Patient safety during fluoroscopically guided medical procedures

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A brief history

Physician viewing fluorescent screen in a direct-view fluoroscopy system. National Library of Medicine
A brief history
Background and definitions

• Interventional reference point (IRP)
• FDA reference point
• Reference point air kerma ($K_{a,r}$)
  – Cumulative dose
  – Reference point dose
• Kerma area product
  – Dose area product
• Peak skin dose
• 95% area load
Relative merits of each

RISKS OF FLUOROSCOPICALLY GUIDED PROCEDURES
Who is at risk?

- Physicians
- Nurses
- Technologists
- Anesthesiologists
- Patient
- Facility
Risks to the operator and staff

- Radiation-induced cataracts
- Radiation-induced cancer
- Infection
- Back injury
- Falls
- Heavy objects
- Litigation
Risks to the patient

• Death
• Puncture of vessel
• Contrast reaction
• Hematoma
• Infection
• Radiation-induced cancer
  – Solid tumor
  – Leukemia
• Deterministic skin injury
• Radiation-induced epilation
Classification of biological effects

Biological effects from ionizing radiation can be broadly classified into two types:

**Deterministic effects**: Effects where the severity of the outcome increases with radiation dose past a certain *threshold*. Radiation doses below the threshold will not result in an effect.

**Stochastic effects**: An effect where the probability of occurrence increases with increasing dose. If the effect occurs, its severity will not depend on dose. No threshold exists for stochastic effects.
Stochastic vs. deterministic

Winning the lottery
Winning the lottery is an example of a stochastic effect
- Buying more tickets increases your chances of winning
- You cannot buy enough tickets to guarantee a win
- You have a chance of winning, albeit very small, with a single ticket
- The amount of money you win is not related to the number of tickets you buy – you win all or nothing

Burning your hand on a stove
Burning your hand on a stove is an example of a deterministic effect
- You can leave your hand on for a very short time and not injure yourself
- If you leave your hand on long enough, you will be burned
- The longer your hand remains on the stove, the more severe the resulting burn
Classification of biological effects

Examples of the **deterministic effects** of exposure to ionizing radiation include cataract formation and radiation induced skin changes

- Skin changes do not occur below some threshold dose. However, once this threshold has been exceeded, the severity of the injury increases with increasing dose.

Cancer is an example of a **stochastic effect** of exposure to ionizing radiation

- Cancer may occur with any exposure to ionizing radiation or may not occur with exposure to large amounts of ionizing radiation. The severity of the effect is constant regardless of the total exposure *i.e.*, one either develops cancer or does not develop cancer.
Radiation induced cancer

• Stochastic effect – risk $\uparrow$ linearly with dose

• Risk depends on
  1. Volume of tissue irradiated
  2. Type of tissue irradiated
  3. Total dose delivered to tissue
  4. Age of patient
  5. Patient genetics

• There is always a risk of stochastic effects if we use ionizing radiation, but we can minimize
Stochastic effects

• Stochastic effects, most notably cancer, can also be induced by (but not linked to) prolonged fluoroscopic procedures

• In some cases the risk to the patient can be reduced

Radiation induced skin injury

• Deterministic effect
  – Risk = 0 below a certain dose, risk = 1 above*
  – Severity increases with increasing dose above $D_{th}$

• In most cases, can be prevented
  – Training of operators
  – Safety program
  – QC of equipment
Thresholds

• For many years, hard thresholds for various types of deterministic skin injuries were quoted

• It has become apparent that these “thresholds” vary widely between patients

• Depends on
  1. Patient genetics
  2. Prior skin irradiation
  3. Disease state/treatment
### Table 1

<table>
<thead>
<tr>
<th>Band</th>
<th>Single-Site Acute Skin-Dose Range (Gy)*</th>
<th>NCI Skin Reaction Grade†</th>
<th>Prompt</th>
<th>Early</th>
<th>Midterm</th>
<th>Long Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0–2</td>
<td>NA</td>
<td>No observable effects expected</td>
<td>No observable effects expected</td>
<td>No observable effects expected</td>
<td>No observable effects expected</td>
</tr>
<tr>
<td>A2</td>
<td>2–5</td>
<td>1</td>
<td>Transient erythema</td>
<td>Epilation</td>
<td>Recovery from hair loss</td>
<td>No observable results expected</td>
</tr>
<tr>
<td>B</td>
<td>5–10</td>
<td>1–2</td>
<td>Transient erythema</td>
<td>Erythema, epilation</td>
<td>Recovery; at higher doses, prolonged erythema, permanent partial epilation</td>
<td>Recovery; at higher doses, dermal atrophy or induration</td>
</tr>
<tr>
<td>C</td>
<td>10–15</td>
<td>2–3</td>
<td>Transient erythema</td>
<td>Erythema, epilation; possible dry or moist desquamation; recovery from desquamation</td>
<td>Prolonged erythema; permanent epilation</td>
<td>Telangiectasia; dermal atrophy or induration; skin likely to be weak</td>
</tr>
<tr>
<td>D</td>
<td>&gt;15</td>
<td>3–4</td>
<td>Transient erythema; after very high doses, edema and acute ulceration; long-term surgical intervention likely to be required</td>
<td>Erythema, epilation; moist desquamation</td>
<td>Dermal atrophy; secondary ulceration due to failure of moist desquamation to heal; surgical intervention likely to be required; at higher doses, dermal necrosis, surgical intervention likely to be required</td>
<td>Telangiectasia; dermal atrophy or induration; possible late skin breakdown; wound might be persistent and progress into a deeper lesion; surgical intervention likely to be required</td>
</tr>
</tbody>
</table>

Note.—Applicable to normal range of patient radiosensitivities in absence of mitigating or aggravating physical or clinical factors. Data do not apply to the skin of the scalp. Dose and time bands are not rigid boundaries. Signs and symptoms are expected to appear earlier as skin dose increases. Prompt is <2 weeks; early, 2–8 weeks; midterm, 6–52 weeks; long term, >40 weeks.

* Skin dose refers to actual skin dose (excluding backscatter). This quantity is not the reference point air kerma described by Food and Drug Administration (21 CFR §1020.32 [2006]) or International Electrotechnical Commission (57). Skin dosimetry is unlikely to be more accurate than ± 50%. NA = not applicable.

† NCI = National Cancer Institute

‡ Telangiectasia associated with area of initial moist desquamation or healing of ulceration may be present earlier.

Radiation injuries

• Radiation-induced skin injuries are particularly troublesome for several reasons
  – Patient does not experience any sensations
  – Latent period means that cause and effect may not be connected by patient or care providers
Multiple coronary angiography, angioplasty, and bypass graft on a single day – estimated peak skin dose > 20 Gy
Radiation injuries

• Radiation injuries can be particularly gruesome and, depending on severity, may never completely heal.

• Most injuries are entirely preventable.


Stages of skin injury

1. Initial response
2. Main response
3. Late effects
4. Permanent changes
Initial response

• The initial response of the skin to X radiation is much like a sunburn
• Erythema caused by vasodilation and release of histamine and other inflammatory agents by mast cells
• The initial response occurs within a few hours and subsides within a few days
  – Presence can be indicative of high likelihood for severe response

Main response

- Main responses include
  - Erythema
  - Dry desquamation
  - Moist desquamation
  - Epilation
    - Temporary or permanent
- Dry and moist desquamation are caused by depopulation of clonogenic cells in the stratum basale
- Epilation is caused by damage to hair follicles

Dry desquamation/epilation


http://latimesimage2.trb.com/lanews/media/photo/2009-12/50945817.jpg
Healing

• Healing of early effects is a result of repopulation of healthy skin cells

• Repopulation occurs from
  1. Surviving clonogenic cells within the irradiated area or
  2. Migration of healthy clonogenic cells from outside the field

Late effects

- Late effects include dermal atrophy, ulceration, telangiectasia, dermatitis, sclerosis, and necrosis
- Occur months to years after main effects
- Caused primarily by vascular damage to the dermis

Permanent skin changes

- Certain radiation-induced skin changes can be permanent
- Hyper- or hypo-pigmentation
- Telangiectasia
- Scarring
- Induration
What can we do?

- **Reduce** the risk of radiation-induced cancer for operator, staff, and patient
- **Prevent** most deterministic effects such as radiation-induced cataracts and skin injuries
- **Recognize** situations where a high probability for injury exists so the patient can be appropriately medically managed
Three-pronged approach

• Pre-procedure actions
• Intra-procedure actions
• Post-procedure actions
Quality Initiatives

Establishing an Interventional Radiology Patient Radiation Safety Program

Joseph R. Steele, MD • A. Kyle Jones, Ph.D. • Elizabeth P. Niman, PA-C

The Interventional Radiology Patient Radiation Safety Program was created to better educate patients who are scheduled to undergo high-dose interventional radiologic procedures about the risks of radiation, better monitor the delivered doses, and reduce the risk for deterministic effects. The program combines preprocedure evaluation and counseling, intraprocedure monitoring, and postprocedure documentation and counseling with the guidelines of the National Cancer Institute and the Society of Interventional Radiology. Between July 2009, when the program was implemented, and September 2010, over 3500 interventional radiologic procedures were monitored and documented, and 63 procedures with an adjusted cumulative dose of more than 3 Gy were identified and further analyzed; four procedures were found to be outside the control limits. Additional review of these four procedures resulted in practice modifications. Anecdotal feedback from physician assistants and attending physicians indicated that the program had another positive effect: Patients who required postprocedure counseling about the potential for radiation-induced skin injuries were no longer surprised by this information. Implementation of this program is straightforward, requires little infrastructure and few resources, and may be applied in most interventional radiology practices. Supplemental material available at http://radiographics.rsna.orglookup/suppl/doi:10.1148/rg.321115002/-DC1.

Abbreviations: CD = cumulative dose, CDc = actual cumulative dose, DAP = dose-area product, RAD-II = Radiation Doses in Interventional Radiology Procedures

Radiographics 2012; 32:277–287 • Published online 10.1148/rg.321115002 • Content Codes: [R] QA

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Pre-Procedure

• Consent ing process
  – Medico-legal aspects
• Patient education
  – Requires staff education
  – Easy-to-understand pamphlets
• Identification of high-risk patients
  – Certain conditions may pre-dispose patient to injury
    • Diabetes mellitus, connective tissue disorders
  – Prior high-CD procedures (JC aspects)
  – RIS
• Credentialing and privileging of users of fluoroscopic equipment
• Procedure planning
Intra-Procedure

• $K_{a,r}$ thresholds
• Ongoing faculty and staff education
  – Dose reduction techniques
    • Removal of grid
    • Store loop/store monitor, not acquisition
  – Be in the room
    • YDNKWIHUYKWIH
• Reduced dose protocols
  – Patients identified during pre-procedure process
• Situational awareness
  – Prior high-dose procedure – projection considerations
Post-Procedure

- Follow-up protocol
- Record dose descriptors *somewhere*
  - $K_{a,r}/KAP/#$ of DynaCT/# of exposures/time
    - RIS
    - Medical record
    - PACS
    - Structured dose reporting is here
- Flag high-dose cases for f/u
  - $K_{a,r} = 5$ Gy (NCRP 168)
  - Procedure specific?
PRE-PROCEDURE ELEMENTS
Informed consent

“Informed consent is a patient's right to be presented with sufficient information, by either the physician or their representative, to allow the patient to make an informed decision regarding whether or not to consent to a treatment or procedure.”

http://www.med-ed.virginia.edu/courses/rad/consent/
Informed consent

- Lack of informed consent is grounds for malpractice lawsuit
- Ethical considerations

I (we) also realize that the following risks and hazards may occur in connection with this particular procedure: *Specific Information Here*

- **ARTERIOGRAPHY / VENOGRAPHY**
  1. Injury to artery or vein.
  2. Loss of function or damage to parts of the body supplied by the artery or vein.
  3. Swelling, pain, tenderness, or bleeding at site of blood vessel perforation.
  4. Aggravation of the condition that necessitated the procedure.
  5. Allergic reaction to injected contrast media.
  6. Possible kidney damage from injected contrast media.

- **INTERVENTIONAL**
  - Pain
  - Bleeding
  - Infection
  - Damage to Surrounding Structures
  - Pneumothorax (Collapsed Lung)
  - Hemoptysis (Coughing Up Blood)
  - Risk of radiation-induced skin injury; In rare cases of lengthy or complex procedures utilizing x-ray, radiation-induced skin injuries have been reported (<1% of cases)

- **Off-Label Use**
I (we) also realize that the following risks and hazards may occur in connection with this particular procedure: *Specific Information Here*

- Arteriography
- Venography
- Interventional

1. Injury to artery or vein
2. Loss of function or damage to parts of the body supplied by the artery or vein
3. Swelling, pain, tenderness or bleeding at site of blood vessel perforation
4. Aggravation of the condition that necessitated the procedure
5. Allergic reaction to injected contrast media
6. Possible kidney damage from injected contrast media
7. ________________________________

- Pain
- Bleeding
- Infection
- Damage to surrounding structures
- Pneumothorax
- Hemothysis (coughing up blood)
- Headache
- Nausea/Vomiting
- Nerve damage
- Paralysis
- Side effects of intrathecal chemo therapy
- Stroke
- ________________________________

Just as there may be risk and hazards in continuing my present condition without treatment, there are also risks and hazards related to the performance of the surgical, medical, and/or diagnostic procedures planned for me.

I (we) realize that common to surgical, medical, and/or diagnostic procedures, is the potential for infection, blood clots in veins and lungs, hemorrhage, pain, emergent coronary bypass surgery, myocardial infarction, arrhythmia’s, renal failure, stroke, allergic reactions, and even death.
Patient education

• Care providers must have the tools and knowledge to explain the risks to the patient without inducing panic

• One approach to this is a pamphlet/handout
  – Mechanisms of injury
  – How we manage radiation
  – Follow up

• Only for certain patients
Identify high-risk patients

• Certain conditions are suspected to pre-dispose patients to radiation induced skin injuries
  – Diabetes mellitus (microvascular disease)
  – Connective tissue disorders
  • Marfan syndrome
  – Ataxia telangiectasia
  – Drug interactions

• Also, a recent high dose procedure can result in the induction of injuries at lower doses in the future


Identify high-risk patients

• Most easily done during the consenting process
• The RIS can be a valuable tool for automatically identifying and flagging these patients
  – Only if the prior procedure was performed in your system or practice
• High risk patients can be routed to a dose sparing protocol, physician can be advised
  – Fewer acquisition runs, more storing of fluoro
  – Alternate $K_{a,r}$ thresholds
  – Postpone procedure?
Multiple and repeated procedures

• Two scenarios
  1. By performing a very complex case in multiple sessions, fx can be used to reduce the likelihood of late effects
  2. If a procedure is repeated, an unexpected skin reaction may occur as the Biologically Equivalent Dose from the two procedures is greater than the dose from the most recent procedure
Physician/staff education

• Physicians performing complex procedures should be trained in the safe use of fluoroscopic equipment

• Continuing education is also necessary considering frequent technological advances

• Understand dose saving features of each type of equipment on which they work
  — Hands-on component
Credentialing vs. privileging

- **Credentialing**: The process by which providers are certified to practice their specialty
  - Board certification
  - State licensure
  - Specialty boards, CAQ

- **Privileging**: The process by which providers are approved to perform specific procedures
  - Certain credentials may be necessary
  - Perform certain number of procedures under personal supervision
  - Continue to perform minimum number of procedures
Continuing education

• Maintenance of Certification and some states require Continuing Medical Education
  – Certain number of hours specific to fluoroscopy may be required

• Vital to stay current and be aware of advances in your discipline/specialty
For example

- ACR looking to require either:
  - Certain credentials
    - Board certification by ABR, etc.
  - OR
  - Privileges to perform specific procedures
    - Education requirements
    - Supervision requirements
Education requirements

• Basic radiation physics
• Basic fluoroscopic physics
• Radiation biology
• Radiation protection
• Radiation safety
• Advanced fluoroscopic physics
  – Patient dose management
• Hands on training also useful
  – Impracticalities
  – Can applications specialists be trusted to provide this?
Advanced Training Program: A Comprehensive Course in the Safe Use of Fluoroscopy

For medical professionals who routinely use fluoroscopy in the diagnosis and treatment of disease.

A. Kyle Jones, Ph.D., Alexander S. Pasciak, Ph.D. and Joseph R. Steele, M.D.
INTRA-PROCEDURE ELEMENTS
K_{a,r} thresholds

- All equipment manufactured after June 2006 is required by law to display $K_{a,r}$
- Alerting the physician at certain thresholds guarantees there are no surprises at the end of a case
- Decisions can be made based on medical management at each threshold
  - Pace of procedure
  - Good practice – YDNKWIHUYKWIH
  - Continuation of procedure at a later time
Establishing $K_{a,r}$ thresholds
<table>
<thead>
<tr>
<th>Threshold</th>
<th>Actions Taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000 mGy</td>
<td>Technologist will notify radiologist that a CD of 2000 mGy has been reached. Radiologist will ensure that radiation is being used appropriately and sparingly. Procedure continues normally.</td>
</tr>
<tr>
<td>3000 mGy</td>
<td>Technologist will notify radiologist that a CD of 3000 mGy has been reached. Radiologist will ensure that radiation is being used appropriately and sparingly. Case should be flagged upon completion.</td>
</tr>
</tbody>
</table>
| 4000 mGy   | Technologist will notify radiologist that a CD of 4000 mGy has been reached. Radiologist will ensure that radiation is being used appropriately and sparingly.  
Threshold for erythema may have been reached, depending on the position of the patient relative to the IRP and orientation of the C-arm during the procedure. Radiologist will assess risk/benefit pace of procedure. Radiologist will ensure that radiation is being used appropriately and sparingly. Technologist considers paging on-duty medical physicist. |
| 6000 mGy   | Technologist will notify radiologist that a CD of 6000 mGy has been reached.  
Radiologist will assess risk/benefit pace of procedure. Radiologist will ensure that radiation is being used appropriately and sparingly. |
| 7000 mGy   | Technologist will notify radiologist that a CD of 7000 mGy has been reached. Radiologist will ensure that radiation is being used appropriately and sparingly. |
| 8000 mGy   | Technologist will notify radiologist that a CD of 8000 mGy has been reached. Threshold for severe skin effects may have been reached. Radiologist will assess risk/benefit pace of procedure and consider continuing the procedure at a later time, depending on patient’s condition. If procedure continues, radiologist will ensure that radiation is being used appropriately and sparingly. Extreme caution should be exercised past this point, and all possible dose reduction methods used, including restricting use of acquisition mode and DSA. |
| +1000 mGy  | Technologist will notify radiologist that a CD of +1000 mGy has been reached. Radiologist will ensure that radiation is being used appropriately and sparingly. |

* DynaCT runs do not contribute significantly to peak skin dose (PSD). This should be considered in cases that utilize DynaCT heavily. An average DynaCT run contributes approximately 200 mGy to the displayed CD.
Published recommendations

Table 3
Summary of Radiation Monitoring Dose Notification Thresholds

<table>
<thead>
<tr>
<th>Parameter</th>
<th>First Notification</th>
<th>Subsequent Notifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak skin dose (PSD)</td>
<td>2,000 mGy</td>
<td>500 mGy</td>
</tr>
<tr>
<td>Reference point air kerma (Kₐ,r)</td>
<td>3,000 mGy</td>
<td>1,000 mGy</td>
</tr>
<tr>
<td>Kerma-area-product (PₖA)</td>
<td>300 Gy · cm²*</td>
<td>100 Gy · cm²*</td>
</tr>
<tr>
<td>Fluoroscopy time (FT)</td>
<td>30 min</td>
<td>15 min</td>
</tr>
</tbody>
</table>

* Assuming a 100-cm² field at the patient’s skin. The value should be adjusted to the actual procedural field size.


<table>
<thead>
<tr>
<th>Air kerma at the IRP (Gyₐ)</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Advise physician that IRP air kerma is 2 Gyₐ so that he/she can assess the benefit/risk pace of the procedure.</td>
</tr>
<tr>
<td>4</td>
<td>Advise physician that IRP air kerma is 4 Gyₐ and that the threshold for erythema might have been reached, depending on how the beam is oriented and how often it has been rotated. Consider moving the projected view to a different skin site.</td>
</tr>
<tr>
<td>6</td>
<td>Advise physician that IRP air kerma is 6 Gyₐ and that the threshold for moderate to severe skin effects might have been reached, depending on how the beam is oriented and how often it has been rotated. Consider moving the projected view to a different skin site.</td>
</tr>
<tr>
<td>8</td>
<td>Advise physician that IRP air kerma is 8 Gyₐ, and that beyond this point there is a potential for severe skin effects, depending on how the beam is oriented and how often it has been rotated. Benefit-risk depends on how critical the patient’s condition is.</td>
</tr>
</tbody>
</table>

Reduced dose protocols

- Many elements of a protocol can be adjusted to reduce radiation dose to the patient
  - Reduce IAKRD for fluoroscopy
  - Reduce IAKRD for acquisition
  - Reduce frame rate for acquisition*
  - Reduce pulse rate for fluoroscopy*
  - Use low dose AEC curve
  - Use additional filtration*
Situational awareness

• For patients who have undergone a recent high dose procedure, use a different projection to reduce skin dose
  – Will definitely reduce 95% area load
  – May not reduce PSD

• May not be able to completely eliminate overlap, but for angled projections can have large benefit
  – Importance of tight collimation
Does “Spreading” Skin Dose by Rotating the C-arm during an Intervention Work?

Alexander S. Pasciak, PhD, and A. Kyle Jones, PhD

ABSTRACT

PURPOSE: To determine if C-arm rotation is beneficial for reducing peak skin dose (PSD) in interventional radiology (IR) and, if so, under what circumstances.

MATERIALS AND METHODS: The Monte Carlo method was used to perform ray tracing for detailed analysis of the effect of C-arm rotation on PSD across a range of patient sizes, C-arm configurations, and procedure types. Automatic dose-rate control curves were generated for modern fluoroscopic systems and were used in the simulations.

RESULTS: Rotating the C-arm to reduce the PSD in most cases contradicted results in increased PSD when the C-arm is rotated from an original posterior-anterior projection, in some cases resulting in a PSD increase by a factor of 5 or more. When prophylactic rotation was performed before a procedure, however, and the C-arm was rotated between opposed, distinct oblique angles, substantial reduction in PSD was achieved for patients of any size.

CONCLUSIONS: Rotating the C-arm during a procedure with the aim of “spreading” dose on the skin of the patient may not result in a reduction in PSD and may increase PSD. However, when used as a prophylactic measure combined with tight collimation, C-arm rotation can be used as a tool to reduce PSD. Tight collimation greatly increases the benefit of C-arm rotation.

ABBREVIATIONS

ADRC = automatic dose rate control, Kₑ = reference point air kerma, LAO = left anterior oblique, PSD = peak skin dose, RAO = right anterior oblique, SSD = source-to-skin distance

Fluoroscopically guided interventional procedures, which are minimally invasive and have fast recovery times, have become the preferred treatment for many conditions that previously required open surgical intervention. In addition, modern fluoroscopic imaging systems, and in particular adjuncts such as three-dimensional rotational angiography, have increased the scope of interventional radiology (IR) procedures (1–5). As the scope of fluoroscopically guided IR has increased, so has the complexity of the procedures, sometimes necessitating extensive use of ionizing radiation or repeated applications, which may put the patient at risk for deterministic skin injury (6,7). Radiation-induced skin injuries are a rare but potentially debilitating side effect of lengthy IR procedures (7–11).

Methods for reducing peak skin dose (PSD) (this term and others that appear in this article are defined in Table 1) have been addressed extensively (6,12–17). One technique that has often been recommended in rotation of the C-arm at various times during a procedure (6,12,14–16). Although one such recommendation is specific to interventional cardiology (12), most authors make general recommendations. This practice is common and is often taught to radiology residents and fellows during clinical training and in commercially available credentialing programs (15). The technique is often applied in a casual fashion, with little knowledge of how the rotation actually affects the PSD, especially for different patient and x-ray field sizes. Also, timing of C-arm rotation, doses, angles, electronic magnification mode, patient size, and the radiographic magnification factor each impacts the effectiveness of varying the C-arm angle and should be considered individually.

Interventional cardiology and IR procedures are performed with different imaging geometries. Because it is often necessary to rotate the C-arm in interventional cardiology procedures to obtain different projections for diag-
Figure 5. Zero-overlap angle as a function of patient size for rotation from initial posteroanterior projection. (a) Abdominal interventions. (b) Pelvic interventions. Lines show the minimum angle to which the C-arm must be rotated, as a function of patient size, to avoid completely overlap between the x-ray field entrance sites on the patient’s skin. Each different line corresponds to a different x-ray field size or shape or both.
### Table 4. Efficacy of C-arm Rotation Angles for Prophylactic Approach for Abdominal Interventions

<table>
<thead>
<tr>
<th></th>
<th>Octagonal XRll (cm)</th>
<th>Rectangular Flat Panel (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>±30 degrees RAO/LAO</td>
<td>40  28  20  14  7</td>
<td>42  32  22  16  11</td>
</tr>
<tr>
<td>95th percentile</td>
<td>Y    Y    Y    N    N</td>
<td>Y    Y    N    N    N</td>
</tr>
<tr>
<td>90th percentile</td>
<td>Y    Y    N    N    N</td>
<td>Y    Y    N    N    N</td>
</tr>
<tr>
<td>50th percentile</td>
<td>Y    Y    Y    N    N</td>
<td>Y    Y    N    N    N</td>
</tr>
<tr>
<td>10th percentile</td>
<td>Y    Y    Y    Y    N</td>
<td>Y    Y    Y    N    N</td>
</tr>
<tr>
<td>5th percentile</td>
<td>Y    Y    Y    Y    N</td>
<td>Y    Y    Y    N    N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>±20 degrees RAO/LAO</th>
<th>40  28  20  14  7</th>
<th>42  32  22  16  11</th>
</tr>
</thead>
<tbody>
<tr>
<td>95th percentile</td>
<td>Y    Y    Y    Y    N</td>
<td>Y    Y    N    N    N</td>
</tr>
<tr>
<td>90th percentile</td>
<td>Y    Y    Y    N    N</td>
<td>Y    Y    N    N    N</td>
</tr>
<tr>
<td>50th percentile</td>
<td>Y    Y    Y    Y    N</td>
<td>Y    Y    Y    Y    N</td>
</tr>
<tr>
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<td>Y    Y    Y    Y    N</td>
<td>Y    Y    Y    N    N</td>
</tr>
<tr>
<td>5th percentile</td>
<td>Y    Y    Y    Y    N</td>
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<td>Y    Y    Y    Y    Y</td>
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**Note:** Y indicates that there is overlap between opposed oblique projections; N indicates no overlap. The minimum angle for which no overlap is present considering patient and x-ray field size should be used. LAO = left anterior oblique, RAO = right anterior oblique, XRll = x-ray image intensifier.
POST-PROCEDURE ELEMENTS
Record dose descriptors

• Medical record has been suggested
  – Perhaps difficult
  – May not be searchable
    • Dictated
    • Scanned

• DICOM Structured Dose Reporting is here
  – Just installed our first system (VC14)
  – Legacy systems may never support
    • Manufacturers have agreed to retrofit back to a certain date
  – Third party options are available

• DICOM headers contain some information
Patient Info: 
Name: [Redacted] 
Sex: [Redacted] 
ID: [Redacted] 
DOB: [Redacted] 
ACCT#: [Redacted] 
Print Date: [Redacted] 
Location: [Redacted]

Patient Position: HFS 

1. DR 
A 66kV 475mA 115.0ms 0.6CL small 0.2Cu 48.0cm 
 ***** 17-Apr-09 13:29:19 1F/s 17-Apr-09 14:26:13
45.4μGy² 1.3mGy LAAO OACR 1F

2. DR 
A 66kV 486mA 118.1ms 0.6CL small 0.2Cu 48.0cm 
 ***** 17-Apr-09 14:27:13 1F/s 17-Apr-09 14:27:13
47.7μGy² 1.4mGy LAAO OACR 1F

3. DR 
A 68kV 436mA 105.6ms 100CL small 0.1Cu 48.0cm 
 ***** 17-Apr-09 14:32:10 1F/s 17-Apr-09 14:32:10
69.1μGy² 2.0mGy LAAO OACR 1F

4. DR 
A 68kV 437mA 105.8ms 100CL small 0.1Cu 48.0cm 
 ***** 17-Apr-09 14:33:19 1F/s 17-Apr-09 14:33:19
69.4μGy² 2.0mGy LAAO OACR 1F

***Accumulated exposure data*** 
Phys: Exposures: 4 Fluoro: 2.0min Total: 769.4μGy² 22.2mGy
Record dose descriptors

• Other possibilities include RIS or logbooks
  – Would like it to be searchable
    • Tracking
    • Practice improvement
    • Identify/prevent sentinel events

• We went with the RIS
  – Manual entry into designated fields
  – Reports can be generated, already linked with procedure (accession number)
  – Automatic analysis of data/entry into database

• Now changing to third party solution – PEMNET
Record dose descriptors

• What we record:
  – $K_{a,r}$
  – KAP
  – Number of acquisition runs
  – Number of rotational angiography runs (DynaCT)
  – Fluoroscopy time
Flagging and f/u of high dose cases

• A high dose case is flagged by the technologist, triggering a follow-up protocol (PA):
  – Patient informed that significant dose (>= 5 Gy) was reached
  – Patient instruction (pamphlet)
    • Signs/symptoms (red area the size of your hand)
    • Instructions (do not scratch or itch)
    • Actions (call us)
  – Telephone or in-person f/u scheduled for 4 weeks
  – Print dose report and archive

• Flag = 5 Gy
  – NCRP 168
Interventional Radiology: Post Procedure Radiation Exposure Information Sheet

Procedure: __________________ Procedure Date:_____

Affected Area: __________________

The procedure you recently underwent is one of the more complex interventions performed by our service. This type of procedures is done with x-ray imaging and requires the use of higher radiation doses compared to other diagnostic imaging studies like chest x-rays or CAT scans.

How much radiation you are exposed to depends on what procedure you have and your specific condition. We make every attempt to minimize the radiation dose but we must weigh the minimal risks of higher exposure to the benefits of the procedure. In general, the risk of complications related to radiation exposure is very small, and substantially less than the other risks of the procedure. Your procedure required a dose of radiation at the upper end of our usual range and while we do not expect to see any effects of the radiation there is a small chance that it could cause skin changes in the area that was treated. These changes might include an area of redness, localized hair loss, itching or flaking of the skin in the exposed area. These changes are usually temporary and fade away within a few days or weeks. In very rare situations more severe damage to skin can require medical attention.

The Physician Assistant (PA) will schedule a telephone follow-up with you next month. During this follow-up, the PA will ask you a few questions about the area of skin that was exposed to high levels of radiation to determine if further treatment or observation is needed.

Please watch for any of these symptoms. The easiest way is to have someone look at your skin, as the area of skin exposed to radiation is on your back. If no one else can help you, do your best by looking in a mirror.

Signs to look for:

• A red area, about the size of your hand
• Flaking skin, like a sunburn
• Areas of localized hair loss
• Constant itching in the affected area

If you see any of these signs, make a note of them and bring them to the attention of the PA during the telephone follow-up. This information will be used to determine if any further treatment is needed, or if the changes will resolve without intervention.

Please do your best not to scratch the irritated area. This can lead to further changes in your skin.

On the diagrams to the right, circle the areas where you are experiencing skin changes. Report these changes to your health care provider on your next visit.

Peak skin dose (PSD) reconstruction

• Many sources of information are available
• A qualified medical physicist can perform a detailed PSD reconstruction
• The process can be automated with server based systems that collect dose information from all systems
Measuring the PSD

• Radiochromic film can be used to measure PSD
• Dose information can be assessed in two ways:
  – A calibrated strip can be used to estimate PSD
  – The film can be scanned and decalibrated to determine PSD

http://online1.ispcorp.com/_layouts/Gafchromic/content/products/xrr/pdf/doseverstripguide.pdf, 10/08
Medical management of skin reactions

- Very high skin doses are only seen in the context of long fluoroscopic procedures
- Knowing who to consult regarding skin reactions is tricky
- Dermatologists may never have seen these types of reactions
- Radiation oncologists seem to be the best to discuss these matters with
  - May not see late/acute effects of same severity
Practice improvement

• Dose information collected can be used to calculate metrics for data driven practice improvement
  – Compare dose metrics to national averages
    • RAD-IR study
  – Identify procedures/physicians/etc. for improvement
  – Control charts for identifying exceptional variation
    • Discuss high dose cases/reactions at M+M
  – Limit liability for procedures performed elsewhere
Hepatic embolization

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Control charts

Figure 5. Details of the four cases that were outside control limits. These cases were reviewed and used to provide learning opportunities. $BMI =$ body mass index, $DSA =$ digital subtraction angiography.
Other areas for concern

• Wound healing
  – Pre-surgery spinal embolization
  – 8, 10, 12 Gy cases
  – How do wounds heal after these doses are delivered < 24 hr prior to surgery?
    • Damage to fibroblasts
    • Literature – only a few papers about mouse experiments

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<td>1.16</td>
<td>0.39, 3.68</td>
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In certain circumstances

• It is necessary and appropriate to administer a high dose of radiation during a fluoroscopically guided procedure
• One must still be conscious of how much radiation has been used
• The risk of injury must be commensurate with the benefits of the procedure
• Medical management after the procedure must be appropriate
Further reading

  - SIR Standards of Practice Committee
  - SIR Safety and Health Committee
  - Discharge/consenting examples
- NCRP Report 168
Acknowledgements

• Mark Sultenfuss, M.D.
• Joseph Steele, M.D.
• Alex Pasciak, Ph.D.