Using a Sterile Disposable Protective Surgical Drape for Reduction of Radiation Exposure to Interventionalists

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OBJECTIVE. The purpose of this paper is to show the effectiveness of a new radiation protection method designed to decrease the amount of scatter radiation received by practitioners performing procedures under fluoroscopic guidance.

MATERIALS AND METHODS. A sterile, disposable, lead-free surgical drape containing radiation protection material composed primarily of bismuth was evaluated for effectiveness in reducing radiation doses to health care personnel. Measurements of phantom scatter, patient scatter, skin entrance, and the effects of collimation, together with comparative monthly thermoluminescent dosimeter recordings, were taken to determine the effectiveness of X-ray beam attenuation using the bismuth drapes.

RESULTS. Scatter radiation to physicians, as measured by thermoluminescent dosimeters placed on each eye, the thyroid, and the wrist, was reduced by 12-fold for the eyes, 25-fold for the thyroid, and 29-fold for the hands when the radiation-attenuating surgical drape was used when compared with control studies performed with a standard nonattenuating surgical drape alone. Monthly thermoluminescent dosimeter measurements decreased fourfold in one physician. Using the protective drape reduced exposure to the assistant in each case to negligible levels. Skin entrance dose was not increased unless the protective drape was placed directly in the X-ray beam. An X-ray attenuation factor equivalent to 0.1 mm of lead with 8 × 8 cm collimation reduced the scatter rates from five- to ninefold despite a 30–40% increase in entrance exposure rate as the lead equivalence increased.

CONCLUSION. Depending on the procedure, the height of the practitioner, and the positioning of the radiation-attenuating surgical drape, use of this drape can substantially reduce the radiation dose to personnel with minimal or no additional radiation exposure to the patient.

The harmful effects of ionizing radiation were recognized shortly after the discovery of the X ray by Wilhelm Conrad Roentgen in 1895 [1–5]. These harmful effects were particularly evident in the hands of individuals exposed repeatedly to the X-ray beam for prolonged periods of time. Erythema, dermatitis, and skin cancer were found to result from this exposure, and it was initially thought that avoiding the primary beam was sufficient protection [2, 6–9]. However, in the 1920s concerns regarding the adverse effects of radiation were again raised with the identification of an increased rate of leukemia in radiologists [1]. This recognition led to the creation of organizations such as the International Commission on Radiological Protection (1928) and the National Committee on Radiation Protection and Measurements (1929, later the National "Council"), which became important in making recommendations on radiation protection. The first recommendations for tolerance doses for radiation workers came from the National Council on Radiation Protection and the International Commission on Radiological Protection in 1934. The recommendations of both those organizations for tolerance doses for radiation workers have decreased by a factor of 5–10 since 1934. This decrease is the result of increased knowledge of the risks from radiation exposure, an increased desire among workers to avoid the harmful side effects of radiation, and improvements in technology [1, 3–5, 8–13].

Although the recommended limit for radiation workers has not changed greatly since about 1958, the philosophy toward radiation protection and limits has changed dramatically. The limit is now regarded as an upper limit of acceptability. The principle of ALARA (as low as reasonably achievable) is

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used to ensure that most exposures will be well below the accepted limit. Experience with the ALARA principle and the limit of 5 rem (50 mSv) per year has allowed the average exposure of workers in the United States—with the exception of interventional radiologists and cardiologists—to decline steadily to about 5% of the limit. The increased use of fluoroscopy by anesthesiologists for pain therapy and during radiation therapy procedures has further expanded the risk to health care providers.

Although the acute effects of radiation are not commonly a problem, the stochastic effects of radiation remain a concern. The probability of the occurrence of stochastic effects is directly related to the radiation dose, but the severity of these conditions is not related to the total dose received. Stochastic effects include carcinogenesis and genetic mutation; they are of particular concern because there is no threshold dose below which the radiation-induced effects will not occur. The nonstochastic effects, such as radiation-induced cataracts, do have a threshold dose, and above this threshold the severity is directly related to the dose. Stochastic events are considered to occur at all doses, but the less the frequency, the lower the dose—thus, the principle of ALARA [1, 4, 5, 8–10].

This article focuses on the use of a new radiation protection device intended to reduce both the unit dose and the overall level of radiation experienced by radiation workers during interventional radiology procedures.

Materials and Methods

This study was conducted in three phases. In the first phase, shields of varying lead equivalency were tested for effectiveness in attenuating scatter radiation from a standard X-ray phantom. The second phase involved testing of a commercially available protective drape (RADPAD; Worldwide Innovations & Technologies, Overland Park, KS) during a series of patient studies with institutional research board approval and informed consent (Fig. 1). The third phase was the routine use of this protective drape, in addition to improved collimation techniques, during interventional procedures by a radiologist who had regularly exceeded recommended radiation exposure levels.

Phase 1

A series of measurements of shielding samples were evaluated for scatter during routine fluoroscopy with a typical angiographic C-arm equipped with a 38.10-cm (15-inch) image intensifier with and without tight collimation (Philips Medical Systems, Best, The Netherlands). The secondary (scatter) radiation exposure rates were measured using an anthropomorphic chest phantom (Nuclear Associates, Carle Place, NY). The scatter rates at 30 cm from the sternum, together with the automatic brightness system fluoroscopic entrance exposure rates, were recorded with and without 8 × 8 cm collimation. In all recordings, the image intensifier was positioned as closely as possible to the chest with a source-to-image distance of 100 cm. The scatter rates were measured with an MDH Model 1015 X-ray monitor using a 180-mL ion chamber (Radcal, Monrovia, CA).

Phase 2

Twelve patient studies were performed using extensive placement of thermoluminescent dosimeters (TLDs). Eight patient studies served as control studies that were performed with the use of a standard nonattenuating surgical drape; and the studies of four patients used the radiation-attenuating drape. The drape was placed on the patient with the window of the drape over the skin puncture site (Fig. 2). All patient studies were performed on the same radiographic equipment (Picker, Cleveland, OH), and all procedures were percutaneous nephrostomy placements performed from the right side of the patient. The monitor was positioned for viewing in the same location for all examinations. Two radiologists participated in each study, with interpretations obtained from nine physicians. Several physicians participated in more than one patient evaluation. All physicians used their own type of standard radiation protection. The 12 patient studies included TLDs placed on the patient and the operators. A TLD was placed on the skin at the level of the entrance dose of each of the 12 patients, and on the thyroid, left eye, right eye, and left wrist of both the primary and the assisting physicians performing the procedure. The TLDs were positioned outside any radiation-protective covering such as lead aprons, thyroid shields, or leaded glasses. The TLDs were taped to the skin immediately lateral to the eye for the eye recordings. Eight control studies were conducted without the protective drape, and four studies were completed under similar conditions using the protective drape, for a total of 108 TLD recordings on the nine participating physicians and the 12 patients.

Phase 3

A single radiologist with consistently excessive TLD measurements was asked to use the protective drapes routinely. In addition, this physician attempted to carefully perform collimation during all procedures. TLD measurements were recorded for 3 months: the first 2 months without the use of the

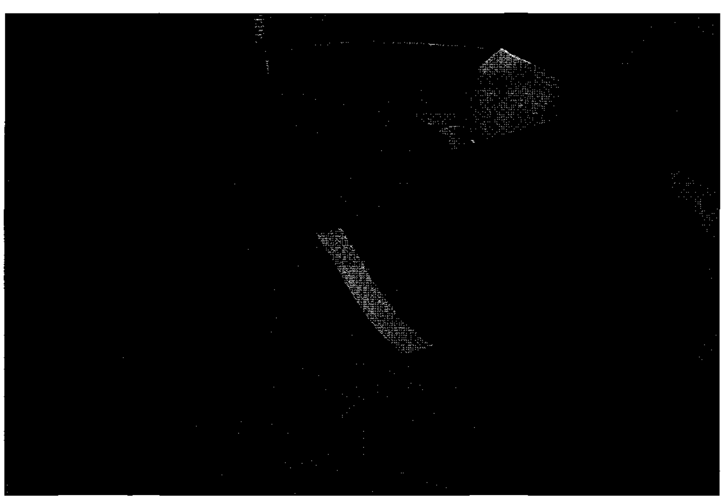

Fig. 1.—Sterile protective surgical drape (32 × 44.5 cm) viewed from back or side placed toward patient (see Fig. 2 for front view). Single arrow indicates 4.5 × 9.5 cm opening for needle and catheter placement. Double arrows show location of adhesive tape to aid in maintaining drape position. Arrowheads outline 11-cm channel designed to be cut if necessary for ease of manipulation around needles and catheters. This channel has been cut in Figure 2.

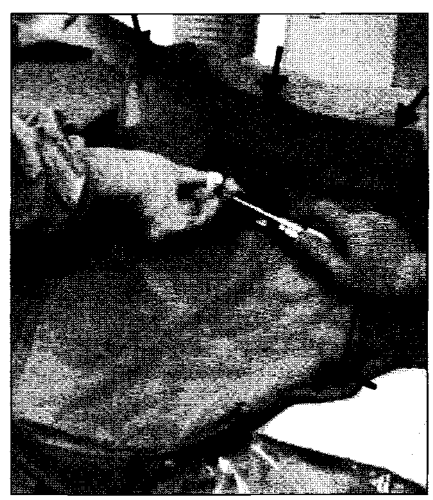

Fig. 2.—Interventional procedure with setup as used in this study. Sterile, disposable, lead-free radiation-protective surgical drape (*arrows*) is placed between operator and primary beam. Operator stands in "shadow" produced by protective drape.

protective drape, and the last month with the protective drape used in most (but not all) procedures.

Results

Phase I

The scatter rates at 30 cm from the sternum, together with the automatic brightness system fluoroscopic entrance exposure rates, are tabulated in Table 1 for various bismuth drape lead equivalencies with no collimation. These same results when 8 × 8 cm collimation is used are also given in Table 1. Note the scatter rates are reduced by five- to ninefold despite a 30–40% increase in entrance exposure as the lead equivalency increases. Also, the scatter (as expected) can be substantially reduced through the use of increased collimation (see Table 1).

Phase 2

Patient studies were performed using a drape of uniform thickness and bismuth content. Scatter radiation to the physicians as measured by the TLDs placed on the thyroid, each eye, and the wrist was reduced by a factor of 12 for the eyes, 25.8 for the thyroid, and 29.4 for the hands. As evidenced by the skin entrance doses to the patients, both the control procedures and the drape-protected procedures were of a broad range of complexity (Table 2). Because TLDs were positioned on the skin surface lateral to each eye, the recordings for the right and left eyes are strikingly different, showing the effect of the skull on scatter X-ray attenuation (Table 3). Note that with the exception of a single left wrist recording during an extended fluoroscopic procedure, measurements for the assistant in each procedure performed with the radiation-attenuating surgical drape were negligible. Presumably, in this case, the assistant was asked to hold or position a device close to the primary beam (Table 2, radiologist 2, left wrist).

Phase 3

A single interventional radiologist who had exceptionally high TLD measurements was given the opportunity to use the protective drapes routinely. In addition, this physician attempted to improve the use of collimation and to keep exposure times to a minimum. This individual's TLD measurements decreased fourfold from the previous 2 months. These results are summarized in Table 4.

Discussion

Radiation protection for radiologists and radiology personnel is an accepted standard of practice in all medical facilities [14–19]. As a result, the occupational radiation dose for most medical workers has declined steadily during the last three or four decades [1, 4, 5, 9, 10]. However, there are exceptions to this decline. Areas of concern include interventional radiol-

TABLE 1 Fluoroscopy Scatter Rate, Skin Entrance Dose, and Percentage of Reduction as a Function of Shielding Lead Equivalency and Collimation

Lead Equivalency (mm at 70 kVp)	Entrance Exposure Rate (μC/[kg · min])	Scatter Rate (μC/[kg · min]) at 30 cm	% Reduction
Without collimation			
0	452	40.5	
0.004	459	34.8	14
0.10	542	15.5	62
0.24	604	6.2	85
0.33	617	5.4	87
0.41	630	4.9	88
0.98	784	2.6	94
With 8 × 8 cm collimation			
0	400	15.0	
0.004	410	12.9	14
0.10	488	4.6	69
0.24	516	3.1	79
0.33	537	3.4	78
0.41	526	3.1	79
0.98	601	2.1	86

TABLE 2 Skin Entrance Dose Measurements (in mGy) from Thermoluminescent Dosimeters

Patient Skin Entrance Dose	Drape	Radiologist 1				Radiologist 2			
		Thyroid (%)	Left Eye (%)	Right Eye (%)	Left Wrist (%)	Thyroid (%)	Left Eye (%)	Right Eye (%)	Left Wrist (%)
408.70	No	0.57 (0.14)	0.68 (0.17)	—	0.99 (0.24)	0.78 (0.19)	0.70 (0.17)	0.51 (0.12)	2.67 (0.65)
54.05	No	0	0	0	0.05 (0.09)	0.03 (0.05)	0	0	0
11.00	No	0.03 (0.27)	0.02 (0.18)	0.02 (0.18)	0.17 (1.5)	0.10 (0.91)	0	0	0
76.63	No	0.46 (0.60)	0.36 (0.47)	0.07 (0.09)	1.39 (1.8)	0.05 (0.07)	0.09 (0.12)	0.02 (0.03)	0.06 (0.08)
—	No	0.31	0.37	0.17	0.41	0.04	0.04	0.02	0.09
—	No	0.06	0.05	0.15	0.06	0.09	0.08	0.11	0.09
—	No	—	0.64	0.65	0.64	—	—	—	—
126.13	No	0.35 (0.28)	0	0.02 (0.02)	2.65 (2.1)	0.42 (0.33)	0.29 (0.23)	0.02 (0.02)	0.40 (0.32)
15.70	Yes	0	0	0	0	0	0	0	0
215.00	Yes	0.04 (0.02)	0	0	0.02 (0.01)	0	0	0	0
388.50	Yes	0.09 (0.02)	0.06 (0.02)	0.03 (0.01)	0.18 (0.05)	0	0	0	0.26 (0.07)
542.70	Yes	0.25 (0.05)	0.28 (0.05)	0.19 (0.03)	0.26 (0.05)	0	0	0	0

Note.—% = percentage of entrance dose. Dash (—) indicates failure or loss of thermoluminescent dosimeter recording.

TABLE 3 Average Thermoluminescent Dosimeter Measurements Expressed as Percentage of Skin Entrance Dose Without and With Protective Drape

Study	Thyroid	Left Eye	Right Eye	Left Wrist
Without drape	0.284%	0.134%	0.046%	0.678%
With drape	0.011%	0.009%	0.005%	0.023%
Dose reduction factor	25.8	14.9	9.2	29.4

TABLE 4 Thermoluminescent Dosimeter Measurements (in mGy) Without and With Protective Drape

Month	Protective Drape	Deep[a]	Shallow[b]
1	No	19.68	19.51
2	No	19.07	18.48
3	Yes[c]	4.83	4.82

[a] Penetrating ionizing radiation at a depth of 1 cm.

[b] Nonpenetrating skin dose.

[c] In addition, an attempt was made to improve collimation and reduce exposure times.

ogy, cardiac catheterizations, and C-arm fluoroscopic procedures [10–16]. Personnel in each of these areas receive radiation exposures that approach or even exceed the recommended dose limits [10, 20–24]. As many as 50% of these personnel have been found to rarely or never wear their assigned dosimeters. Reasons for this lack of compliance probably include skepticism about the risk as estimated by the dosimeter, fear of being asked to limit fluoroscopy time, and the excessive administrative requirements of investigating high TLD measurements even if they are within the recommended guidelines [12, 13]. Interventional radiologists continue to be exposed to radiation that will produce substantial side effects such as radiation-induced cataracts and radiation dermatitis [2, 3]. Routine angiography procedures, particularly cerebral angiography, result in relatively low levels of radiation exposure unless advanced interventional procedures are required [12, 20, 22, 24, 25]. However, abdominal angiography may result in substantially greater doses, especially to the hand, for which the dose may be nearly 10 times as great as for cerebral angiography. The hand dose during cardiac catheterization may be as much as 20–50 times the dose in cerebral procedures with similar procedure times. Similar differences are also seen for exposure to the eyes and the thyroid gland. When the procedures are complex, the doses may be as much as 50% greater than has typically been reported [12, 20, 22, 24].

As interventional radiology procedures increase in complexity, the length of these procedures often increases proportionately, and the physicians and staff are required to be near the patient and the X-ray tube for prolonged periods of fluoroscopic time. It is increasingly common for the fluoroscopy beam to be on for as long as 60 min or more for a given case, and dose rates may be as much as 5 R (1290 μC/kg) per minute. Workers in this environment are increasingly exposed to greater levels of radiation, and the trend is toward more rather than less radiation risk [2, 8, 10–28].

A number of methods have been devised to decrease the radiation dose to medical workers, including radiation-protective aprons, thyroid shields, leaded glasses, and several types of ceiling- or floor-mounted shields [2, 6, 7, 14–19, 25–28]. In addition, radiation-attenuating surgical gloves have been advocated because hand doses are generally greater than doses to other parts of the body [2, 6, 7, 25, 28] (Tables 2 and 3). The combination of forward-scattered X rays, backscattered X rays, and secondary electrons released from the glove material reduces the effectiveness of these radiation-attenuating surgical gloves [7]. Some publications caution that radiation-attenuating gloves should not be relied on as a primary means of radiation protection, and that the first line of defense is to keep the examiner's hands out of the primary beam [2, 6]. Our study supports this point by showing that limiting exposure to the primary beam and decreasing the amount of scatter will markedly decrease the radiation dose not only to the hands (as much as 30-fold) but also to the thyroid (25-fold) and the eyes (12-fold). The radiation exposure to support staff or an assistant may be negligible, even for prolonged and complicated procedures, when the method reported here is used. Given the demand for complex procedures that involve prolonged radiation exposure, reducing the dose to physicians and staff is increasingly important.

The concept of using a radiation protection shield placed on the patient to attenuate the scatter radiation that may reach an operator is not new. Results similar to those presented here have been shown for similar shields produced from lead [15–19]. However, because of the need for universal precautions and the toxic nature of lead, the use of nondisposable lead devices has not proven practical [29–35]. The use of materials other than lead for radiation shielding has also been thoroughly investigated. The device investigated here is a lead-free, disposable, radiation-protective, and sterile surgical drape that not only allows a sterile surgical barrier but also provides substantial radiation protection to the primary operator (Tables 2–4). Because it is lead-free, the device does not raise additional environmental concerns and can be disposed of in the same way as any surgical drape [29–32]. The results of our study are equally important for support personnel and assistants, who may receive negligible amounts of radiation even during long and complex fluoroscopic procedures when this radiation-protective surgical drape is used (Table 2).

At the time of this writing, the price is approximately $34 per drape, which adds relatively little to the cost of the procedure. Opening the package and positioning the drape on the patient usually takes less than 1 min. Because the drape is radiopaque, it may need to be repositioned from time to time during complex procedures, or it may be removed completely and later replaced if necessary. Because the drape material is flexible, these adjustments can usually be done in a few seconds. However, if the largest area of the drape is initially placed on the side of the patient nearest the operator, the need for repositioning is usually minimal. We believe that the large reduction in radiation dose to the operator is well worth the small amount of time and the relatively little added cost required to use the drape.

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