic procedures were used.

Sixteen thermoluminescent dosimeters (TLDs) were placed, two at each of eight circumferential sites, around each patient's head to measure site-specific skin doses. These TLD sites were spaced at even intervals on a stockinette headband with the first site centered on the forehead during each treatment session. The TLDs were polytef disks impregnated with lithium fluoride, measuring 12.4 mm in diameter and 0.4 mm in thickness (Teledyne Inc., Westwood, NJ). The TLDs were calibrated with cobalt-60, and calibration was corrected by a factor of 0.83, since lithium fluoride overresponds to low-energy x-rays (18). The calibration accuracy of the TLDs was $\pm$5%, single standard deviation. The dynamic dose range for the TLDs was 0.20 mGy to 1000.01 Gy, and although the full dynamic range of our TLDs was not tested, calibration testing of sample TLDs was performed to ascertain accuracy of epilation level doses.

The number of digital subtraction angiograms obtained was recorded, as was fluoroscopy time for each procedure. The dosimeter measurements were compared with TLD sites and exposure times. The parameters evaluated for each patient included fluoroscopy time in minutes and number of digital subtraction angiograms in milliampere-minutes (mA·m).

In the first portion of the study, skin dose levels and dose distributions were evaluated in 12 consecutive patients undergoing interventional neuroradiologic procedures. These 12 patients included eight males and four females, 8 to 55 years old (mean age, 34 years). Procedures included embolization of an arteriovenous malformation (n = 8), venous sinus stenting (n = 2), aneurysm coiling (n = 1), and superselective angiography (n = 1). The baseline technique used to control radiation dose concentrated on minimizing fluoroscopy time and using maximum primary beam collimation. Machine set-up parameters were not altered in this part of the study.

Possible supplemental beam filtration dose effects were evaluated with a pressed wood phantom. The wood phantom had a measured density of 0.70 g/cm^3 and was constructed from seven 1.8-cm-thick pressed wood sheets. An operational ionization chamber was used for the attenuation measurements (Keithly model 35055 with ionization chamber model 96020A, Cleveland, Ohio). The operational instrument measurements were compared with a reference ionization chamber (Radcal model 2025 with ionization chamber model 20X5-3, Monrovia, Calif). Ionization chamber measurements were made at a source image distance of 50 cm and machine parameters for phantom evaluation were manual mode at 10 kV(p) and 50 mA, similar to settings chosen for interventional neuroradiologic applications. Attenuation measurements were repeated for each of three evaluated supplemental beam filters, in addition to measurements obtained for the existing 3.0 mm of aluminum machine filtration. The three individually tested supplemental filters were chosen on the basis of results and materials investigated for previously published supplemental filtration applications (15, 16) or

materials chosen for commercial marketplace introduction by manufacturers of angiographic equipment. The three chosen filters included 0.5 mm aluminum per 0.076 mm copper, 0.5 mm aluminum per 0.152 mm copper, and 0.5 mm aluminum per 0.125 mm tantalum. These measurements allowed us to choose a filter that optimally reduced skin dose but did not significantly reduce the 8-cm depth dose and therefore did not adversely affect image quality. An 8-cm depth dose was chosen to approximate the center of the calvaria.

Filter selection also included subjective evaluation of filter effects by interventional neuroradiologists. During each of three interventional procedures (before the dosimetry portion of the study), the three supplemental filters were inserted into the tube-mounted filter receiver for visual evaluation of six specific items, namely, two different microcatheters including flow- and guidewire-directed samples (discussed below), a microguidewire, quality of intravascular manual injection of contrast material, bone detail, and background noise. Two microcatheters were evaluated for ease of visualization of the distal tip markers of, first, a 0.018-in guidewire-directed microcatheter (Target, Inc; Fremont, Calif) and, second, a standard model flow-directed microcatheter (Balt, Inc; Montmorency, France). The 0.016-in Seeker microguidewire (Target, Inc; Fremont, Calif) was evaluated for ease with which body and tip portions were seen. The intravascular contrast material was evaluated for visibility and dynamic fluoroscopic tracking of a manually injected bolus of 1 mL of nonionic radiopaque contrast material diluted to a concentration of 150 mg I/mL, injected at a customary rate of 0.5 mL/s through the flow-directed and microguidewire-directed microcatheters. Bone was evaluated by visibility of calvarial and petrous landmarks used during intracranial microangiography, and the background noise was assessed by subjective effects of varying background noise seen with each of the supplemental filters.

In the second portion of the study, skin dose levels were evaluated in 18 patients with TLDs during interventional neuroradiologic procedures with the use of an additional beam filtration (0.5 mm aluminum per 0.076 mm copper). This filter was constructed by taping together two 5-in square sheets of elemental metal (Alcoa of Northern California) at a total unit cost of 24 cents. These 18 patients included 11 male and 7 female subjects, 15 to 75 years old (mean age, 38 years). Procedures performed included embolization of an arteriovenous malformation (n = 10), embolization of a carotid-cavernous fistula (n = 3), embolization of a meningioma (n = 2), and superselective angiography (n = 3). This patient population was considered equivalent to the first group in terms of case composition. Maximum TLD measurements with additional filtration were determined for each patient. As with the previous clinical portion of the study, fluoroscopy time was minimized and tight collimation was used but machine parameters were not specifically altered.

In the third part of the study, the same added beam filtration was used as in the second part. After analyzing the batch data obtained from the second group of patients, we presumed that machine set-up was independently affecting skin dose measurements. The fluoroscopic boost factor was set to the nonboosted minimum and the digital subtraction angiography (DSA) differential gain was set at B. These machine values were arrived at after conducting an in vitro evaluation that we thought was necessary at this juncture.

In vitro fluoroscopic boost and DSA gain dose evaluations were done independently. An operational ionization chamber was used for these measurements (Keithly model 35055 with ionization chamber model 96020A, Cleveland Ohio). The operational instrument measurements were compared with a reference ionization chamber (Radcal model 2025 with ionization chamber model 20X5-3, Monrovia, Calif). Ionization chamber measurements were obtained at a source image distance of 50 cm. On this unit, the operator-controlled fluoroscopic setting hardkeys are denoted small *r* for nonboosted, medium *r*, and large *r* for the two increasing boosted stations.

In addition to controlling the fluoroscopic boost and DSA differential gain settings, we also modified the position of the x-ray tube and image intensifier. Analysis of circumferential TLD data from the first and second groups of patients was performed at this time and showed markedly asymmetric skin doses when opposite sides of the calvaria were compared in both groups. The marked asymmetry led us to believe that by paying careful attention to patient and tube placement we could achieve a reduction in skin dose. A more symmetric dose was sought by reversing the location of the x-ray tube and image intensifier at 5-minute fixed intervals. An arbitrary interval of 5 minutes was chosen because it corresponded to the auditory fluoroscopy timer interval, and the procedure nurse documented tube rotations at the 5-minute intervals. Rotation of the tube and image intensifier to different positions every several minutes would result in a more even skin dose distribution (see "Discussion").

Ten patients were studied in the third portion of our investigation. This group included seven male and three female subjects, 10 to 86 years old (mean age, 46 years). The procedures performed in these patients included embolization of an arteriovenous malformation (n = 6), embolization of an arteriovenous fistula (n = 1), balloon test occlusion (n = 1), and superselective angiography (n = 2). The three clinically evaluated groups were of similar relative composition, including a majority of patients requiring embolization of adhesive arteriovenous malformations and a mixture of patients being treated by means of simple subselective catheterization, and miscellaneous interventional neuroradiologic procedures, including stentings, coilings, and non–arteriovenous malformation particulate embolotherapy. We thought it would be valuable to assess any clinical attempts at dose reduction in the context of a variety and range of procedures typically performed by an interventional neuroradiologic service rather than to restrict the entry criteria and potentially bias the application of the evaluated dose-reduction techniques. Maximum TLD measurements after additional filtration

and careful machine set-up were determined for each patient.

We used linear regression analysis and correlation coefficients to compare the maximum doses in groups 1, 2, and 3. We chose to evaluate primarily the maximum dose rather than the integral dose, since we thought that any percentage decrease of the maximum dose would be more easily appreciated than a similar percentage decrease of the integral dose. We were also interested in our ability to decrease specifically the demonstrated higher-level threshold doses, such as those causing epilation and erythema. Data from the subjects in all phases of the study were evaluated in terms of the largest dose measured for each procedure.

Results

Table 1 shows the times for fluoroscopy and DSA along with maximum TLD measurements for the 12 patients in the first portion of the study (the control group). Maximum TLD measurements for the 12 control subjects ranged from 0.31 to 2.70 Gy (mean, 1.51 ± 0.88). TLD measurements were highest in the temporal (mean, 1.18 Gy) and the occipital (mean, 1.29 Gy) regions.

For evaluation of the pressed wood phantom filter, surface dose reduction and 8-cm reduction of depth dose were calculated for each of the supplemental filters and compared with the filter normally used in the machine (ie, 3.0 mm aluminum). The filter of 0.5 mm aluminum per 0.076 mm copper produced a reduction of 23% in depth dose and 44% in surface dose. The filter of 0.5 mm aluminum per 0.152 mm copper produced a reduction of 40% in depth dose and 57% in surface dose. The filter of 0.5 mm aluminum per 0.125 mm tantalum produced a reduction of 80% in depth dose and 82% in surface dose. The tantalum-containing filter was found to cause sufficient heat loading of the x-ray tube to interfere with the clinical examination through unacceptable delays in tube cooling. The filter of 0.5 mm aluminum per 0.076 mm copper was found to give the greatest ratio of surface dose reduction to depth dose reduction. This filter did not cause any appreciable subject degradation of phantom image quality for any of the six variables evaluated (see "Materials and Methods") nor was there any appreciable effect on tube heating. The filter of 0.5 mm aluminum per 0.152 mm copper and that of 0.5 mm aluminum per 0.125 mm tantalum, however, caused noticeable and unacceptable changes in the subjective parameters evaluated. This was particularly evident with microguidewire clarity and background noise. The filter of 0.5 mm aluminum per 0.076 mm copper was chosen as the subjectively approved filter that produced maximum reduction in surface dose and minimum reduction in depth dose, thereby also causing minimum alteration in the intracalvarial image.

Table 2 shows the times for fluoroscopy and DSA along with the maximum TLD measure-

TABLE 1: Fluoroscopy and DSA times and maximum thermoluminescent dosimetric measurements for control group

Patient	Fluoroscopy Time, min	DSA Time, mA-min	Radiation Dose, Gy
1	62	255	2.24
2	40	130	1.08
3	10	38.5	0.69
4	27	0	0.44
5	20	159	0.31
6	84	193	2.70
7	15	88	1.18
8	45	80	1.50
9	53	146	2.24
10	26	165	1.81
11	76	139	2.70
12	11	154	1.33
Mean ± SD	39 ± 25	129 ± 69	151 ± 88

Note.—DSA = digital subtraction angiography.

TABLE 2: Fluoroscopy and DSA times and maximum thermoluminescent dosimetric measurements for group with additional filtration

Patient	Fluoroscopy Time, min	DSA Time, mA-min	Radiation Dose, Gy
1	40	205	1.68
2	58	123	1.05
3	36	167	1.65
4	7	39.5	0.27
5	40	162	1.39
6	32	161	0.75
7	15	132	0.41
8	20	233	0.44
9	100	305	1.19
10	41	168	1.13
11	25	127	0.70
12	61	132	0.31
13	1	31.3	0.25
14	39	90.6	0.82
15	26	80.5	0.56
16	59	183	2.42
17	14	187	1.90
18	25	54	0.36
Mean±SD	36 ± 24	143 ± 70	96 ± 64

Note.—DSA = digital subtraction angiography.

TABLE 3: Fluoroscopy and DSA times and maximum thermoluminescent dosimetric measurements for group with additional filtration and control of machine set-up values

Patient	Fluoroscopy Time, min	DSA Time, mA-min	Radiation Dose, Gy
1	74	64.2	0.63
2	10	83.3	0.24
3	26	60.5	0.81
4	19	58.2	0.51
5	31	48.7	0.13
6	40	287	1.23
7	15	87.8	0.32
8	14	119	0.34
9	25	105	0.75
10	58	161	0.84
Mean±SD	31 ± 21	107 ± 72	58 ± 34

Note.—DSA = digital subtraction angiography.

ments for the 18 patients whose treatment included additional filtration. No significant differences could be seen in the fluoroscopy time and DSA time. Maximum TLD measurements for each patient in whom supplemental beam filtration was used ranged from 0.15 to 2.42 Gy (mean, 0.96 ± 0.64 Gy), resulting in an average dose reduction of 35% compared with the control group.

In vitro evaluation of machine factor measurements done before the third portion of the study showed that x-ray output was boosted by approximately a factor of two per setting for each of the two fluoroscopic boost stations. By using a constant kV(p), we caused the current in the tube to be 1.5, 2.8, and 5.5 mA, respectively, simply by changing the x-ray boost factors from nonboosted to first boost and then second boost stations. The measured x-ray dose output was 0.0081, 0.0155, and 0.032 Gy/min, respectively, for the three stations.

DSA dose/differential gain settings also showed an increase by approximately a factor of two per setting for each of four keyboard-controlled console settings, labeled A, B, C, and D. The respective doses per digital subtraction angiogram were 0.001, 0.0025, 0.005, and 0.01 mGy. Qualitative evaluation showed greater than acceptable image noise for differential gain setting A (similar to the image results found with the tantalum filter), but settings B and higher proved acceptable. The first fluoroscopic nonboosted station (small *r*) and the second DSA dose/differential gain setting (B) were chosen for routine examinations.

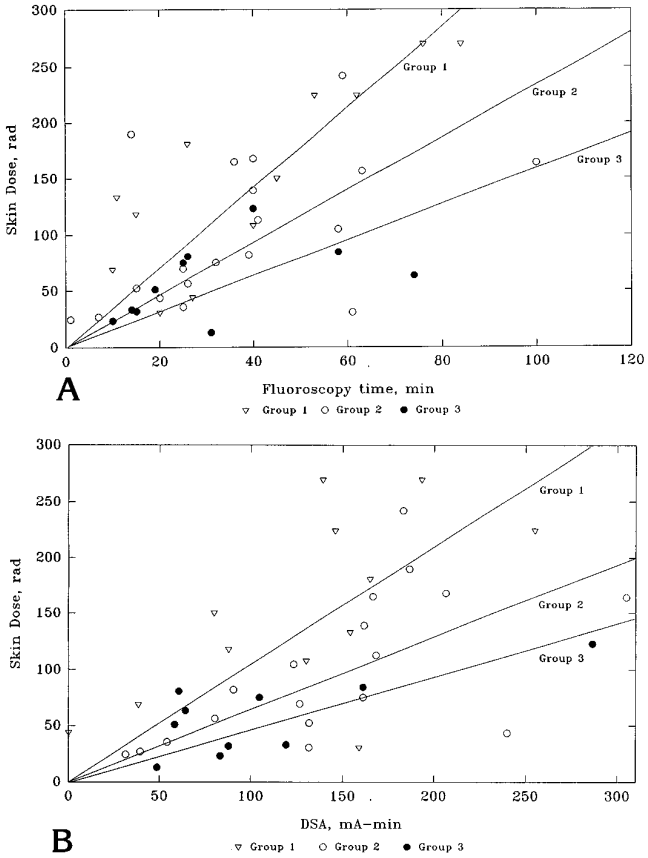

Fig 1. *A* and *B*, The maximum measured skin dose in radians is plotted as in independent function of live fluoroscopy time (*A*) and DSA milliampere-minutes (*B*). *Open triangles* represent data points for group 1 (the control group), *open circles* represent data points for group 2 (the group with supplemental primary beam filtration alone), and *filled circles* represent data points for group 3 (the group with supplemental primary beam filtration in addition to attention to technical factors). Progressive decreases in the slope of the skin dose lines are apparent when comparing group 2 with group 1 and group 3 with group 2.

Table 3 shows times for fluoroscopy and DSA along with the maximum TLD measurements for the group in which additional filtration and alteration of machine set-up values were added to the treatment. Again, no significant differences could be seen in fluoroscopy time and DSA time as compared with groups 1 and 2. Maximum TLD measurements in this group ranged from 0.13 to 1.23 Gy (mean, 0.58 ± 0.34). These steps lowered the average maximum skin dose to 63% of the dose given in the control group.

Figure 1 shows linear regression analysis data for the control group and the two experimental groups. In Figure 1A the maximum skin dose is compared with fluoroscopy time and in

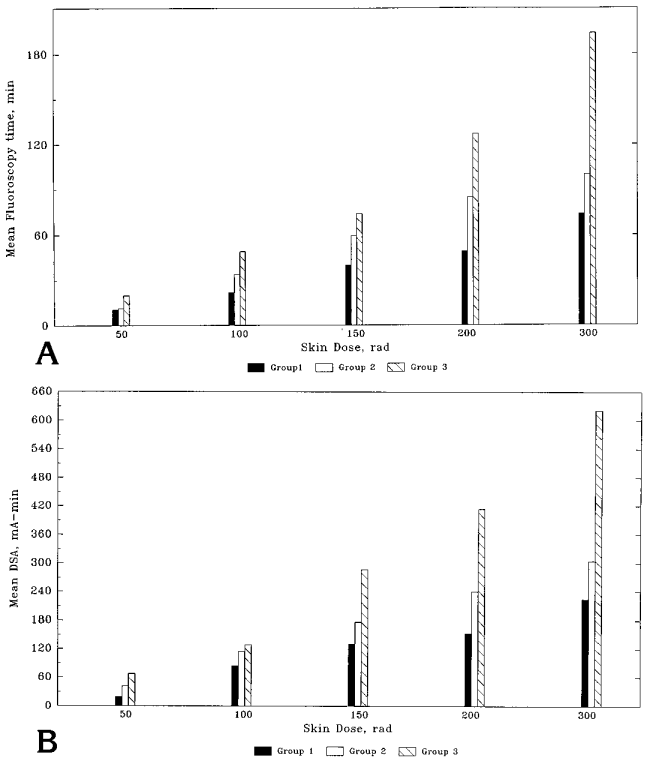

Fig 2. *A* and *B*, Bar graphs show the amount of projected rather than measured exposure time needed in fluoroscopy minutes (*A*) and DSA milliampere-minutes (*B*) based on the linear regression analysis for each of the three study groups to achieve 0.5-, 1.0-, 1.5-, 2.0-, and 3.0-Gy (50, 100, 150, 200, and 300 rad) skin doses. The *solid bar* represents group 1, the *open bar* represents group 2, and the *cross-hatched bar* represents group 3.

Figure 1B the maximum skin dose is compared with DSA milliampere-minutes. Both figures reveal significantly significant reductions in the slope of the three groups independently for fluoroscopy time and DSA time ($P = .0001$). The slope decreases with added filtration (group 2) and decreases even further with filtration plus close attention to technical factors (group 3).

A statistically significant difference was also found among the three groups when comparing mean site dosage ($P = .019$) and the largest dosage site measured ($P = .0068$). The slope differences diverge progressively as the lines are followed to increasing doses and exposure times, showing that potential dose reductions are significantly greater with prolonged fluoroscopy and DSA exposure times than with shorter exposure times.

Figure 2 projects the potential advantages of these dose differences at unachieved high exposure times. The two bar graphs show the amount of exposure time that would be needed with each of the three groups on the basis of projections of available data points for progressively increasing skin doses through an epilation dose of 3.00 Gy. As an example, note that according to Figure 2, over 180 minutes of fluoroscopy time or more than 600 mA-min of DSA would need to be accrued in group 3 to achieve epilation level doses that would be accrued with only 75 minutes of fluoroscopy or 220 mA · min of DSA in group 1.

The equipment used in this study could not record the beam current or peak kilovolt for fluoroscopy, although the DSA image data were specifically recorded and allowed precise tabulation of DSA parameters over the course of each study. The data are displayed as though total skin dose results from fluoroscopy or DSA. Some examinations required an even division between fluoroscopy and DSA in terms of milliampere-minutes. The equipment used for these examinations is unable to determine the specific dose proportions attributable to fluoroscopy or DSA independently, since many dose-related parameters vary throughout a study, such as patient-tube proximity, collimation, and fluoroscopy magnification time periods. To perform a specific analysis of two such variables, continuous measurements of independent parameters, such as patient-tube distance and collimated field size, need to be recorded.

Discussion

Interventional neuroradiologic procedures may cause large doses of radiation to be delivered to the craniofacial region (17). Recent studies have discussed and reported documented and hypothetical effects related to such interventional neuroradiologic procedures (3, 10). However, we are not aware of any study that has documented the actual effects of implementing specific dose-reduction measures. Head and neck radiation has specifically been shown to affect the hair, skin, brain, salivary glands, teeth, eyes, and optic nerves (4–9, 19, 20). Temporary and permanent hair loss has been shown to result from radiation exposure (4, 5). Reported postradiation changes to the skin include temporary and permanent epilation, erythema, desquamation, dermal necrosis, atrophy, and telangiectasia (4–9, 21). Radiation effects have included the development of malignant and benign brain and salivary gland tumors (22, 23). Radiation-induced disorders of

tooth bud growth include agenesis, enamel dysplasia, disordered tooth development, and abnormal root formation (24, 25). Ionizing radiation has also been shown to induce cataract formation (26, 27).

Measurements from our control group (treatments performed without altered filtration or modification of machine factors) showed some skin doses at or near levels sufficient to induce skin effects. Epilation may be seen at a dose of 3 Gy, erythema at 6 Gy, and desquamation at 15 Gy (4–9, 21). Erythema and epilation have previously been reported at respective doses greater than 2 to 3 Gy (1–5, 11, 19, 28). Four patients in our control group had maximum TLD measurements greater than 2 Gy (Table 1). These findings were in part explained by asymmetric skin doses applied to opposite sides of the calvaria. This asymmetry was due to placement of the patient and the tube, and we thought it was correctable. In group 3 we attempted to achieve a partial reduction in skin dose by switching the location of the x-ray tube and image intensifier at fixed 5-minute intervals triggered by the fluoroscopy timer. Rotating the positions of the tube and image intensifier should result in more uniform distribution of the skin dose even though the total skin dose will not be lessened. This technique, in effect, serves to redistribute the radiation dose when possible so that it does not disproportionately affect a given volume of tissue. These potential beneficial effects are more effectively realized with longer procedures, in which a unilateral concentrated dose of greater than 3 Gy would be difficult to avoid, allowing a redistributed dose of approximately 1.5 Gy to each side of the scalp and thereby avoiding the epilation threshold. Each tube rotation takes about 30 seconds to complete and therefore adds approximately 6 minutes of nonfluoroscopy time to each hour of fluoroscopy time per procedure. We did not find this maneuver to be overly time-consuming or inconvenient.

Technique parameters that affect dose and that can be varied by the operator include fluoroscopic settings, use of the fluoroscopy boost option, pulse-progressive fluoroscopy, and DSA dose setting. The specific method used to control fluoroscopic image brightness also may affect dose. As an example, image brightness may be decreased by reducing the amount of radiation dose delivered or, alternatively, by keeping an overly high dose constant and decreasing the video brightness. The former method clearly reduces total dose when compared with the latter method, and the method of gain setting is determined by each manufacturer of fluoroscopic equipment.

Before choosing optimal settings for fluoroscopy dose stations and the DSA dose/differential gain settings, we quantitatively and subjectively evaluated the available settings by using the six subjective categories discussed in the "Materials and Methods." It was found that each step increase for either fluoroscopy or dose/differential settings resulted in approximately double the previous step dose. We found that we could routinely use the lowest fluoroscopy dose station and the second lowest dose/differential gain setting while achieving acceptable imaging for interventional neuroradiologic procedures.

Supplemental machine options can play a significant role in increasing or decreasing radiation dose. Certain machines are available with a boost option. When used, this option permits dose rates as high as 0.5 Gy/min. Avoiding such boosting results in much lower absorbed skin doses. An option that serves to decrease dose is a "last image hold" feature, which permits the last displayed screen image to remain visible for evaluation until fluoroscopic examination is reinitiated. Additionally, pulse-progressive fluoroscopy holds tremendous promise for dose reduction, and this feature used in concert with "last image hold" has been reported to reduce entrance skin exposure by at least a factor of 10 (11).

This study shows that the combination of additional filtration and close attention to machine settings results in a measurable maximum skin dose reduction of 63%. Close attention to other operator-controlled variables will also reduce the overall dose during a procedure. These include careful collimation, rotation of tube position, judicious use of magnification, and minimization of scatter by placing the patient as close to the image intensifier as possible.

Concerns about radiation risk from fluoroscopy have increased the interest of the Food and Drug Administration in amending performance standards on fluoroscopic equipment in an attempt to establish limits on radiation output (29, 30). Both fluoroscopy and DSA contribute to radiation dose in patients undergoing interventional procedures. It is difficult to quantitate precisely the percentage of radiation dose

delivered separately by each of the two methods during the course of an interventional procedure. Multiple confounding variables include fluoroscopic time, magnification, patient positioning, and number of angiograms obtained. We attempted to derive approximate calculations of fluoroscopy and DSA doses per minute by dividing the maximum measured doses by the known fluoroscopic times and DSA milliampere-minutes for each patient (Table 1). This approximate calculation showed approximately doses of 0.016 Gy/min and 0.008 Gy/min for fluoroscopy and DSA, respectively.

Limitations of our study were introduced by its design intentions; namely, to reduce skin dose below the threshold for injury without interfering with the treatment regimens of the representative interventional neuroradiologic procedures. We documented decreases in skin dose using a previously undescribed method of tube rotation, inexpensive supplemental filtration, and attention to machine selection parameters. In this study we could not separate the dose contribution from fluoroscopy from the dose contribution from DSA. However, the primary value of the study lies in the documentation of the net decreases in skin dose attainable with the application of techniques to reduce skin dose in actual interventional procedures. This study also serves as a template for future studies in the analysis of the sources of radiation and dose reduction in interventional radiology. Information regarding accumulated skin dose during each procedure may also help avoid excessive doses from these procedures. For some procedures, skin injury may be an unavoidable side effect when otherwise terminal disorders are treated; however, it is important to recognize when skin dose begins to approach the threshold for injury. In future studies, real-time dose information may be the most effective way to suggest imminent dose-related complications.

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References

1. *Medical Bulletin 24*. Washington, DC: US Food and Drug Administration; 1994:No. 2:6
2. *FDA Public Health Advisory: Avoidance of Serious X-ray-Induced Skin Injuries to Patients during Fluoroscopically Guided Procedures*. Washington, DC: US Food and Drug Administration; September 30, 1994
3. Wagner LK, Eifel PJ, Geise RA. Potential biological effects following high X-ray dose interventional procedures. *J Vasc Intervent Radiol* 1994;5:71–84
4. Potten CS. *Radiation and Skin*. Philadelphia: Taylor and Francis, 1985
5. International Commission on Radiation Protection. *Nonstochastic Effect of Ionizing Radiation. ICRP Publication #41*. New York: Pergamon Press, 1984
6. Hopewell JW. The skin: its structure and response to ionizing radiation. Int J Radiat Biol 1990;57:751–773
7. Chahbazian CM. The skin. In: Moss WT, Cox JD, eds. *Radiation Oncology: Rationale, Technique, Results*. St Louis: Mosby, 1989; 83–111
8. Dutreix J. Human skin: early and late reactions in relation to dose and its time distribution. In: *Radiation Damage to Skin: Fundamental and Practical Aspects. Br J Radiol* 1986(suppl 19):22–28
9. Ellis J. Tolerance of skin in radiotherapy with 200 kV x-rays. *Br J Radiol* 1942;15:348–350
10. Huda W, Peters KR. Radiation-induced temporary epilation after a neuroradiologically guided embolization procedure. *Radiology* 1994;193:642–644
11. Bushong SC. Hazards evaluation of neuroangiographic procedures. *AJNR Am J Neuroradiol* 1994;15:1813–1816
12. Bergeron P, Carrier R, Roy D, Blais N, Raymond T. Radiation doses to patients in neurointerventional procedures. *AJNR Am J Neuroradiol* 1994;15:1809–1812
13. Kuwayama N, Takaku A, Endo S, Nishijima M, Kamei T. Radiation exposure in endovascular surgery of the head and neck. *AJNR Am J Neuroradiol* 1994;15:1801–1808
14. Rudin S, Bednarek DR, Miller JA. Dose reduction during fluoroscopic placement of feeding tubes. *Radiology* 1991;178:647–651
15. Yamaguchi C, Yamamoto T, Terada H, Akisada M. Effect of tungsten absorption edge filter on diagnostic x-ray spectra, image quality, and absorbed dose to the patient. *Phys Med Biol* 1983; 28:223–232
16. Chamberlain CC. The reduction of patient skin dose in interventional radiography (abstr). In: Proceedings of the 39th annual health physics society meeting. San Francisco: Health Physics Society, 1994
17. Geise RA, Moore MJ, Latchaw RE, Ritenour ER, Rufenacht DA. Dose reduction in neurological embolization procedures (abstr). *Radiology* 1992;185(P):330
18. Attix FH, Roesch WC, Tochilin E. *Radiation Dosimetry*. New York: Academic Press, 1966;II:274
19. Jolles B, Harrison RG. Enzymatic process and vascular changes in the skin radiation reaction. *Br J Radiol* 1966;39:12–18
20. Young WC, Thornton AF, Gebarski SS, Cornblath WT. Radiation induced optic neuropathy: correlation of MR imaging and radiation dosimetry. *Radiology* 1992;185:904–907
21. International Commission on Radiological Protection. *The Biological Basis for Dose Limitation in the Skin*. New York: Pergamon Press, 1992;59
22. Preston MS. Prior X-ray therapy for acne related to tumors of the parotid gland. *Arch Dermatol* 1989;125:921–924
23. Modan B, Baidatz D, Mart H, Steinitz R, Levin SG. Radiation induced head and neck tumors. *Lancet* 1974;1:277–279
24. Weyman J. The effect of irradiation in developing teeth. *Oral Surg* 1968;25:623

25. Sonis A, Tarbell N, Valachovic R, Gelber R, Schwenn M, Sallan S. Dentofacial development in long-term survivors of acute lymphoblastic leukemia: a comparison of three threatment modalities. *Cancer* 1990;66:2645–2652
26. Merriam GR Jr, Focht EF. A clinical study of radiation cataracts in relationship to dose. *AJR Am J Roentgenol* 1957;77:759–785
27. Merriam GR Jr, Focht EF. A clinical and experimental study of radiation cataracts in relationship to dose. *AJR Am J Roentgenol* 1957;77:759–785
28. Shope T. Avoidance of serious X-ray-induced skin injuries to patients during fluoroscopically-guided procedures. *American Association of Physicists in Medicine Newsletter* November–December 1994;14
29. *Regulations for the Administration and Enforcement of the Radiation Control Health and Safety Act of 1968.* Washington, DC: US Department of Health, Education, and Welfare. Part 1020, section 32
30. Center for Devices and Radiologic Health. FDA draws attention to concerns about radiation risk from fluoroscopy. *Radiol Health Bull* 1992;26:1–3