How I Do It

Minimizing Radiation-induced Skin Injury in Interventional Radiology Procedures[1]

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Abbreviations:
DAP = dose-area product
IRP = interventional reference point

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See also the editorial by Wagner in this issue.

Skin injury is a deterministic effect of radiation. Once a threshold dose has been exceeded, the severity of the radiation effect at any point on the skin increases with increasing dose. Peak skin dose is defined as the highest dose delivered to any portion of the patient's skin. Reducing peak skin dose can reduce the likelihood and type of skin injury. Unfortunately, peak skin dose is difficult to measure in real time, and most currently available fluoroscopic systems do not provide the operator with sufficient information to minimize skin dose. Measures that reduce total radiation dose will reduce peak skin dose, as well as dose to the operator and assistants. These measures include minimizing fluoroscopy time, the number of images obtained, and dose by controlling technical factors. Specific techniques—dose spreading and collimation—reduce both peak skin dose and the size of skin area subjected to peak skin dose. For optimum effect, real-time knowledge of skin-dose distribution is invaluable. A trained operator using well-maintained state-of-the art equipment can minimize peak skin dose in all fluoroscopically guided procedures.

Radiation-induced skin injury has been recognized for the past decade as a potential complication of fluoroscopically guided interventions (1–5). Most of the reported injuries have been the result of cardiac interventions, but some have been caused by interventional or neurointerventional radiologic procedures (5).

Skin injury is a deterministic effect of radiation. This means that once a threshold dose has been exceeded on a portion of the patient's skin, the severity of injury at that point increases with increasing dose (5). (This and other radiobiology terms are defined in the Table.) The threshold dose for transient skin injuries is typically 2 Gy for erythema and 3 Gy for hair loss.

Since 2 Gy is the threshold for the earliest detectable effect of radiation on the skin, it is also a reasonable action level for purposes of dose management and prudent patient care. Note, however, that this is an arbitrary number. The actual threshold needed to cause injury in a particular patient varies due to factors that include individual biologic variation in radiation sensitivity and the presence of coexisting diseases such as diabetes mellitus and connective tissue disorders (3). The injury threshold is also reduced in previously irradiated skin. For these reasons, some patients will show signs of deterministic injury at a relatively low dose. In addition, sensitive patients are likely to experience more severe injury at higher doses than are typical patients. The pathologic and clinical features and the threshold doses for the full spectrum of radiation-induced skin effects are described extensively in a recent review (5).

Peak skin dose is the highest dose delivered to any portion of the patient's skin. Reduction of peak skin dose can reduce the likelihood and type of skin injury occurring in any patient. The authors of several publications (1,4,6,7) have described techniques for reducing the total radiation dose to the patient during fluoroscopically guided procedures. Only a few (8,9) have specifically addressed the concept of minimizing peak skin dose, because this quantity has been both difficult and inconvenient to measure.

In this article, we review various dosimetry techniques for fluoroscopically guided procedures. We describe specific principles and methods for reducing peak skin dose, based on lessons learned from real-time mapping of skin-dose distribution. These principles are illustrated by using cases from our own practice.

Radiobiology Terms

Term	Definition
Biologic variation	Differences between individuals in threshold dose or degree of response to radiation; may be idiopathic or due to underlying disease; different portions of patient's skin also differ in radiosensitivity
Deterministic effect	Radiation effect characterized by a threshold dose; injury does not occur unless threshold dose is exceeded; once threshold dose is reached, severity of injury increases with increasing dose; examples: hair loss and cataracts
Dose fractionation	Delivery of radiation over period of time (eg, days or weeks); occurs in interventional radiology when multiple procedures are performed in same patient on different days
Stochastic effect	Radiation effect whose probability of occurrence increases with increasing dose; severity of effect is independent of total delivered dose; example: radiogenic cancer
Threshold dose	Minimum radiation dose at which a deterministic effect can occur (threshold will vary somewhat among individuals)
Transient erythema	Mild observable skin reaction to radiation; has threshold dose of 2 Gy and resembles a sunburn; subsides by 48 hours after exposure and is frequently not noticed by patient

DOSE MEASUREMENT

The ideal dose-measurement technique provides the operator with sufficient information to avoid or minimize radiation effects on the skin during a procedure. Unfortunately, although a number of dosimetric methods are available, this ideal is not achievable with most currently available systems.

There are a number of generally available real-time dosimetric methods. These can be classified as either overall measurements or point measurements. Overall measurements include fluoroscopy time, dose-area product (DAP), and cumulative dose delivered to a reference point. All overall measurements are indirect measurements of dose. These methods measure various quantities that are analogues of the total dose delivered to the patient during a procedure. Patient dose can be estimated from these indirect measurements but cannot be determined precisely. Point measurements are obtained with any of a variety of instruments placed directly on the patient to quantify the dose delivered to a specific point on the skin. Point measurements are direct measurements of dose.

At present, fluoroscopy time is the only method of dose estimation required by the U.S. Food and Drug Administration for fluoroscopic equipment sold in the United States. Many manufacturers supplement the fluoroscopic timer with an acquisition frame counter, which indicates the number of images obtained. These tools provide a poor analogue of dose for several reasons. They provide no information regarding x-ray field size or position. They do not account for differences in dose rates resulting from differences in equipment, technique, or patient size. In general, time measurements do not provide the means for an accurate estimate of dose. When necessary, the information can be used as an essential part of reconstructing the dose delivered to a specific patient.

DAP measurement capability is required by the European Union for fluoroscopic equipment sold there. This technology is therefore often available (frequently as an option) on interventional equipment currently sold in the United States. DAP is measured in units of grays times square centimeters and expresses the total x-ray flux in the beam (10). Because dose decreases proportionately to the square of the distance from the focal spot and the area of the irradiated field increases proportionally in the same way, DAP is independent of source-to-skin distance (11). DAP is typically measured with an ionization chamber located near the collimator (Fig 1). If the entire irradiated field is intercepted by the patient, DAP is a good measure of total radiation dose and, therefore, is a reasonable measure of the risk of stochastic radiation effects. However, DAP is a poor analogue of skin dose. A large dose delivered to a small skin area yields the same DAP as a small dose delivered to a large skin area. Estimation of absorbed skin dose from DAP data has a potential error of at least 30%–40% (7).

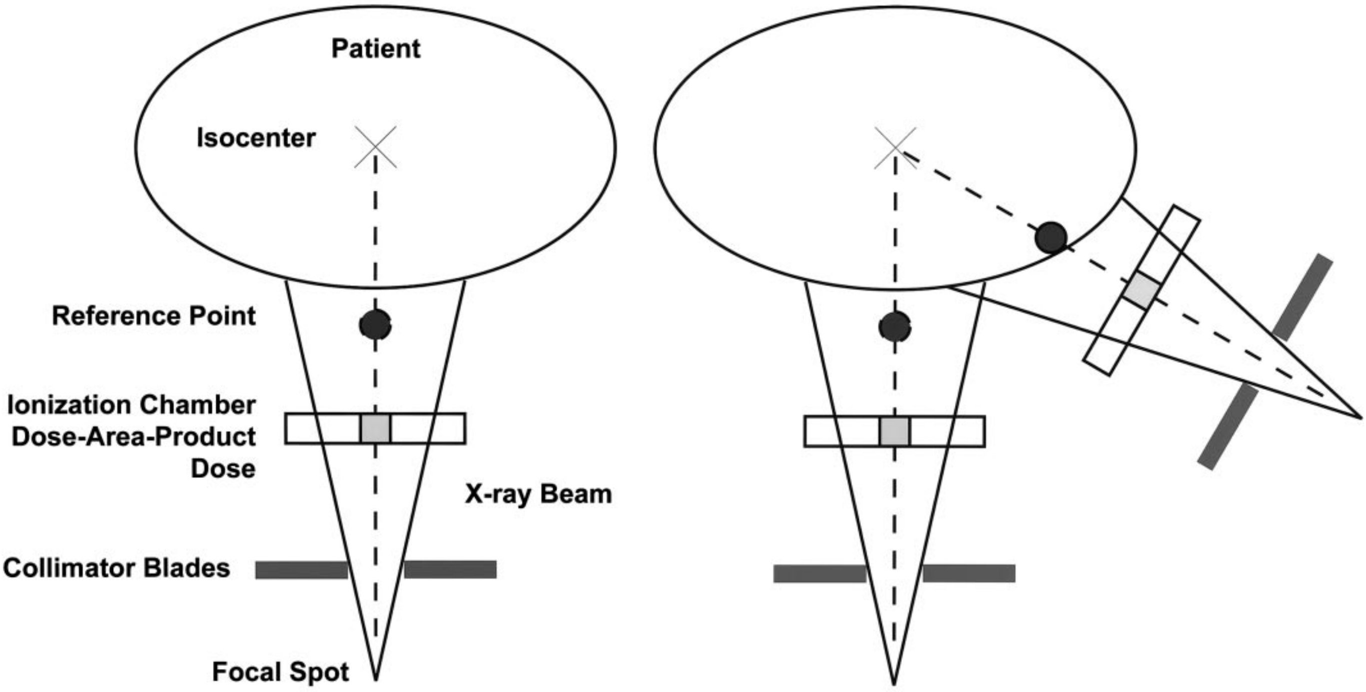
The International Electrotechnical Commission recently introduced the concept of cumulative dose delivered at a defined point in space called the IRP (12). The IRP is located on the central ray of the x-ray beam, 15 cm from the isocenter, toward the focal spot (Fig 1). Depending on the patient's size, the table height, and the angulation of the beam, the IRP may be outside the patient, may coincide with the skin surface, or may be inside the patient (Fig 1). The IRP moves relative to the patient as beam position changes. Because of these factors, cumulative dose is usually an overestimate of peak skin dose.

Fluoroscopic systems with integrated cumulative dose-measurement capability have only recently become available. Add-on accessories that provide the same capability, such as PEMNET (Clinical Microsystems, Arlington, Va), are available for most current and older systems (13,14). Both integrated and add-on equipment can display dose rates and cumulative doses at the IRP to the operator in real time.

Real-time measurements of skin dose are possible only at one or a few selected points on the skin (15). A radiolucent probe using either a metal-oxide semiconducting field-effect transistor, or MOSFET (Med-Tec, Orange City, Iowa), or a scintillation dosemeter (McMahon Medical, San Diego, Calif) (15–17) is placed at the presumed point of peak skin dose. Accurate placement is essential to determine peak skin dose but is usually impossible. Skin-dose distribution is complex, and the site of peak skin dose can rarely be predicted (17,18).

Non–real-time measurements of peak skin dose can be obtained by using thermoluminescent dosimeter arrays or low-sensitivity film. Difficulties include the availability of large enough sheets of film for convenient use in clinical situations (17). Results are not available until after the procedure has been completed and the film or thermoluminescent dosimeter array have been analyzed (19). The assistance of a medical physicist is usually necessary. A major problem is the lack of feedback to the operator during the procedure.

A software-based method for real-time calculation and display of a skin-dose map and peak skin dose has recently been introduced (CareGraph; Siemens Medical Systems, Iselin, NJ). It is available as an option for certain interventional systems. A modeling process is used to calculate skin dose. The software receives real-time data on table height and position, gantry angle and position, collimator size and position, and DAP



a. b.

Figure 1. Diagrams of a C-arm fluoroscopic unit. **(a)** Location of the DAP meter ionization chamber and the interventional reference point (IRP) (●) are shown. The DAP meter measures x-ray flux across the entire beam. The small central volume is used to measure dose along the central ray. **(b)** Note that the relationship of IRP (●) to skin surface changes with gantry angulation. This relationship also varies with changes in table height.

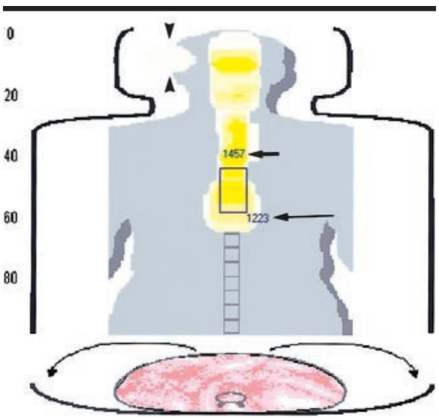


Figure 2. Skin-dose map display obtained during spinal arteriography. A map of the skin-dose distribution is shown. The map is displayed as if the skin surface were cut along the midline anteriorly and reflected laterally, as shown in the diagram at the bottom of the figure. As skin dose increases, the color of the corresponding portion of the skin map changes from white through yellow and orange to red. Note the region of skin dose (arrowheads) due to arteriography in the lateral plane. The current radiation field is indicated by the blue rectangle, and the current value of peak skin dose within this field is displayed in blue (*1223,* long arrow). The current value of peak skin dose for the entire skin surface is displayed in green (*1457,* short arrow). The display also indicates, in tabular form (not shown), cumulative dose, DAP, fluoroscopy time, peak skin dose, and 95% area load.

from the fluoroscopic unit. The patient's height, weight, and location on the table are used to create a model of the patient's skin surface. From moment to moment, the software calculates which portion of the skin surface is being irradiated, as well as the dose rate to each 0.5-cm^2 patch of skin. The dose data are integrated and the results displayed on a computer monitor in real time as a map of skin dose (Fig 2). The calculated position of the radiation field is displayed as an overlay on the skin map and is adjusted in real time as the collimator size or shape is changed and as the table or gantry is moved.

DOSE REDUCTION

Minimization of skin dose is best accomplished by making all possible efforts to reduce radiation dose in general while maintaining adequate image quality for diagnosis and intervention. Dose reduction requires attention to several basic principles, all of which have been discussed in detail in several excellent reviews (4,6,9) and are summarized here. These include *(a)* control of fluoroscopy time, *(b)* control of the number of images obtained, and *(c)* control of technical factors that affect dose. Techniques that reduce patient dose usually also reduce scattered radiation and, therefore, provide the additional benefit of reducing dose to the operator and assistants.

Control of fluoroscopic time is the direct responsibility of the operator. Fluoroscopic time can be minimized by means of the judicious use of intermittent fluoroscopy, last-image hold, and, when available, electronic collimation. (Electronic collimation provides an overlay of the collimator and filter position on the image displayed with last-image hold, so that collimators and filters can be adjusted without the use of fluoroscopy.)

Control of the number of images obtained during a procedure requires awareness and planning. With modern digital subtraction angiography units, it is a simple matter to set the unit to acquire images at a rate of two or more images per second and then perform the entire angiographic run at that rate. This is neither necessary nor desirable. As all radiologists who have ever used a cut-film angiographic unit are well aware, the limited magazine capacity of those devices forces the use of filming sequences that minimize the number of images obtained while ensuring that no important information is lost. Digital subtraction angiog-

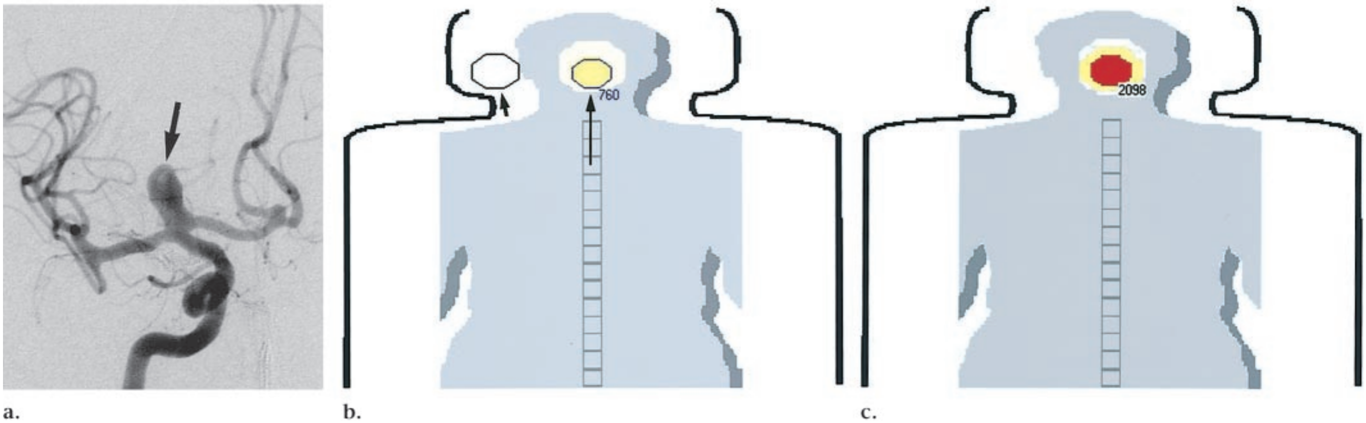


Figure 3. **(a)** Right internal carotid arteriogram obtained in the frontal plane before treatment with detachable coils of an internal carotid bifurcation aneurysm (arrow). The skin-dose maps obtained **(b)** early in the procedure and **(c)** at the conclusion of the procedure are also shown. The procedure was performed in a biplane room. **(b)** The midline octagon (long arrow) indicates the radiation field from the frontal plane, and the lateral octagon (short arrow) indicates the radiation field from the lateral plane. The cumulative dose for the procedure was 2,458 mGy, and the peak skin dose was 2,098 mGy. **(c)** The red color on the skin-dose map indicates that the skin dose to this area exceeded 2,000 mGy. The dose index was 0.85, and the 95% area load was 46.3 cm^2.

raphy units can and should be preprogrammed with the same imaging sequences as are used for cut-film angiography. If the only purpose of an image is to document what is seen on the last-image hold, there is no need to perform an additional imaging run. Instead, the last-image hold at fluoroscopy should be recorded. If the last-image hold demonstrates the finding, it is of sufficient quality. It may be noisy, but no additional dose has been expended to obtain it.

Dose can also be minimized through optimization of technical factors. Some of these are under the operator's direct control and can be optimized with any fluoroscopic device. These include maximizing source-to-skin distance, minimizing the air gap between the patient and the image intensifier, and limiting the use of electronic magnification. The assistance of a medical physicist may be required for optimization of other technical factors, including beam filtration, grid removal (when appropriate), and adjustment of fluoroscopic voltage (kVp) and fluoroscopic and digital imaging dose settings. These settings should not be changed in a way that impairs image quality to the point where it is inadequate for diagnosis and guidance of interventions.

Additionally, if dose-saving pulsed fluoroscopy is available, the operator should use it whenever possible. The cases we describe were performed with dose-saving pulsed fluoroscopy at a rate of either 15 or 7.5 pulses per second. With our equipment, these pulse rates decrease the fluoroscopic dose rate by 47% and 72% respectively, as compared with the dose rate at conventional fluoroscopy. Note, however, that pulsed fluoroscopy can be accomplished with different methods, some of which do not reduce the dose rate. Some pulsed fluoroscopy modes actually yield a higher dose rate than does conventional fluoroscopy. If in doubt, check with the manufacturer of the fluoroscopic equipment or have a medical physicist measure the dose rate for each pulsed fluoroscopy mode.

Finally, outdated equipment should be replaced with new fluoroscopic units that incorporate current dose-reduction technology. Patient protection should not be sacrificed in the interest of economy. Every operator who uses fluoroscopic equipment must ensure that the individual who makes the purchasing decision for new fluoroscopic units is aware of the importance of dose-reduction technology. Some of the dose-reduction mechanisms (eg, dose-saving pulsed fluoroscopy, beam filtration, electronic collimators) are available only on certain manufacturers' equipment or are extra-cost options. Increased demand for this technology should result in greater availability and improved products through competition among vendors.

REDUCTION OF PEAK SKIN DOSE

Measures that reduce total radiation dose will also reduce peak skin dose. Two simple basic techniques are also available that are intended specifically to reduce

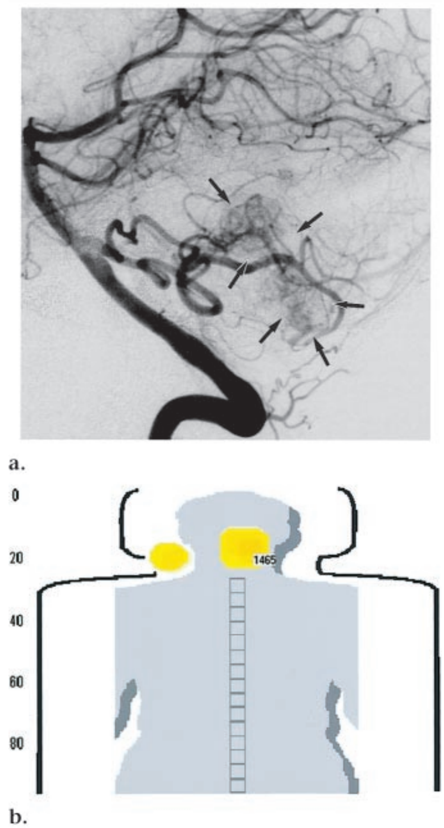


Figure 4. **(a)** Posterior fossa arteriogram obtained in the lateral plane before embolization of a cerebellar arteriovenous malformation (arrows). **(b)** Skin-dose map obtained at the conclusion of the procedure. The yellow color is a visual indicator that skin dose was less than 1,600 mGy. The cumulative dose was 3,481 mGy; peak skin dose, 1,465 mGy; dose index, 0.42; and 95% area load, 24.5 cm^2.

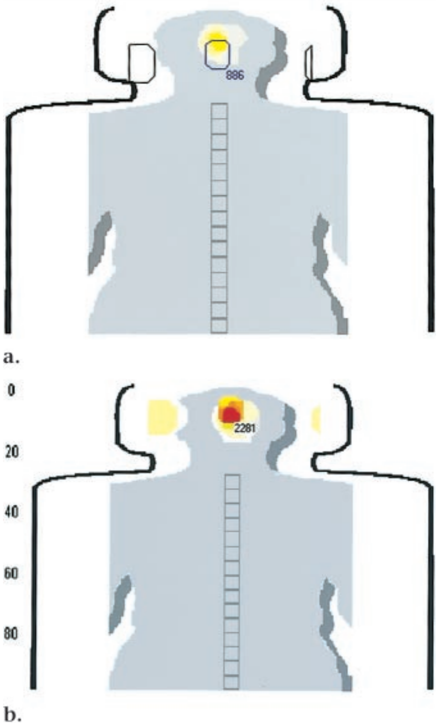


Figure 5. Skin-dose maps obtained during and after occlusion with detachable coils of a basilar artery tip aneurysm. **(a)** Skin-dose map obtained approximately one-third of the way through the procedure, with 19.6-minute fluoroscopy time and a cumulative dose of 1,213 mGy. At this time, the peak skin dose was 886 mGy. The darker yellow color indicates a skin dose of between 1,000 and 1,200 mGy, and the paler yellow color indicates a region of lower skin dose. The skin map demonstrates that the dose has been spread over a larger skin surface than the radiation field (indicated by the blue rectangle). Compare this skin-dose map with those in with Figure 3. **(b)** Skin-dose map obtained at the conclusion of the procedure, with 3,493-mGy cumulative dose, 2,281-mGy peak skin dose, dose index of 0.65, and 95% area load of 10.5 cm^2. The 95% area load was minimized with the use of table movement and gantry angulation. As indicated by the zone of yellow and orange colors, which represent doses of 1,200–2,000 mGy, the dose has been spread over a larger area of skin. As a result, the red area (skin dose > 2 Gy) is smaller than the radiation field. Compare with Figure 3.

peak skin dose. The first technique is to change the position of the radiation field on the patient's skin by using gantry angulation, table movement, or both. The second technique is to reduce the size of the radiation field by using collimation. The purpose of these techniques is to spread or "smear" the skin dose over as large an area as possible. Spreading the administered dose over a larger area accomplishes two things. First, it reduces peak skin dose. Second, it reduces the

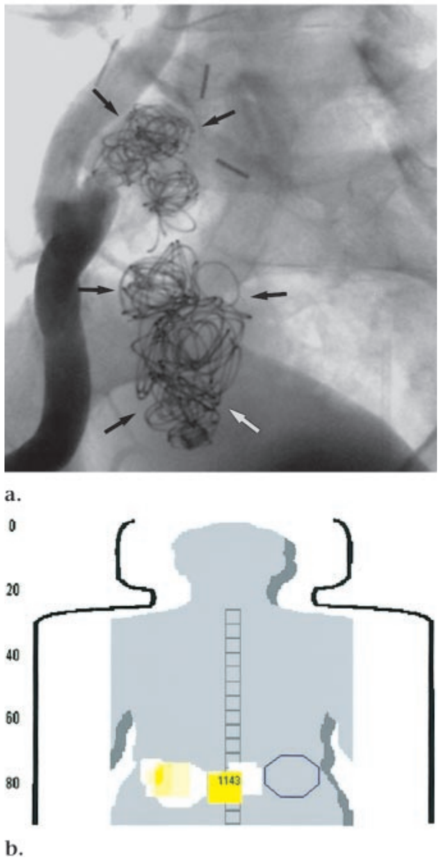


Figure 6. Coil embolization of an internal iliac artery aneurysm. **(a)** Pelvic arteriogram obtained in the frontal plane after embolization demonstrates multiple coils (arrows) within the aneurysm. **(b)** Skin-dose map obtained at the end of the procedure demonstrates the effect of gantry angulation during the procedure, with 3,449-mGy cumulative dose, 1,143-mGy peak skin dose, dose index of 0.33, and 95% area load of 13.3 cm^2. The skin-dose map demonstrates the skin doses from all of the radiation fields as a series of overlapping squares and octagons. The light yellow color indicates that skin dose in most of these fields was less than 800 mGy. The blue outline indicates the radiation field at the conclusion of the procedure.

area of skin subjected to the peak skin dose.

In this regard it is useful to consider two concepts. The first is the dose index—the ratio between peak skin dose and cumulative dose for a procedure. The dose index is a measure of the effectiveness of efforts to minimize peak skin dose. A low dose index indicates that efforts to reduce peak skin dose have been effective. The second is the 95% area load. This is the area of skin subjected to skin doses greater than the 95th percentile of skin dose for the procedure. It is a measure of the size of the skin area at highest risk.

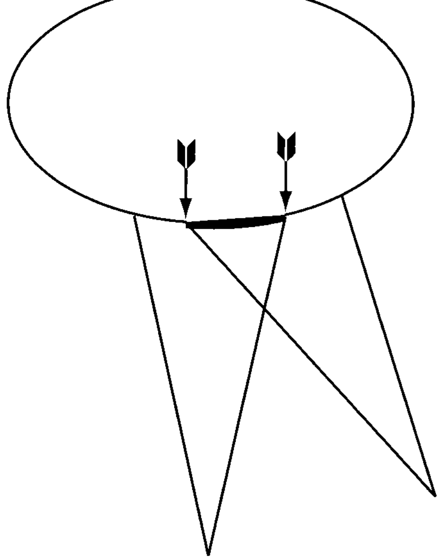


Figure 7. Diagram demonstrates result of gantry angulation with overlapping radiation fields. The skin surface in the overlap area (arrows) receives radiation in both gantry positions. This can often be avoided with a greater degree of collimation.

Application of these concepts is shown in Figure 3, which demonstrates the skin-dose distribution and peak skin dose resulting from treatment of an aneurysm of the internal carotid bifurcation. This procedure was performed early in our experience with the skin-dose mapping software. The operator did not use the real-time information available. Once an appropriate gantry angulation and table position were identified, neither was changed during the remainder of the intervention. No dose spreading occurred. As a result, the peak skin dose was 2,098 mGy, above the 2-Gy threshold for transient erythema. The cumulative dose was 2,458 mGy; therefore, the dose index was 0.85. In other words, 85% of the total dose administered during the entire procedure was directed at one area on the scalp. The 95% area load was 46.3 cm^2.

Figure 4 demonstrates embolization of a cerebellar arteriovenous malformation in another patient. During the course of the procedure, the radiation field was changed slightly by using gantry angulation or table movement. The skin dose due to each irradiated field is clearly indicated on the skin-dose map. The overlapping radiation fields are depicted as rectangles of different colors corresponding to the skin dose at these sites. As compared with the procedure depicted in Figure 3, even though the cumulative dose (3,481 mGy) was higher for the pro-

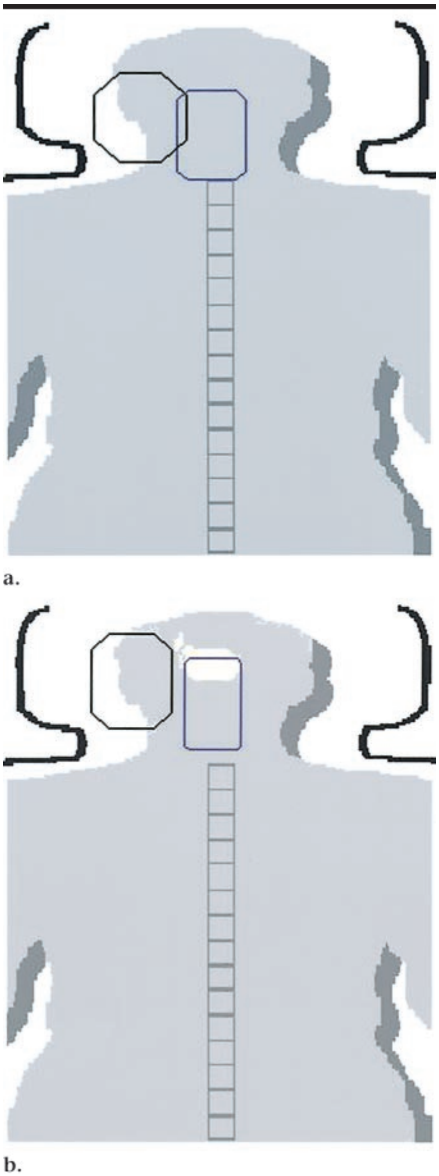


Figure 8. Skin-dose maps obtained at the start of an embolization procedure for treatment of a cerebral arteriovenous malformation. **(a)** Initial collimation of the frontal and lateral fluoroscopic radiation fields resulted in an area of overlap on the skin of the posterolateral right side of the neck and head, indicated only by position of the radiation fields on the skin-dose map. **(b)** After review of the skin-dose map, the collimation of both radiation fields was adjusted. No useful information was lost, and the overlap disappeared.

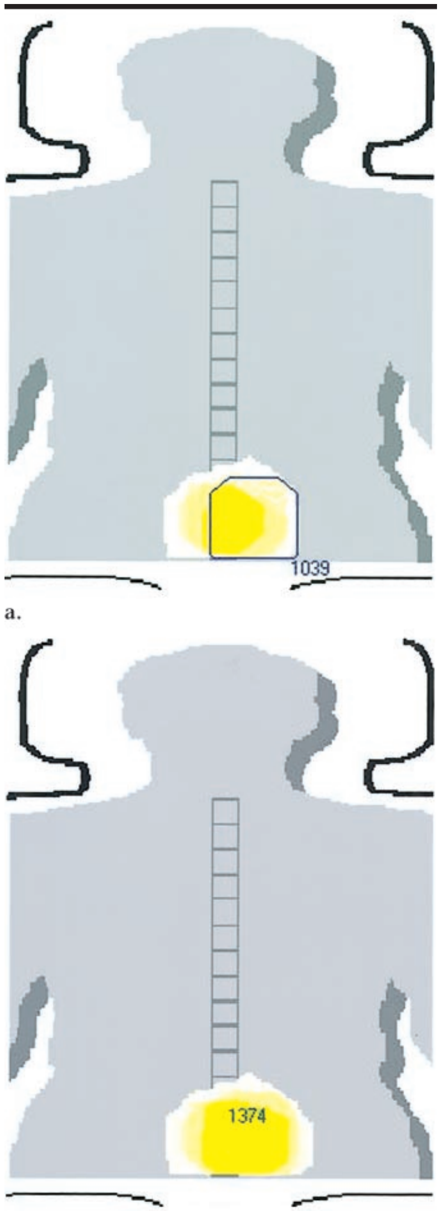


Figure 9. Skin-dose maps obtained **(a)** during and **(b)** at the conclusion of uterine artery embolization. Note that the irradiated field (blue outline) is relatively large and extends across the midline. At the conclusion of the procedure, the peak skin dose was located in the patient's midline as a result of bilateral overlapping radiation fields. The skin-dose map shows a central orange region representing skin doses of 1,200–1,400 mGy surrounded by lighter yellow areas representing regions of progressively lower skin dose. Cumulative dose was 2,875 mGy; peak skin dose, 1,374 mGy; dose index, 0.48; and 95% area load, 26.5 cm^2.

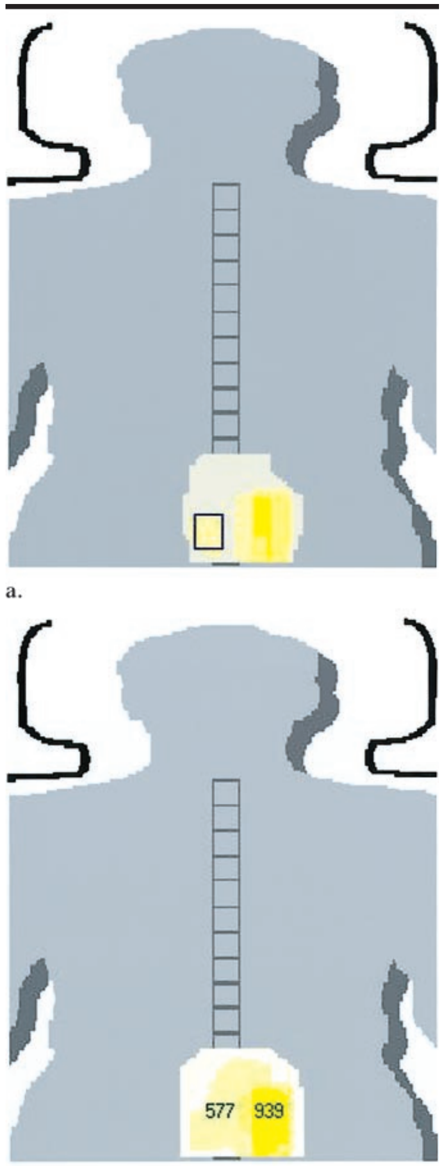


Figure 10. Skin-dose maps obtained **(a)** during and **(b)** at the conclusion of uterine artery embolization performed with careful attention to collimation and dose spreading. **(a)** Note the relatively small size of the irradiated field (blue rectangle). This image was recorded during embolization of the right uterine artery. Bilateral fields of this size do not overlap. **(b)** At the conclusion of the procedure, the skin-dose distribution was bilobed and spared the midline. The region of maximum skin dose is indicated by the darker yellow zone, which indicates a skin dose of 800–1,000 mGy. The rest of the pelvis contains only zones of light yellow, indicating regions with skin doses less than 600 mGy. The cumulative dose was 3,022 mGy; peak skin dose, 939 mGy; dose index, 0.31; and 95% area load, 12.8 cm^2.

cedure shown in Figure 4, the peak skin dose (1,465 mGy), dose index (0.42), and 95% area load (24.5 cm^2) were all decreased. This was due to dose spreading. The peak skin dose was below the 2-Gy threshold, despite the higher cumulative dose.

Even if it is not possible to reduce peak skin dose below 2 Gy, dose spreading may decrease the size of the skin area that receives the peak skin dose. This reduces the size of the skin area at highest risk. Figure 5 demonstrates skin-dose maps obtained approximately one-third of the way through a procedure to occlude a basilar artery tip aneurysm with detachable coils and at the conclusion of the procedure. Table movement and gantry angulation have been used to spread the dose over a larger area, which minimized the 95% area load.

The dose-spreading techniques of table movement and gantry angulation are equally effective for nonneurologic interventions performed with single-plane fluoroscopic units. Figure 6 shows an internal iliac artery aneurysm treated with coil embolization and the skin-dose map obtained at the conclusion of the procedure. With the deliberate use of dose spreading to reduce peak skin dose, the dose index was held to 0.33, with a peak skin dose of 1,149 mGy and a 95% area load of 13.3 cm^2.

Collimation of the irradiated field is as important as dose spreading. Even with the use of dose-spreading techniques, different irradiated fields can overlap on the skin surface (Figs 4, 5, 7). The overlap area receives a higher dose. Optimal collimation may prevent overlap, especially with biplane fluoroscopic units (Fig 8).

Optimal collimation improves the effectiveness of dose-spreading techniques. Consider Figures 9 and 10, which are examples of two uterine artery embolization procedures. In the procedure performed early in our experience with skin-dose mapping, depicted in Figure 9, the radiation field was relatively large and frequently extended across the midline. Despite the use of dose-spreading techniques, substantial overlap of radiation fields occurred. The midline area received the peak skin dose. The procedure depicted in Figure 10 was performed with careful attention to dose spreading and collimation. Note that there are two separate areas of peak skin dose, one in each hemipelvis. The midline region is spared. The peak skin dose and the dose index were both lower, despite the higher cumulative dose in this procedure as compared with that in the procedure depicted in Figure 9.

DISCUSSION

In 1994, the Food and Drug Administration recommended that dose be recorded in the patient's medical record for all fluoroscopically guided procedures when there was a possibility that skin dose might be high enough to produce skin injury (20). Since dose cannot be recorded if it cannot be measured, this implies that some means of measuring dose should be available with all fluoroscopic units. Measurement of fluoroscopy time alone is clearly inadequate. Cumulative dose or DAP may be used, but the former is an overestimate of peak skin dose and the latter gives no direct information about skin dose at all.

Measurement of peak skin dose is the most reliable method for estimating the risk of skin injury. Manufacturers of fluoroscopic equipment should be encouraged to provide this capability on all of their equipment. If procedures with the potential for high peak skin doses are performed by using fluoroscopic equipment without the capability to measure either total dose or peak skin dose, consideration should be given to the use of film-based methods for determination of peak skin dose (17,19).

Minimization of peak skin dose requires the use of both standard methods to reduce total dose and specific methods to reduce peak skin dose. Both are important, and neither alone is sufficient. Both require active operator awareness and participation.

Measures that reduce total dose will also reduce peak skin dose. Attention to operator-controllable factors (minimization of fluoroscopy time and the number of images acquired) is essential. Equally essential is insistence that the facility or institution that owns the fluoroscopic equipment support dose-reduction efforts through the purchase of modern equipment with the necessary dose-reduction features. This equipment includes mobile fluoroscopic C-arm units used outside the radiology department.

Our examples demonstrate that methods designed to reduce total dose are not, by themselves, sufficient. Dose index and 95% area load, both of which are measures of the effectiveness of efforts to minimize peak skin dose, can vary widely for any given type of procedure, depending on whether techniques to reduce effective peak skin dose are used. As shown by the examples in Figure 3, 5, 9, and 10, both dose index and 95% area load are clearly operator dependent.

Dose-spreading techniques have been shown to be effective (8). For optimal effect, however, we believe that they must be used in conjunction with a real-time skin-dose map that indicates the current radiation field. This display should be located in the procedure room where it is continuously visible to the operator. The skin-dose map provides a clear indication of the effectiveness of dose-reduction techniques, while the overlay display of the radiation field permits intelligent manipulation of table position, gantry angulation, and collimator position. Our experience indicates that real-time knowledge of skin-dose distribution permits effective dose spreading with relatively small amounts of gantry angulation and table motion.

With well-maintained state-of-the-art equipment and skin-dose map information, it is possible to minimize peak skin dose in all fluoroscopically guided procedures. This requires both knowledge and constant vigilance on the part of the operator. Operator training in radiation safety and radiation protection is at least as important as equipment design.

We have observed that a real-time skin-dose map is an invaluable teaching tool for all operators, regardless of their level of experience. It provides constant feedback regarding the effectiveness of dose-reduction techniques, and it guides efforts to minimize peak skin dose. It is not possible to obtain this kind of information in any other way during a procedure. Before this capability was available, we all believed that we were managing dose effectively. However, all of us have modified our technique based on what we have learned from the use of this tool.

Despite maximum effort, it is not always possible to keep peak skin dose below the 2-Gy threshold for transient erythema. Patient factors, anatomic variations, disease complexity, and the type of procedure may combine so that a prolonged procedure with a high radiation dose is unavoidable. This is not necessarily a contraindication to performing or continuing a procedure. It also does not necessarily indicate poor technique on the part of the operator. As with all of medicine, it is necessary to consider all of the benefits and risks of the fluoroscopically guided procedure, as well as all of the benefits and risks of alternative therapies, if any are available.

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