KEY POINTS

• The effects of radiation on the conceptus depend on both radiation dose and gestational age.

• Organogenesis is the most critical gestational age. Radiation doses that may result in malformations can be reached during fluoroscopically guided procedures.

• Whenever possible, exposure to the conceptus in utero should be avoided.

• Termination of pregnancy is not justified at fetal doses of less than 100 mGy.

Fetal responses to radiation

<table>
<thead>
<tr>
<th>Gestation stage</th>
<th>Differentiation level</th>
<th>Possible radiation-induced sequelae in humans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-implantation</td>
<td>None</td>
<td>Spontaneous abortion/prenatal death</td>
</tr>
</tbody>
</table>
| Organogenesis     | Varies from low (germ layers) to high (complete organism) | 1. Malformations, increasing in likelihood as dose increases  
|                   |                       | 2. Increased risk of prenatal death          |
| Fetal growth      | High                  | 1. Microcephaly  
|                   |                       | 2. Growth retardation  
|                   |                       | 3. Severe mental retardation  
|                   |                       | 4. Childhood leukemia*               |

*There is a slight risk for childhood leukemia at all stages, with the strongest evidence indicating a higher risk in the 2nd and 3rd trimesters.
Fetal doses and levels of concern

The likelihood of observing the effects listed in the previous slide depends on the fetal dose, which can be estimated by a qualified medical physicist.

<table>
<thead>
<tr>
<th>Fetal dose range</th>
<th>Potential for effects</th>
<th>Likelihood of effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50 mGy (&lt; 5 rad)</td>
<td>No effects.</td>
<td>Effects are possible, increasing in likelihood with increasing dose. The likelihood of effects decreases with increasing gestational age, with no effects expected at diagnostic doses. Effects are possible at high fetal doses that can be reached during complex fluoroscopic cases.</td>
</tr>
<tr>
<td>50-100 mGy (5-10 rad)</td>
<td>Potential for effects is uncertain, and if they do exist, are likely too subtle to be observed clinically.</td>
<td></td>
</tr>
<tr>
<td>&gt; 100 mGy (&gt; 10 rad)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Childhood cancer

Irradiation in utero at any stage of pregnancy has been associated with an increased risk of childhood cancer at doses as low as 10 mGy.*

However, the individual probability of a child developing cancer is still very low, as the background incidence of childhood cancer is small.

In light of this evidence, exposure of the conceptus in utero should be avoided if possible.

Management of exposed patients

“Termination of pregnancy at fetal doses of less than 100 mGy is not justified based upon radiation risk. At higher fetal doses, informed decisions should be made based upon individual circumstances.”


KEY POINTS

• Always wear personal radiation shielding, and consider using lead eyewear if your lens dose is greater than or equal to 15 mSv/yr (1500 mrem/yr).

• Protective gloves should not be used, as they offer little protection and may result in an increase in dose to the patient if used in the field of view.

• Instead, focus on keeping your hands out of the X-ray beam when possible.

• Appropriate storage of personal radiation shielding will greatly extend its life.
Personal radiation shielding

This type of equipment consists of several items:

- Apron or vest/kilt combination
- Thyroid shield
- Lead eyewear

Garments are available in a variety of lead-equivalent thicknesses from 0.25 to 0.5 mm Pb, lead eyewear is available in lead-equivalent thicknesses up to 0.75 mm.

A garment thickness of 0.35 mm is adequate for most personnel. Check your state regulations for specific requirements.

Choosing a protective garment

Protective garments should be chosen carefully, as there are a number of factors to consider:

1. What type of garment – do you need a garment that provides protection only in the front? Do you want full protection in the back? Or is a garment that provides some protection in the back, but not full protection, acceptable? Ask your vendor what options they offer.
2. What level of protection do you want? A 0.5 mm lead equivalent garment offers more protection than a 0.35 mm lead equivalent garment, however, it will also be heavier.
3. Consider that the protection offered by lead-free and lead-composite garments will vary substantially with the quality of radiation to which they are exposed (see Table).

<table>
<thead>
<tr>
<th>Garment</th>
<th>40 kVp</th>
<th>80 kVp</th>
<th>100 kVp</th>
<th>120 kVp</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (lead)</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>B (lead-free)</td>
<td>0.45</td>
<td>0.46</td>
<td>0.45</td>
<td>0.46</td>
</tr>
<tr>
<td>C (lead-free)</td>
<td>0.37</td>
<td>0.47</td>
<td>0.42</td>
<td>0.42</td>
</tr>
</tbody>
</table>

*The maximum error in these measurements was calculated to be ±0.02 mm.
P = primary, S = scattered.

Orthopedic strain and injury

A number of recent studies have reported on the relatively high incidence of orthopedic injury, including lumbar and cervical spine, foot, and ankle problems, among physicians performing fluoroscopically-guided procedures.*

It is important that all occupational hazards in the fluoroscopy lab be weighed and balanced, and that disproportionate focus not be placed on any single hazard.

Many different radiation protection strategies, often with similar effectiveness, can be employed. Some devices, such as mobile shields, sterile radioprotective drapes, and suspended shields, may enable physicians to reduce the weight of the protective garments they wear and therefore reduce orthopedic strain.

Feedback from occupational radiation dosimeters can also be used to analyze the effectiveness of radiation protection strategies, and adjustments to adjunct devices and protective garments can be made based on this data.


Eye protection

Radiation doses to the lens of the eye as low as 750 mGy* may result in the formation of cataracts.

Lens dose can be reduced by wearing protective leaded eyewear and also by following the other Cardinal Rules of Radiation Protection. In addition to reducing lens dose, eyewear provides the secondary benefit of acting as a splash guard.

Eye protection

Tips for reducing eye dose:

• Maintain the X-ray tube under the table when possible, and never position it over the table.
• When lateral views are used, it is much better to stand near the image receptor than the X-ray tube.
• Use suspended shields to block scattered radiation directed towards your eyes.
• Different types of lead eyewear provide different levels of protection, and side shields are important.
• Uncomfortable glasses that are not worn provide no protection.


Lead eyewear provides excellent protection, however, it does not attenuate all stray radiation that strikes it, and is susceptible to radiation scattered from the body and head. In addition, the operator is often facing the viewing monitor, which means the side of the head is exposed to the most intense radiation, the area that is typically the weakest point of lead eyewear.

The closer a shield is to a source of radiation, the more effective it is. When used appropriately, a suspended shield blocks the majority of scattered radiation directed at the head and upper body of the operator, including the thyroid and eyes. Use of a suspended shield is recommended if it does not interfere with the goals of the procedure.

Doses that are ALARA are achieved through the use of complementary radiation protection strategies.
Protective gloves

The biggest concern related to the use of protective gloves in the FOV is the likely increase in patient dose rate. Because the AEC feedback system increases radiation output to penetrate the glove, patient dose may increase. Scatter and secondary electron production in the glove itself also contribute to hand dose. These factors imply that the hand dose reduction offered by protective gloves is small,* and the same applies to protective skin creams.

Instead of relying on protective gloves or creams, develop good habits and keep your hands out of the FOV when possible.† Occasional brief exposure of the hands to the X-ray beam after it has passed through the patient is acceptable. A ring badge can be worn to monitor radiation dose to the hands if concerns arise, however, sterility concerns may need to be addressed.

Wearing protective gloves to reduce contributions to extremity dose from scattered radiation is an acceptable radiation protection practice if the hands do not enter the FOV.


Kerma area product (P_{KA})

**Advantages**

- Includes all contributions to peak skin dose
  - Fluoroscopy
  - Digital acquisition imaging
  - Etc.
- Includes information about practice habits
  - Poor collimation will result in higher P_{KA}

**Disadvantages**

- High P_{KA} not specific for high risk of skin injury
  - X-ray field size dependence
- Better indicator of risk for stochastic effects than tissue effects
Reference air kerma ($K_{a,r}$)

### Advantages
- **Preferred metric for assessing risk for skin injury**
- Includes all major contributors to peak skin dose (PSD)
- High $K_{a,r}$ is specific for a higher risk of skin injury
- Low $K_{a,r}$ is specific for low risk of skin injury
- Display is required by law on all equipment manufactured after June 10, 2006

### Disadvantages
- $K_{a,r}$ may overestimate the PSD if multiple, non-overlapping projections are used
- Relationship of $K_{a,r}$ to the PSD depends on several factors
  - Distance between IRP and skin surface
  - Beam quality and X-ray field size

Relationship between peak skin dose and $K_{a,r}$

The **peak skin dose (PSD)** is the highest radiation dose to any area of a patient’s skin. The PSD is challenging to measure, and the $K_{a,r}$ is often used as a surrogate for the PSD.

When a non-isocentric geometry is used (e.g., vascular), the $K_{a,r}$ is usually a good indicator of the PSD. That is, if the $K_{a,r}$ is 5 Gy, the PSD is close to 5 Gy.* When an isocentric geometry is used (e.g., cardiology), the $K_{a,r}$ usually underestimates the PSD because the skin of the patient is located at or near the IRP.

The exact relationship between PSD and $K_{a,r}$ depends on many factors, most notably the position of the patient with respect to the IRP. The use of dense table pads may also result in differences between the $K_{a,r}$ and PSD.

You can find more information about the relationship of PSD and $K_{a,r}$ including clinical examples, in the [Establishing a Patient Safety Program course from FluoroSafety](#).

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*Jones AK, Ensor JE, Pasciak AS. How accurately can the peak skin dose in fluoroscopy be determined using indirect dose metrics? Med Phys 41:071913, 2014.
Dose metrics and follow-up

Depending on the fluoroscope, one or more of the dose metrics that we have learned about may be available. If $K_{\text{a,r}}$ is available, it should be the metric of choice. If any of the thresholds in the table below are exceeded for a study, the irradiated skin site of the patient should be examined between two weeks and one month after the procedure to check for signs of injury.

<table>
<thead>
<tr>
<th>Dose metric</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference air kerma ($K_{\text{a,r}}$)</td>
<td>5,000 mGy</td>
</tr>
<tr>
<td>Kerma area product ($P_{\text{ka}}$)</td>
<td>500 Gy-cm$^2$</td>
</tr>
<tr>
<td>Fluoroscopy time</td>
<td>60 minutes</td>
</tr>
</tbody>
</table>

Data from NCRP Report No. 168: Radiation dose management for fluoroscopically-guided interventional procedures.

Recursive filtering

Recall that recursive filtering is an image processing technique that reduces noise in fluoroscopic images.

Recursive filtering works well when changes from one fluoroscopic frame to the next are small.

If large changes occur, or recursive filtering is too strong, artificial lag will result and the fluoroscopic images will be blurred.

Many recursive filtering algorithms incorporate protections against motion blurring. These algorithms may reduce or eliminate recursive filtering when the patient table is moved or when changes from one frame to the next exceed a threshold. Images will appear noisier when recursive filtering is reduced.
Strategies for managing motion

Motion blurs structures and organs in the fluoroscopic image, reducing contrast and hindering diagnosis and intervention. Effective motion management requires that the dominant cause of motion blur be identified and addressed. Common causes include:

**Pulse width selection:** The fluoroscopic pulse width, the length of time during which X-rays are produced by the tube, is analogous to the shutter speed in photography. It may be configured directly on a modern fluoroscope, or its value may be controlled through the selection of the organ program (imaging preset).

When configured directly, the selected width (in milliseconds) is often the maximum desirable pulse width. The actual pulse width will be affected by other parameters, such as the kV and focal spot.

Other factors that affect motion blur

**kV selection:** The selection of a low kV, especially when large amounts of added filtration are used, can cause the ADRC feedback system to select a pulse width that is wider than desirable. There is, of course, a tradeoff, as selection of a higher kV will reduce iodine contrast.

**Focal spot selection:** Smaller focal spots improve sharpness, especially for isocentric procedures. However, less power can be applied to the X-ray tube when a small focal spot is used. Tradeoffs must be made to reduce the applied power. These may include increasing the kV to reduce the tube current, or increasing the pulse width. Selection of a larger focal spot will reduce the pulse width, kV, or both.

**Recursive filtering algorithm:** Recursive filtering algorithms, which combine small fractions of several previous fluoroscopic image frames to reduce image noise, can cause artificial lag, a form of motion blur. Recursive filtering is almost always applied to fluoroscopic images to reduce image noise, however, lower levels (and perhaps no recursive filtering at all) may be applied during cardiac angiography where intra-frame motion can be substantial.
# System technical parameters for balancing patient ESDR and image quality

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Fluoroscopic pulse rate</th>
<th>ACQ frame rate</th>
<th>CINE frame rate</th>
<th>kV target†</th>
<th>Cu filtration†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vascular</td>
<td>7.5-10 pps</td>
<td>1-4 fps*</td>
<td>N/A</td>
<td>70 kVp</td>
<td>0.2-0.6 mm</td>
</tr>
<tr>
<td>Cardiac</td>
<td>15-30 pps</td>
<td>2-4 fps</td>
<td>15-30 fps</td>
<td>70 kVp</td>
<td>0.2-0.6 mm</td>
</tr>
<tr>
<td>Neurology</td>
<td>4-10 pps</td>
<td>2-7.5 fps</td>
<td>N/A</td>
<td>80 kVp</td>
<td>0.1-0.6 mm</td>
</tr>
<tr>
<td>Orthopedic</td>
<td>4-7.5 pps</td>
<td>Single shot only</td>
<td>N/A</td>
<td>80 kVp</td>
<td>0.2 mm</td>
</tr>
<tr>
<td>Urology</td>
<td>7.5-10 pps</td>
<td>1-4 fps</td>
<td>N/A</td>
<td>80 kVp</td>
<td>0.2 mm</td>
</tr>
<tr>
<td>Pain management</td>
<td>4-7.5 pps</td>
<td>1-4 fps</td>
<td>N/A</td>
<td>80 kVp</td>
<td>0.2 mm</td>
</tr>
<tr>
<td>GI</td>
<td>4-10 pps</td>
<td>1-4 fps</td>
<td>N/A</td>
<td>90 kVp</td>
<td>0.2 mm</td>
</tr>
</tbody>
</table>

*Occasionally higher frame rates will be necessary, e.g., spinal embolization (7.5 fps)
†For a typical patient with normal BMI during fluoroscopic imaging
The “Tetrad”
The four most important things to remember before starting a fluoroscopic procedure

Raise the patient table to the highest comfortable working height

Lower the image receptor as much as practicable

Take one step back away from the fluoroscope

Collimate the X-ray field to the area of interest

Also, don’t forget to check the reference air kerma ($K_{a,r}$) occasionally!
Dose Reduction Opportunities from the Advanced Training Program on the Safe Use of Fluoroscopy

1. Maintain the patient as far as practicable from the X-ray source. This means raising the patient support to the highest comfortable working level.
2. Maintain the image receptor as close to the patient as practicable.
3. Always use the spacer cone.
4. Use a PA projection whenever possible. Lateral and oblique projections increase patient and operator dose.
5. Remove the grid when performing procedures on small patients (less than 50 lbs).
6. Use the least amount of magnification necessary to perform the procedure.
7. Always collimate to the anatomical area of interest.
8. Use pulsed fluoroscopy instead of continuous fluoroscopy. Ensure that the pulse rate in fluoroscopy mode and the frame rate in acquisition mode are as low as practicable.
9. Become familiar with the vendor-specific dose reduction features of your fluoroscope.
10. Pregnant and pediatric patients require special consideration. Use the pregnant and pediatric patient checklists included in this booklet on every patient, every time.
Pediatric patient checklist

☐ Anti-scatter grid removed if patient weighs less than 50 lbs.
☐ If available, reduced dose pediatric program selected, including pediatric AEC control curve
☐ Lowest practicable fluoroscopic pulse rate and DSA frame rate selected
☐ Use of digital acquisition restricted or eliminated, use Store Monitor/Store Fluoro
☐ Patient as far from X-ray source as practicable
☐ Image receptor as close to the patient as practicable
☐ Lowest magnification practicable selected
☐ X-ray beam collimated tightly to area of interest
Pregnant patient checklist

☐ Apron positioned on X-ray tube side of patient to identify the level of the conceptus
☐ Conceptus maintained outside FOV
☐ Lowest practicable fluoroscopic pulse rate and DSA frame rate selected
☐ Use of digital acquisition restricted or eliminated, use Store Monitor/Store Fluoro
☐ Patient as far from X-ray source as practicable
☐ Image receptor as close to the patient as practicable
☐ Lowest magnification practicable selected
☐ X-ray beam collimated tightly to area of interest