Minimizing Radiation-induced Skin Injury in Interventional Radiology Procedures

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.
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 dosimeter (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.
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-cm² 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-
raphy units can and should be pre-
programmed with the same imaging se-
quences as are used for cut-
film angiog-
raphy. 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 demon-
strates the
finding, it is of suf-
ficient qual-
ity. 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 maxi-
mizing source-to-skin distance, minimiz-
ing the air gap between the patient and
the image intensifier, and limiting the
use of electronic magnification. The as-
sistance of a medical physicist may be
required for optimization of other tech-
nical factors, including beam filtration,
grid removal (when appropriate), and ad-
justment 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 inade-
quate for diagnosis and guidance of in-
terventions.

Additionally, if dose-saving pulsed flu-
oroscopy is available, the operator should
use it whenever possible. The cases we
describe were performed with dose-sav-
ing 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 ac-
tually yield a higher dose rate than does
conventional fluoroscopy. If in doubt,
check with the manufacturer of the flu-
oroscopic 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 tech-
nology. Patient protection should not
be sacrificed in the interest of economy.
Every operator who uses fluoroscopic equipment must ensure that the individ-
ual who makes the purchasing decision
for new fluoroscopic units is aware of the
importance of dose-reduction technol-
ogy. Some of the dose-reduction mecha-
nisms (eg, dose-saving pulsed fluoroscopy,
beam filtration, electronic collimators) are
available only on certain manufacturers’
equipment or are extra-cost options. In-
creased demand for this technology should
result in greater availability and improved
products through competition among ven-
dors.

**REDUCTION OF PEAK SKIN DOSE**

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

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**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 cm².

**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 cm².
Minimizing Radiation-induced Skin Injury

The purpose of these techniques 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 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.

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 cm².

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 procedure, the radiation field was changed slightly by using 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.
The procedure shown in Figure 4, the peak skin dose (1,465 mGy), dose index (0.42), and 95% area load (24.5 cm²) 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.
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 cm².

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, even with 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.

**References**

5. Koenig TR, Wolff D, Mettler FA, Wagner LK. Skin injuries from fluoroscopically guided procedures. I. Characteristics of ra-