Optimizing dose and image quality in fluoroscopy

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Disclosure

• I am co-owner of Fluoroscopic Safety, LLC, a company that markets educational programs on the safe use of fluoroscopy
Educational objectives

• Identify targets for dose and image quality optimization in fluoroscopy
• Describe strategies for exploiting these targets
• Realize that dose optimization must be consider in the broader context of procedural goals
Optimize, not reduce

• We should always be speaking in terms of **optimizing** clinical procedures that are **justified**

• The use of “dose reduction” implies efforts to reduce dose without consideration of image quality

• Especially in fluoroscopy, attempting to reduce dose with a blind eye towards image quality can actually **increase** dose in the end
Targets for optimization

- Equipment configuration/calibration
- Practice/use of fluoroscopy
- Technology
EQUIPMENT CONFIGURATION AND CALIBRATION
Easy targets for optimization

- Minimum filtration
- Positioning without radiation configured to be enabled by default
- Configure desired organ program to be loaded by default
- Use of variable frame rate
- Mask averaging
- Choose the right equipment
- Use pulsed fluoroscopy and configure it to use the Aufrichtig scale
Effect of tube filtration on surface dose (microgray) for same detector signal to noise ratio.

Bushberg et al. The Essential Physics of Medical Imaging, 3rd ed.
Contrast and beam quality

- Iodine contrast is strongly affected by beam quality
- The addition of filtration allows the use of low kV while maintaining dose at an acceptable level
  - Traditional, Program-Switched
- Sacrifices may need to be made to maintain kV at desired level
  - E.g., focal spot

Balancing filtration

- Impact in FLU vs. ACQ
- Must consider impact on related organ program parameters
  - Pulse width
  - Focal spot size
- Configuration options
  - “Traditional” method
    - Static filter
  - “Program-switched” method
    - Filtration linked to organ program (e.g., Philips)
    - Seissl method (e.g., Siemens)

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<thead>
<tr>
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<tbody>
<tr>
<td>1 HAE 2K</td>
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<td>Fluoro Angio</td>
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<td>Fluoro Angio</td>
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<td>7.5 P/s</td>
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<td>15 P/s</td>
</tr>
<tr>
<td>3 DynaCT</td>
<td>HEPATIC VFR Manual</td>
<td>5s-1k DR 1.5°F</td>
<td>8sDR 0.5°F</td>
<td>8s_DR_HQ 0.5°F</td>
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<td>4 Vesogr.</td>
<td>Veno 1 1 F/s</td>
<td>Veno 2 2 F/s</td>
<td>DSA 3 3 F/s</td>
<td>Veno Single</td>
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<td>7.5 P/s</td>
<td>15 P/s</td>
</tr>
<tr>
<td>5 Biliary</td>
<td>PTC/Drain 1 F/s</td>
<td>PTC Sub 1 F/s</td>
<td>Native 2 2 F/s</td>
<td>Single Single</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fluoro Angio</td>
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<td>Fluoro Angio</td>
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<td>15 P/s</td>
</tr>
</tbody>
</table>
Variable frame rate (VFR) imaging

- The concept of this technique is quite simple – by reducing the total number of ACQ frames, dose is reduced.
- Frame rate reduction is triggered by:
  - Time
  - Manually
Mask averaging

• Reduction in image noise that can translate directly in to reduction in dose with virtually no impact on image quality

• Unfortunately, in my practice it is rarely used
3.6 uGy/fr

2.4 uGy/fr
Aufrichtig scale for pulsed fluoroscopy

- The human visual system has a finite integration time of approximately 200 ms
- Richard Aufrichtig studied this phenomenon and derived an empirical relationship relating the necessary dose per pulse to the pulse rate
- The use of lower pulse rates results in an LIH image of higher quality

\[
\left( \frac{I_{AKRD_2}}{I_{AKRD_1}} \right) = \sqrt{\frac{PPS_1}{PPS_2}}
\]

Illustration courtesy of Phil Rauch, M.S.
Illustration courtesy of Phil Rauch, M.S.
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PHYSICIAN PRACTICE
Physician practice

• Physicians have plenty on their mind during a complex FGI
• We cannot expect them to also retain detailed knowledge of equipment settings and apply this knowledge during a case
• We should provide simple instructions and configure protocol defaults with this in mind
• *Speak their language*
Key aspects

• The Tetrad
• Notification levels and associated actions
• Dose audits
The “Tetrad”

1. Raise the patient table to the highest comfortable working height.

2. Lower the image receptor as much as practicable.

3. Take one small step back or down the table away from the patient.

4. Collimate the X-ray field to the area of interest.

Order is important!
Procedural geometries

Using Good Practice is essential during fluoroscopic procedures, including maintaining the patient as far from the X-ray source as practical. This is common in vascular and interventional procedures, and results in a *non-isocentric* geometry.

The dose rate at the skin surface will be lower in a non-isocentric geometry than in an isocentric geometry.

**Isocentric geometry**

**Non-isocentric geometry**

*Establishing a Patient Safety Program in Fluoroscopy, Fluoroscopic Safety, LLC.*
<table>
<thead>
<tr>
<th>Dose Metric</th>
<th>First Notification</th>
<th>Subsequent Notifications (increments)</th>
<th>SRDL</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{\text{skin,max}}$</td>
<td>2 Gy</td>
<td>0.5 Gy</td>
<td>3 Gy</td>
</tr>
<tr>
<td>$K_{a,r}$</td>
<td>3 Gy</td>
<td>1 Gy</td>
<td>5 Gy$^a$</td>
</tr>
<tr>
<td>$P_{\text{KA}}$</td>
<td>300 Gy cm$^2$$^b$</td>
<td>100 Gy cm$^2$$^b$</td>
<td>500 Gy cm$^2$$^b$</td>
</tr>
<tr>
<td>Fluoroscopy time</td>
<td>30 min</td>
<td>15 min</td>
<td>60 min</td>
</tr>
</tbody>
</table>

$^a$See additional discussion concerning the value 5 Gy in Section 4.3.4.2.

$^b$Assuming a 100 cm$^2$ field at the patient’s skin. For other field sizes, the $P_{\text{KA}}$ values should be adjusted proportionally to the actual procedural field size (e.g., for a field size of 50 cm$^2$, the SRDL value for $P_{\text{KA}}$ would be 250 Gy cm$^2$).
Notification levels by lab/fluoroscope type

Differences in notification levels reflect differences, technical and geometric, in how fluoroscopically-guided procedures are performed. A number of factors influence the ratio of peak skin dose (PSD) to RAK: procedural geometry, backscatter, and attenuation by the patient support and pad.

Each notification level should involve a procedural pause and communication of the radiation dose status to the operator.

<table>
<thead>
<tr>
<th>Lab/fluoroscope type</th>
<th>Typical ratio of PSD to RAK (PSD/RAK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vascular/interventional radiology</td>
<td>1.0</td>
</tr>
<tr>
<td>Cardiac catheterization</td>
<td>1.3-1.4</td>
</tr>
<tr>
<td>Interventional neuroradiology</td>
<td>1.0-1.3</td>
</tr>
<tr>
<td>Mobile C-arm</td>
<td>1.0-1.5</td>
</tr>
</tbody>
</table>

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### Example – Vascular/Interventional Radiology

<table>
<thead>
<tr>
<th>RAK notification level (mGy)</th>
<th>Corresponding PSD (mGy)</th>
<th>Suggested action</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,500</td>
<td>2,500</td>
<td>Verify Good Practice is being used.</td>
</tr>
<tr>
<td>5,000</td>
<td>5,000</td>
<td>Substantial radiation dose level. Flag patient for f/u. Measure and record table height.</td>
</tr>
<tr>
<td>7,500</td>
<td>7,500</td>
<td>Verify Good Practice. Re-evaluate risk/benefit pace of procedure, entering range of potential skin injury.</td>
</tr>
<tr>
<td>10,000</td>
<td>10,000</td>
<td>Verify Good Practice. Re-evaluate risk/benefit pace of procedure. Skin injury more likely.</td>
</tr>
</tbody>
</table>

*And every 1,000 mGy above 10,000 mGy. These notification levels are for illustration purposes only and the numbers are approximate.*
Example – Interventional cardiology

<table>
<thead>
<tr>
<th>RAK notification level (mGy)</th>
<th>Corresponding PSD (mGy)</th>
<th>Suggested action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,800</td>
<td>2,500</td>
<td>Verify Good Practice is being used.</td>
</tr>
<tr>
<td>3,600</td>
<td>5,000</td>
<td>Substantial radiation dose level. Flag patient for f/u. Measure and record table height. Consider rotating C-arm.</td>
</tr>
<tr>
<td>5,400</td>
<td>7,500</td>
<td>Verify Good Practice. Re-evaluate risk/benefit pace of procedure, entering range of potential skin injury.</td>
</tr>
<tr>
<td>7,200</td>
<td>10,000</td>
<td>Verify Good Practice. Re-evaluate risk/benefit pace of procedure. Skin injury more likely. Consider rotating C-arm.</td>
</tr>
</tbody>
</table>

*And every 700 mGy above 7,200 mGy. These notification levels are for illustration purposes only and the numbers are approximate.*

*The use of an isocentric geometry means that PSD is often greater than RAK for interventional cardiology procedures.*

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Dose audits

• The simple act of beginning to record dose metrics will often on its own trigger practice changes
• Stratification of the data can identify specific targets for improvement
• Compare to normative data sets
  – E.g., RAD-IR study

Recommendation 19
Facilities shall have a process to review radiation doses for patients undergoing FGI procedures.
Advisory data based on measured dosimetric quantities (in particular $P_{KA}$ or $K_{n,\gamma}$ to manage overall performance, and $K_{n,\gamma}$ to manage deterministic effects) should be used for quality assurance purposes.

NCRP 168
Radiation dose audits

TECHNOLOGY
Technological advances

• Detector technology
  – Higher acquisition bit depth
  – Crystalline silicon
    • Electron mobility
    • Active pixel sensors

• X-ray tube technology
  – Flat emitter
Polycrystal Silicon

Amorphous Silicon

a-Si TFT

LTPS TFT

Flow of Electrons

Source

Drain

<table>
<thead>
<tr>
<th>Backplane</th>
<th>a-Si:H</th>
<th>poly-Si</th>
<th>mono-Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monolithic array size</td>
<td>Large</td>
<td>Medium</td>
<td>Small</td>
</tr>
<tr>
<td>e⁻ mobility</td>
<td>1 cm²/V-s</td>
<td>100 cm²/V-s</td>
<td>1000 cm²/V-s</td>
</tr>
<tr>
<td>TFT mask steps</td>
<td>4-5</td>
<td>5-11</td>
<td>5-11</td>
</tr>
<tr>
<td>Leakage current</td>
<td>Low</td>
<td>Higher</td>
<td>Higher</td>
</tr>
<tr>
<td>Radiation hardness</td>
<td>Excellent</td>
<td>Good/Fair</td>
<td>Poor</td>
</tr>
<tr>
<td>Large scale uniformity</td>
<td>Good</td>
<td>Fair</td>
<td>Poor</td>
</tr>
<tr>
<td>Cost/yield</td>
<td>Low/High</td>
<td>High/Low</td>
<td>High/Low</td>
</tr>
</tbody>
</table>
Further reading

  – SIR Standards of Practice Committee
  – SIR Safety and Health Committee
  – Discharge/consenting examples
• NCRP Report 168