Review

Skin Injuries from Fluoroscopically Guided Procedures: Part 2, Review of 73 Cases and Recommendations for Minimizing Dose Delivered to Patient

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The benefits of fluoroscopically guided interventional procedures are reflected in the increasing number of interventions that are performed each year. In 1996, more than 700,000 interventional procedures were performed in the United States [1, 2]. However, these procedures can deliver a high radiation dose to a patient's skin. Unfortunately, some patients have been injured by the radiation [3–28]. In this report we review 73 cases of radiation-induced skin injury directly related to interventional work [3–28]. Most cases (67) were reported within the last 5 years (1996–2000). Seven cases originate from Wolff D (1999, personal communication), and nine cases originate from our own observations [21, 25] (Table 1). More are known; however, data are presently unavailable because of legal proceedings. Twenty of 26 cases reported to the United States Food and Drug Administration between 1992 and 1995 [6] were not included in our review because no details about procedures and skin damage were mentioned. In part 1 of this two-part series [29], we reviewed the biology and progression of skin injuries with examples from our database of 73 patients. In this report, we examine the same 73 patients for common features that may explain the causes of these injuries and identify ways to reduce the radiation dose to the skin.

Case Reports

The site of the skin injury depends on the type of procedure and corresponds in all cases to the beam entrance site. The site of injury is on the back when the tube is in a posteroanterior projection (e.g., transjugular intrahepatic portosystemic shunt (TIPS) placements or some coronary procedures), over the scapula when the beam is oriented in a left or right anterior oblique plane (e.g., coronary interventions), or in the axilla when the tube is positioned laterally (e.g., radiofrequency ablation and some coronary interventions).

Radiation Skin Dose Monitoring

Real-time measurement of the absorbed skin dose was not performed in any of the patients. A retrospective dose estimate was made in 21 patients, using available data on fluoroscopy time, cineradiography, and so forth. The dose was frequently calculated as the total dose that accumulated over several procedures separated by various intervals. The dose for a single procedure (eight patients) ranged from 8 to 58 Gy. Although the accuracy of some estimates can be questioned, the results show that dangerous radiation levels are possible.

Equipment Malfunction and Deficiencies

Rosenthal et al. [18] report a woman who underwent radiofrequency catheter ablation that required 65 min of fluoroscopy. The machine failed in its pulsed mode, which resulted in a continuous output at a high tube current. The subsequent skin dose was estimated as between 15 and 26 Gy. At 3 weeks the patient developed pruritus and her skin blistered and necrosed. It subsequently healed slowly over the next 4–5 months.

In 1976, Iyer [3] published a report of two cases of severe radiation injury. One was related to a single coronary angiogram with an estimated skin dose of 22 Gy. The second case involved placement of a cardiac pacemaker and resulted in an estimated dose of 58 Gy. Severe equipment deficiencies were cited as the causes of these high doses.

Breast Lesions

Two female patients developed skin lesions at the lateral aspect of the right breast. One was a 17-year-old girl who underwent two radiofrequency ablation procedures [20] (Fig. 1). The other was a 52-year-old woman who had several coronary procedures [11]. The patients developed early and late skin changes including early erythema, moist desquamation, and ulceration. Female breast tissue, especially in young patients, is among the most radiosensitive for induced cancer. Between 1920 and 1955, radiation-induced breast cancer was a known late complication resulting from direct

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exposure of the breast during the treatment of pulmonary tuberculosis using fluoroscopically guided, artificially induced pneumothoraces [30]. In the two injuries that we reviewed, the location shows that the entrance beam was directed onto the right breast in a lateral or a shallow oblique direction. Dose to the breast tissue is likely to be quite high under these circumstances and will increase the risk of breast cancer.

Coronary Angiography and Intervention—47 Patients

The high proportion of coronary procedures (47 cases) in our database reflects the high number of annually performed cardiologic interventions compared with other procedures [1] (≈700,000 coronary procedures vs. ≈30,000 other procedures). Three patients underwent only diagnostic coronary angiography. The remaining 44 had additional percutaneous transluminal angioplasty, 11 had stent placements, and two had mechanical thrombolysis. Some patients had several procedures performed on separate days. Thirty-six patients showed signs of early skin reactions that include an erythematous reaction, dry and moist skin desquamation, and ulceration. Even more reports mentioned late skin changes, including chronic ulcers. Twelve patients required a skin graft (Table 2).

The mean age of injured patients undergoing coronary procedures was 60.1 years, and 89% were men. Radiation use in two large series of patients—1503 and 992 patients—who underwent coronary angiography and interventions was studied by Pattee et al. [31] and Cusma et al. [32], respectively (Table 2). The mean ages in their groups were 56.0 and 64.6 years, with a male distribution of 77.5% and 64.3%, respectively. The male predominance reflects the sex distribution of coronary artery disease. The reason for the higher number of male patients in our group is unknown; there is no known male predilection for radiation injuries [33]. Potential explanations include a larger body habitus or more advanced disease in men.

Pattee et al. [31] and Cusma et al. [32] found mean fluoroscopic times of 5.4 and 4.5 min, respectively (Table 2), and mean cine times of approximately 1 min for diagnostic coronary angiographic procedures. The fluoroscopy time for angioplasty is much longer and reportedly averages about 20 min. We found significantly longer fluoroscopic times in injured patients, up to 172 min for a single procedure. The average time was about 1 hr (12 patients). These procedures sometimes involved more than one lesion. One patient had a single angiogram that lasted 34 min. All patients had late skin damage. For the case requiring the longest time (172 min), two stenotic areas of the same artery were treated by atherectomy, percutaneous transluminal coronary angioplasty, and stent placement. The number of cine frames in this patient is unknown but is thought to be between 4000 and 6000. After a prolonged erythema, a nonhealing skin ulceration developed in the region of the right scapula, possibly as a result of biopsy. The lesion required skin grafting (Fig. 2; and Table 1, patient 8). Long fluoroscopic times were also noted by Shope [6] (>120 min) and Poletti [9] (101 min)

TABLE 1 Fourteen Patients with Radiation-Induced Skin Injuries

Patient No.	Sex, Age	Procedure	Location of Skin Lesion	Time[a] (min)	Vessel Treated
1	Male, 54	Angiography, PTCA	Right scapula	57	CFX
2	Male, 56	Angiography, PTCA	Below right axilla	58	RCA
3	Male, 63	Angiography	Left scapula	34	RCA
4	Male, 65	Angiography, PTCA, stent	Right scapula	69	LAD
5	Female, 75	2 Angiographies, 1 PTCA	Below right axilla	42	RCA
6	Male, 64	2 Angiographies, 2 PTCAs	Left scapula	63	RCA, LAD
7	Male, 83	Angiography, 2 PTCAs	Right scapula	40	LAD, OM
8	Male, 57	Angiography, 2 PTCAs, atherectomy, stents	Right scapula	172	CFX
		Angiography, PTCA, atherectomy, stent	Right mid back	73	LAD
9	Male, 69	Angiography, 2 PTCAs	Mid back	100	LAD, RCA
10	Male, 67	Angiography, stent	Left scapula	Unknown	LAD
11	Male, 62	Angiography, stents	Mid back	50.4	LAD, ostium in LCA
12	Male, 53	3 Angiographies, stents	Right mid back	63	RCA
13	Male, 48	2 Angiographies, 1 PTCA	Mid back	19	RCA
14	Male, 49	2 TIPS + 1 TIPS attempt	Mid back	(13–16 hr)[b]	

Note.—PTCA = percutaneous transluminal coronary angioplasty, CFX = circumflex artery, RCA = right coronary artery, LAD = left anterior descending artery, OM = obtuse marginal branch, LCA = left coronary artery, TIPS = transjugular intrahepatic portosystemic shunt.

[a] Total fluoroscopy time.

[b] Total procedure time.

Fig. 1.—17-year-old girl with history of cardiac arrhythmia who underwent two cardiac ablation procedures within 13 months. Photograph taken 2 years after last intervention shows atrophic indurated plaque at right lateral chest wall involving posterolateral aspect of right breast. Induration resulted in limited movement of her right arm. Long-term risk of breast cancer is increased. (Reprinted with permission from [20])

in patients who had skin damage after several procedures on the same day.

Reasons for the prolonged interventions included three-vessel disease [16], dissection during coronary balloon dilatation [11, 13] (Table 1, patient 4), cardiac event [17], and a tortuous iliac artery and anomalous origin of the right coronary artery [14].

The absorbed dose rate to the skin for conventional fluoroscopy is typically 0.02–0.05 Gy/min. Cineradiography involves a dose rate that is roughly 10 times greater per imaging frame. For 30 frames per second, the typical rate is about 0.3–0.6 Gy/min [21]. However, quoting such data is hazardous because wide variations in these values occur, depending on patient size, imaging geometry (including angulation), frame rate, peak kilovoltage, and other factors. These variations are a major source of uncertainty in any retrospective dose assessment. Using a chest phantom, Cusma et al. [32] showed that the dose increases by 50% when the mean anteroposterior chest diameter is increased from 23 to 28 cm. Coronary angiography uses various projections, usually right or left anterior oblique, with different degrees of craniocaudal angulation to visualize the entire coronary system. Increasing angulation increases the length of the X-ray path through tissue and puts the skin closer to the X-ray source. Angulation of the beam from 40° left anterior oblique to 40° left anterior oblique with 30° of cranial angulation multiplies the dose rate by a factor of 4 [32]. The actual increase depends on how the equipment maintains image brightness and will vary for different fluoroscopes. About 83% of injuries occurred with the beam in a steeply angled orientation (Table 3 and Fig. 2).

Pattee et al. [31] and Cusma et al [32] estimated the mean skin dose from a percutaneous transluminal coronary angioplasty at 1.24 and 3.7 Gy, respectively (Table 2). Neither estimate is corrected for changes in irradiated skin site caused by different beam angles during the procedure, and both may overestimate the real dose. A recent study by Hwang et al. [34] determined a mean skin dose of 1.02 Gy for a percutaneous transluminal coronary angioplasty (Table 2). The dose was measured with a skin dosimeter, the position of which could be verified on the fluoroscopic image. The radiation dose for a single stent placement ranged between 1.53 [34] and 3.76 Gy [32]. In our review of injured patients, skin dose was retrospectively estimated in 11 of the 47 patients. The cumulative dose ranged from 10.0 to 38.4 Gy in these patients (Table 2), 10 of whom had two or more procedures. Four of these patients required a skin graft. The estimated doses in these patients are much higher than the mean doses reported for average procedures.

TABLE 2 Radiation Injuries Related to Coronary Angiography and Intervention

Injury Characteristic	Koenig et al. [29]	Pattee et al. [31]	Cusma et al. [32]	Hwang et al. [34]
No. of cases	47	1503	992	200
Early skin reaction	36			
Late skin reaction	42[a]			
Chronic ulceration	25			
Skin graft	12			
Mean age	60.1 yr	56 yr	64.6 yr	
Male	89%	77.5%	64.3%	
Fluoroscopy time[b]				
Angiography (*n* = 1)	34 min	5.4 min[c]	4.5 min[c]	
Angioplasty (*n* = 12)	19–172 min	19 min[c]	21 min[c]	
Cumulative skin dose[d]	10.0–38.4 Gy			
Mean skin dose				
Angiography			1.35 Gy[e]	0.18 Gy[f]
Angioplasty		1.24 Gy[g]	3.71 Gy[e]	1.02 Gy[f]
Stent, one			3.76 Gy[e]	1.53 Gy[f]
Stents, multiple, with atherectomy				2.5 Gy[f]
Repeated procedures				
>1 Angioplasty in 3 yr	66%	21%		
>2 Angioplasties in 3 yr	14%	4%		
>1 Procedure in 6 wk	34%			
>1 Procedure in 1 wk	22%			

[a]Data on late skin reaction are not available in five additional patients (e.g., no follow-up, patient deceased).

[b]For a single procedure.

[c]Mean fluoroscopic time.

[d]Estimated in 11 patients.

[e]Estimated using PEMNET system (Clinical Microsystems, Arlington, VA). Total dose does not account for changes in beam orientation.

[f]Direct measurement of skin dose using scintillation dose monitors (McMahon Medical, San Diego, CA).

[g]Estimated from fluoroscopic time and cineradiographic film length on basis of assumed dose rates. Total dose does not account for changes in beam orientation.

TABLE 3 Location of Skin Lesions in Coronary Procedures

Lesion Location	No.	Beam Orientation	Vessel Treated
Mid back	8	Posteroanterior	MLCA, LAD, RCA
Right scapular or subscapular	16	45–60° LAO (±30° cranial angulation)	LAD, CFX, RCA
Right lateral region below axilla	9	Transverse	LAD, RCA
Left scapular or subscapular	12	30–45° RAO (± 20–30° cranial angulation)	LAD, RCA, CFX
Right anterolateral chest	3	120° LAO	LAD

Note.—MLCA = main left coronary artery, LAD = left anterior descending artery, RCA = right coronary artery, LAO = left anterior oblique, CFX = circumflex artery, RAO = right anterior oblique.

Cardiac Radiofrequency Catheter Ablation—12 Patients

Approximately 22,000 cardiac radiofrequency catheter ablation procedures were performed in 1996 for the treatment of supraventricular and selected ventricular tachyarrhythmia [1]. The high success rate and low incidence of significant complications has made this a widely used and safe procedure [18, 35]. Fluoroscopy is used to localize the position of the intracardiac catheter.

Twelve cases of radiation-induced skin injury after radiofrequency ablation were reviewed. Patients' ages ranged between 7 and 50

A B

Fig. 2.—57-year-old man with coronary artery disease involving left circumflex artery who underwent several percutaneous transluminal coronary angioplasties with stent placements and rotational atherectomy that used 172 min of fluoroscopy. Five months later, similar procedure was performed for left anterior descending artery, involving 73 min of fluoroscopy and more than 2000 frames of cine. Both procedures were performed in steep beam angulation (Table 1, patient 8).
A, Photograph 1 year after last procedure shows ulcer formation below right scapula (possibly a result of biopsy). Lower lesion (erythema) seen at right mid back resulted from second intervention. At time of second intervention, cause of first erythematous lesion was not recognized.
B, Photograph taken 2 years after last procedure. Lesion was very painful throughout its course and required skin grafting.

years; three were younger than 18 years (7, 12, and 17 years). Only one patient needed a second procedure after an interval of 11 months.

Fluoroscopic times varied between 45 and 190 min, the latter resulting from a technically difficult case [19]. These times are at the longer end of the range of 46.5 ± 31 min found by Park et al. [35] in a series of 500 patients undergoing cardiac ablation procedures.

Early skin changes included erythema, blister formation, skin desquamation, and acute ulceration. Late changes consisted of hypo- and hyperpigmentation, telangiectasia, skin induration, recurrent erosions, severe ulceration, and scarring. The affected skin areas were on the back or the right arm. Radiation doses were estimated in three patients to range from 11 to 20 Gy, which is more than 10 times the mean radiation exposure of 0.93 ± 0.62 Gy in the series of Park et al. [35]. Reasons for the high doses and long fluoroscopy times were a difficult procedure [19, 20], unfavorable positioning of the patient's arm [20, 21], and faulty equipment [18].

Wagner and Archer [21] describe a severe radiation injury to a patient's arm. The dose delivered to the arm was probably more than 25 Gy during only 20–25 min of fluoroscopy to that specific skin area. The arm was positioned in the primary X-ray beam close to the X-ray port. The patient subsequently developed deep skin ulceration above the elbow joint [21, 29]. The humerus was exposed after about 5 months. Vañó et al. [20] described a similar, but less severe, injury to the arm of a 7-year-old girl from similar circumstances.

TIPS Placement—Seven Patients

We reviewed seven cases of radiation skin injury after TIPS placement. The patients were all men between 42 and 61 years old. Because of incomplete or unsuccessful initial attempts, four patients had two or more procedures. Procedure times were given in five patients and varied between 4 hr 20 min and 6 hr 30 min for a single procedure. Two patients who underwent three TIPS procedures had total procedure times between 12 hr 15 min and 16 hr.

Total fluoroscopic times are uncertain. Saxon and Lakin [36] mention that an uncomplicated procedure usually can be completed in approximately 90 min of procedure time, which suggests that the procedures resulting in injury were difficult and prolonged, requiring more fluoroscopy than usual.

Patients had skin reactions ranging from acute erythema with discoloration immediately after hospital discharge to skin ulceration after several months. Four patients needed a skin graft. Three patients needed repeated skin grafts [24, 25] (Table 1, patient 12). Deep tissue ulceration was present for more than 4 years in one patient with a suspected hypersensitivity to radiation [25] and for about 1 year or longer in three others (Table 1, patients 8, 9, and 12). The lesions were located in the mid back or in right subscapular location, which corresponds to the use of the posteroanterior projection.

Neuroradiologic Embolization—Three Patients

Three cases of skin damage in patients ranging between 32 and 38 years old have been reported after embolization procedures for arteriovenous malformations. The arteriovenous malformations were located in the paraorbital [26] and cerebral [28] areas and at the level of the lumbar vertebrae L3–L4 [27].

The interventions to treat the paraorbital and cerebral arteriovenous malformations resulted in temporary epilation of scalp hair in the occipital and temporal regions. The hair regrew after 2–3 months. Skin dose in one case was estimated to be 6.6 Gy [26]. The dose to the patient with the embolization of the lumbar arteriovenous malformation was about 25 Gy over the course of 4 months. The epidermis sloughed about 4 weeks after the last procedure. The wound healed with conservative treatment during the following weeks, but a residual dyspigmented scar remained [27].

Norbash et al. [37] reported that in a series of 87 patients who underwent interventional neuroradiologic procedures, nine (10%) experienced temporary or long-term epilation. Epilation after neuroradiologic procedures is probably not an uncommon finding, but it should initiate a review of radiation management practices.

Other Interventions

Skin injuries related to other interventional procedures in the abdomen and chest were reported to the Food and Drug Administration between January 1992 and October 1995 [6]. These injuries include three cases of multiple hepatic and biliary interventions (e.g., angioplasty, stent placement, and biopsy), percutaneous cholangiography followed by multiple embolization procedures (one case), renal angioplasty (two cases), and catheter placement for chemotherapy (one case). A case of renal and biliary angioplasty resulted in skin damage severe enough to necessitate skin grafting. Details regarding the other cases were not published. A case of skin necrosis after two renal angioplasties was recently described by Dandurand et al. [13].

Technical Factors for Controlling Dose and Skin Damage

Long Exposure Times to Same Skin Area

The most prevalent common factor for injury is long exposure times to a single skin site. Physicians must be appropriately trained in the safe and efficient completion of the procedure [38, 39]. Keeping track of fluoroscopy on-time, in the absence of real-time dose monitoring, can assist in maintaining on-times at a minimum [38, 39]. Times should be reviewed to ensure that they are within the norm for the specific procedure. For example, if the fluoroscopy time exceeds 30 min, a consultation with more experienced staff might be called, or the beam orientation might be adjusted to a new skin area. Action protocols should be established according to the facility's procedures.

Use of dose-saving variable pulsed fluoroscopy is of significant benefit in reducing the dose rate to the skin [40–43]. This technology reduces effective beam on-time by pulsing the beam many times a second at a frequency suitable for the study. For example, by using pulses that are on only half the time, dose rate on some units decreases by a factor of two. Varying the frequency to lower pulse rates results in lower dose rates to the skin. Actual dose abatement depends on the equipment, and some machines do not reduce the dose at all or may even increase it. A medical physicist can verify the actual behavior.

Irradiation Through Thick Masses of Tissue

Fluoroscopically guided interventional procedures use low-energy X-ray radiation that is rapidly attenuated as the beam penetrates tissue, resulting in absorption that is most intense at the surface where the beam enters the patient. The dose decreases by a factor of about 2 for every 45–50 mm of soft-tissue depth [44]. For this reason, the radiation absorbed dose is greatest in the dermal and epidermal tissues of the skin at the entrance beam site. Because of the low penetrability of these X-rays, much greater entrance skin dose rates are required in large patients or for steeply angled beam orientations. As a result, many injuries are associated with large patients and steep beam angles through thick body parts (Figs. 1–3). A quantitative assessment of the relationship of patient weight to cases of injury was not possible because of lack of data. In one particularly severe injury, the patient weighed 160 kg (Fig. 3 and Table 1, patient 11). The photographs in our review suggest that overweight or heavyset individuals are common among injured patients. In addition to the recommendations in the previous paragraphs, standard procedures, such as assuring that the image intensifier is kept close to the patient and the X-ray source as far away as possible, become much more important for minimizing dose rate [21].

The separator cone is a mechanical safety device that prevents skin from approaching too close to the X-ray source by forcing a minimum distance between the source and the surface of the exit-beam port. This separator device can be removed, and often is, because it interferes with the mechanical rotation of the X-ray unit. For some units the devices are not easily removed and replaced. Some other X-ray units have nonremovable separator devices. The separator cone, when used properly, plays an important role in assisting with skin dose management.

Skin dose rate is usually reduced when the beam energy is increased. Some machines use a heavy beam filter (e.g., 0.2 mm of copper) to harden the beam and to reduce the entrance skin dose rate [37, 45, 46]. Such a filter typically has a minimal effect on image quality, often even improving quality. Such filtration is highly recommended if patients are large or steep beam angles are frequently used. Alternatively, increasing the fluoroscopic peak kilovoltage in some procedures will decrease the dose to the patient but may result in a loss in image contrast that may or may not be acceptable for the proper completion of the procedure [40, 46, 47].

Scatter-Removing Grid

The scatter-removing grid improves image quality by removing scattered X-rays from the image. The reduced scatter causes a loss in image brightness. To compensate, X-ray output is increased, which increases dose. During procedures in which a large air gap exists between the patient and the image intensifier, the grid is unnecessary because the air gap permits a good portion of the scattered X-rays to escape before interacting in the image receptor. Soderman et al. [46] showed that removing the grid during neuroradiologic interventional procedures can reduce dose to the patient by about 34%. Removing the grid for other procedures, such as pain management, that use large air gaps be-

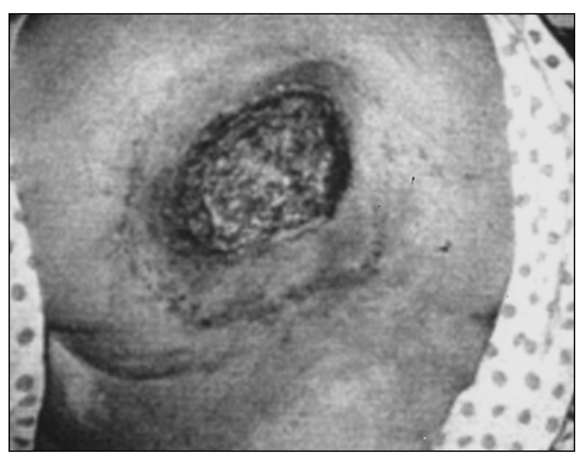

Fig. 3.—62-year-old man weighing 160 kg (350 lb) with history of angina, congestive heart failure, and diabetes mellitus (type II). Patient underwent coronary angioplasty and stent placement of left anterior descending artery and ostium of left coronary artery. Fluoroscopy time was recorded at 50 min during 2.5-hr procedure. Photograph approximately 7 months later shows full-thickness radiation injury measuring 15 cm (6 inches) in diameter on patient's mid back. Patient underwent skin grafting 8 months after procedure. Because of partial failure of first graft, lesion was regrafted 1 month later (Table 1, patient 11).

tween the patient and the image intensifier might also be possible to reduce the dose to the skin.

Field of View

Another factor contributing to the severity of a radiation wound is the size of the radiation field. Large lesions are clinically less well tolerated [48]. If the dose is sufficiently great to totally deplete basal cells in the irradiated area, healing of a skin defect (e.g., moist desquamation) occurs mainly from the edges of the lesion. Regeneration will then be relatively ineffective and prolonged, exposing tissues to the risk of secondary ulceration [49].

Collimators are devices that can be manually adjusted to reduce the field of view of the X-ray exposure. Collimation is recommended for the following reasons: it reduces the patient's stochastic risk of induced cancer by reducing the volume of tissue exposed; it reduces scatter radiation in the room; the smaller field allows better recovery of injured tissue; and it can reduce the accumulated dose to the skin by eliminating the overlap of fields when different beam angles are used. An example of how overlapping fields contribute to skin injury is shown in Figure 4, in which secondary ulceration is present at the overlap of the fields from two angioplasty procedures. However, the more narrow the collimated field is, the higher is the dose to the remaining irradiated skin [21, 40]. The higher dose occurs because narrow collimation also reduces scatter to the image, which results in reduced image brightness. To compensate, the machine typically increases dose rate. If the field is collimated to block part of the area that is used to control image brightness, the system will think that image brightness is decreasing and will also increase dose rate.

Field of view can also be adjusted using electronic or geometric magnification [21]. With geometric magnification, an air gap exists between the patient and the image intensifier, which increases the entrance dose to the skin according to the inverse-square law. How dose rate changes under electronic magnification depends on machine design and operation, but typically it increases as magnification increases.

Several authors identified the extensive use of a high-magnification mode as an important factor leading to high radiation doses [5, 7, 9, 15, 18, 23]. Under these circumstances, many fluoroscopes operate at very high output. Patient 9 in Table 1 is an example of an injury in which the highest magnification mode (4.5-inch [11.43-cm] field size) was used during the procedure (Fig. 5). Fluoroscopy on-time was 100 min, with probably 2000–3000 cine frames. The radiation dose was estimated as 13–22 Gy.

High-Skin-Dose Modes of Operation

Several reports (e.g., see [5, 7, 15] and Fig. 5) have cited the extensive use of imaging modes that produce high dose rates or high resolution. Dose rates to the skin are typically much greater when high magnification is used. Cineangiocardiography, digital fluorography, high-dose-rate fluoroscopy, and high-magnification modes must be used sparingly and judiciously [21].

Extraneous Body Parts in the Beam

Injuries to the arms and breasts occurred in several cases. Keeping the patient's arms out of the field of view is essential because doses are increased by the machine to penetrate the extra tissue. Dose accumulation can be rapid in these tissues if they are located on the port side of the X-ray system. Appropriate arm rests and a conscientious effort to avoid direct irradiation of a woman's breasts are also important elements of good patient care.

Real-Time Dose Monitoring

No dose monitoring was reported for any of the reviewed cases. Real-time dose monitoring is not available on many fluoroscopic machines. Installing real-time dose monitoring equipment has many advantages. Dose is a far more relevant indicator of risk than fluoroscopy on-time, and monitoring it eliminates the need to monitor fluoroscopy time. Furthermore, a dose monitor keeps track of doses from fluorography and cine as well as from fluoroscopy, whereas fluoroscopy on-time ignores these other factors. Knowing the skin dose, or at least an approximation of it, will assist physicians in the benefit–risk decisions

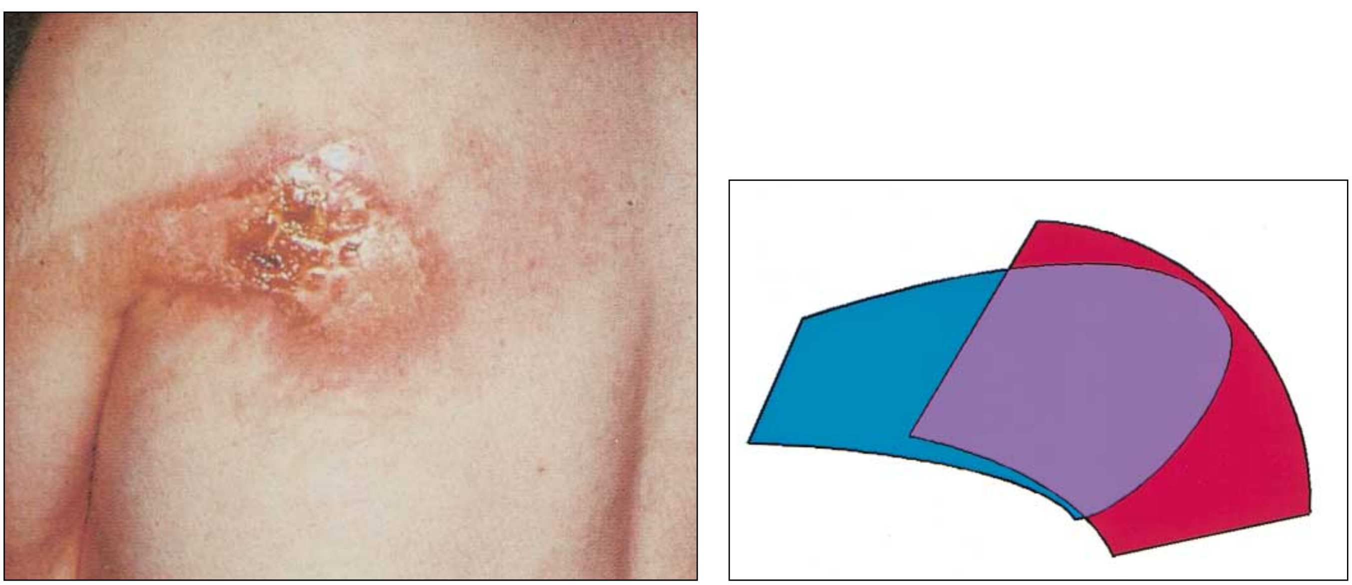

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Fig. 4.—69-year-old man with history of angina who underwent two angioplasties of left coronary artery within 30 hr.
A, Photograph taken 1–2 months after last procedure shows secondary ulceration over left scapula in area where two radiographic fields overlap. (Reprinted with permission from [11])
B, Diagram shows region of overlap of two fields. Curved outline of fields results from projection of rectangular X-ray field onto curved surface of patient's back.

concerning potential alternative actions when dose accumulation becomes a concern. Knowing the rate of dose accumulation can be a warning to take action to lessen the dose rate early in the procedure. Dose rate monitors will also catch the X-ray output malfunctions that occasionally occur and result in injury to patients [3, 18]. Although this capability will be available on future equipment, retrospectively fitting such devices on established equipment is recommended [38].

Dosimeters that allow real-time dose measurement are preferred over postprocedure readout dosimeters. Various dosimeter systems are reviewed in articles by Geise and O'Dea [50], Hwang et al. [34], Cusma et al. [32], and Wagner and Pollock [51]. Protocols for each procedure should be developed that define a certain dose (e.g., 1–3 Gy) as a threshold dose at which some action is taken. For example, beam angulation could be changed to avoid irradiation of the same skin area for a prolonged time [38, 39].

Fig. 5.—69-year-old man with coronary artery disease involving left anterior descending and right coronary arteries. Two percutaneous transluminal coronary angioplasties and one diagnostic angiography examination were performed with 100 min of fluoroscopy at highest magnification. Patient developed pronounced erythema at 3 weeks that progressed to moist skin desquamation. Area of deep ulceration was present at 3 months. Photograph shows lesion that did not heal over course of 17 months. Elliptic shape of lesion is caused by two sequential procedures that used nearly the same tube position (Table 1, patient 9).

Quality Control

The value of a good quality control program in managing radiation use has been discussed by many authors [39, 52–54]. Such programs not only assure that dose rates are appropriate, they also help the physician to minimize procedure time by assuring high standards of image quality.

Training in Fluoroscopic Technique

Many physicians from a wide variety of specialties are becoming involved in interventional work. Most specialties provide little or no training in the biologic effects and appropriate and inappropriate applications of radiation [38, 39, 55]. Wagner et al. [40] have shown how easy it is to increase the skin dose to patients by deviating slightly from standard methods of skin dose management. In their example of a 90-min beam-on time, a difference of 8 Gy between standard and nonstandard techniques was shown. Even greater differences can be achieved. Training of physicians in the proper use of fluoroscopic technique should be required [38, 39, 55].

Conclusions

In part 1 of this two-part series, the following points were made regarding treatment of a patient before and after a fluoroscopically guided interventional procedure: Physicians must be able to recognize radiation-induced skin changes. The patient should be asked about previous procedures, and the patient's skin should be examined, when appropriate, for prior radiation-induced skin changes. The history should include health conditions and medications that might increase the patient's risk for a radiation response to the procedure. After lengthy procedures, patients should be advised to examine the skin at the beam entrance site in the next several weeks for any changes that may occur.

This second part of our series indicates that multiple technical factors contribute to circumstances that result in radiation injury to patients from fluoroscopy and accompanying fluorography. Foremost on the list are long fluoroscopy times through thick body parts and no radiation dose monitoring. Appropriate training in the safe and efficient completion of a procedure is essential. Physicians should seek the assistance of more experienced interventionalists before attempting a difficult procedure beyond their own experience.

Other contributing factors include unnecessary direct irradiation of certain body parts such as arms and breasts and the overuse of high-dose-rate modes of operation. We reviewed recommendations to improve patient care that include avoiding long durations of fluoroscopy over the same skin area, especially through thick body masses; appropriately using dose-reducing pulsed fluoroscopy or other low-dose-rate modes of operation; using heavy beam filtration; removing the grid when appropriate; establishing action thresholds for long procedures; removing breasts and arms from the entrance beam; measuring doses delivered to patients; and training personnel in the low-dose technical application of radiation. A good quality control program and proper use of the separator device, collimation, and field of view will also contribute to an appropriately low skin dose.

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