Managing Pediatric Fluoroscopic Imaging

Keith Strauss, M.Sc., FAAPM, FACR
Keith.Strauss@cchmc.org
8/1/2018
Introduction

• Evolution of fluoroscopic equipment last 40 years
• Pediatric
  • Challenges
  • Advantage
• **Teamwork** between radiologist, technologist, qualified medical physicist (QMP), and equipment manufacturer
  • Roles
  • Impediments to positive teamwork
• Examples of successful reconfigurations
Tripping Through Memory Lane

Compliance Testing Era:

• Last 40 years of 20th Century
• Equipment used open loop control logic

80 kVp Waveform
Tripping Through Memory Lane

Compliance Testing Era:

- **Continuous fluoroscopy**
  - Voltage and current changed in parallel responding to patient size
  - Selection of Field of View
  - 2 – 3 dose level settings to image receptor

- **Equipment malfunctions**
- **Calibration errors**
  - Manual vs automatic
  - Numerical values alone were inadequate
Tripping Through Memory Lane

Configuration/Operations Era:
- First years of 21\textsuperscript{st} Century
- Equipment used computer controlled, feedback-stabilized control logic

Mid Frequency Generator: kV left; mA right
Tripping Through Memory Lane

Operational Parameters

• Type of Exam
• Patient Size: Does one button select all?

AAPM TG125
Current General Challenges

Image quality requirements unique as a function of:

- Exam type and **Patient Size**

**Configuration Choices**

- Focal spot size
- X-ray beam filtration
- Geometry: patient vs equipment
- Grid management
- Pulse rates and widths
- Detector air kerma rates
- Appropriate image processing
Pediatric Challenges

• Fluoroscope
  • Patient irradiation

<table>
<thead>
<tr>
<th>Adult</th>
<th>Pediatric</th>
</tr>
</thead>
<tbody>
<tr>
<td>45 – 140 kg</td>
<td>2 – 140 kg</td>
</tr>
<tr>
<td>26 – 42 cm¹</td>
<td>5 – 42 cm¹</td>
</tr>
<tr>
<td>5 HVL: 32</td>
<td>11 HVL: 2048</td>
</tr>
</tbody>
</table>

Automatic Brightness Systems (ABS) struggle with the larger range of required radiation required for pediatric size variance.

¹Kleinman PL, et. al. Patient Size Measured on CT Images as a Function of Age . . . AJR2010;194:1611-1619.
Pediatric Challenges

Same age patients vary dramatically in size.

• Abdomens of:
  • Largest 3 year olds and
  • Smallest adults are the same size.

• Patient cross section size, not age, should be used.
Pediatric Challenges

Imaging equipment is well
• Designed and
• Configured\(^1\)
• ‘out of the box’ for imaging adult patients.

BUT

• The same can not be said about configurations for pediatric imaging!
• Has vendor developed pediatric specific configurations?

\(^1\)Insuring the use of design strengths while compensating for design weaknesses for a specific size patient and imaging task.
Pediatric Challenges

Why should your child or grandchild receive less consideration during imaging than that of their parents or grandparents?

- **Majority** of imaging equipment sold is installed in adult facilities, but eventually all these units will perform some pediatric imaging.
- ~ 80% of all pediatric imaging is performed in adult hospitals

Maximize Benefit/Risk = manage image quality/manage patient dose

- **Increasing** image quality and **decreasing** patient dose is not always the answer when configuring fluoroscopic equipment!
Pediatric Advantage

X-ray units designed to image adult patients produce a higher air Kerma rate than required to penetrate small pediatric bodies; choices of

- Focal spot
- Beam filter
- Grid
- Voltage, current and pulse width combination
- Air Kerma rate at image receptor
- Patient positioning (geometric magnification)
Teamwork

• Team
  • Radiologist
    • Ultimate responsibility for overall patient care
    • Controls the patient’s dose depending on modality
  • Technologist
    • Impacts patient care during the imaging process
    • Controls the patient’s dose depending on modality

• Both are primarily focused on patient care.
• Both need better training on the implications to patient care due to the design and configuration of the imaging equipment.
• Both may expect too much from equipment manufacturer!
Teamwork

• Team
  • Qualified Medical Physicist
    • *Interpreter*: different understanding of imaging process by front line care givers vs design engineers of imaging equipment
    • Unique imaging needs of the practice (patient needs)
    • Strengths and weaknesses of design of offered equipment
  • Surprises should be greatly reduced.
  • Compliance testing seldom improves patient care.
  • Acceptance testing crucial to determine proper configuration of complex imaging equipment.
Teamwork

• Team
  • Representatives of equipment manufacturer
    • Sales representatives:
    • Product Specialists:
    • Product Managers: lowest level of decision makers/changers
    • Design Engineers
    • Imaging Physicists
  • All vendor employees must operate within a business model
    • Focus on profit may limit configuration changes.
    • Litigation concerns may stifle creativity in the field.
Challenge

• Team members have different primary goals
  • Customer seeks improved patient care
    • Quality exacts a price
      • Hardware change
      • Software change
      • Labor to alter configuration
  • These changes are opposed by equipment manufacturers
    • . . . our FDA 510k approval does not allow field changes!
Solution?

• FDA’s reaction to 510k stalemate:

Pediatric Information for X-ray Imaging Device Premarket Notifications


Contains Nonbinding Recommendations

For previously 510(k) cleared x-ray imaging devices, optimization of imaging parameters and provision of pediatric-specific protocols by manufacturers solely at the request of end users generally does not by itself necessitate submission of a new 510(k) submission.
Challenge

• Team members have different primary goals
  • Customer seeks clinical image quality at managed dose
    • Technology’s best images may not always be necessary!
    • Trade image quality for dose savings
  • New paradigm

• Manufacturer must compete with competitors
  • Desire to produce best possible images at all times
Challenge

• Team members have different primary goals

• Qualified medical physicist needs better understanding of equipment’s design features

• Manufacturer guards equipment design feature details
  • Non disclosure agreements may be difficult to negotiate
Challenge

Qualified medical physicist needs quantitative test tools

- **Quantitative** assessment of image quality with inexpensive phantoms is desired.
- Modulation Transfer Function (MTF)
- Noise Power Spectrum (NPS)

Need unprocessed images from image receptor
Solution

- Qualified medical physicist needs better tools . . .
- Four major components
  - Single exposure control of Voltage, tube current, exposure time, focal spot, added filtration
- Export of ‘For Processing’ images
- Electronic documentation of system configuration
- Calibration factors within RDSR report for air Kerma and Kerma area product dose display
Reality

• Standard published in 2012
• Available only on most recent purchases
• Treated as a revenue opportunity by one manufacturer
  • Charged significant dollars for feature
  • Extra not charged for service logs or troubleshooting routines
• Why are XR27 features treated differently?
Successful Example

• How impactful are end user driven reconfigurations when cooperation from manufacturer is won?

• General Pediatric Fluoroscopy (VCUG)
  • 1995: Continuous Fluoroscopy: 3 – 6 mGy air Kerma\(^1\)
  • 2001: Pulsed Fluoroscopy: 0.4 – 0.6 mGy air Kerma\(^1\)
  • 2015: Reduced pulse rates: 0.25 – 0.45 mGy air Kerma

Solution

- **International Electro-Technical Commission (IEC)**
  - International standards organization with working groups that develop and maintain standards for the different modalities of imaging.
    - Some European nations promulgate IEC standards into law.
    - FDA is beginning to adopt IEC standards as opposed to rewriting outdated FDA regulations
  - **Positive example:**
    IEC CT working group currently developing a standard for the calculation and display of Size Specific Dose Estimate (SSDE) on all future CT scanners in support of pediatric imaging.
Successful Reconfigurations

- Pulsed fluoroscopy that is not preferred by radiologists to continuous fluoroscopy is not properly configured.
AFFECT OF PULSE WIDTH

PW 2.4 ms
Acquired at 30 fps
Displayed at 7.5 fps

PW 7.4 ms
Acquired at 30 fps
Displayed at 7.5 fps

PW 2.4 ms
Displayed 7.5 fps

PW 7.4 ms
Displayed 7.5 fps
Successful Reconfigurations

• Manufacturers have added spectral filtration
  • Thin Copper sheets paired with 1 mm Aluminum
  • Reduces patient air Kerma relative to detector air Kerma.
  • Multiple thicknesses: larger thickness = less patient dose
  • Pulse width increased to produce adequate air Kerma at detector.
• Motion unsharpness in image.
  • Pediatrics: 1 – 5 msec
  • Adults: 3 – 10 msec
  • Bariatrics: 10 – 20 msec
• Typically a software as opposed to field modification.
Successful Reconfigurations

• Manufacturers tend to configure excessive pulse rates.
  • With practice, operators can adapt to lower pulse rates

• Interventional fluoroscopy
  • 30 and 15 pps have been replaced by 15 and 7.5 pps in children

• General fluoroscopy
  • 8 and 4 pps have been replaced by 4 and 2 pps in children
Successful Reconfigurations

- Air Kerma at Image Receptor (AKIR)
  - During Variable Rate Pulsed Fluoroscopy
  - Increased **Perceived Noise** With Decreased Pulse Rates,
  - **Not loss of Temporal Resolution** is
  - Primary cause for rejection of low pulse rate fluoroscopy

- Increase in AKIR / Frame$^1 \propto (30/\text{Pulse Frequency})^{1/2}$
  Maintains **perceived noise** due to less frame integration by eye/brain function when pulse rate > 7.5 p/s.

---

AUFRICHTIG PRINCIPLE

IR Exp/frame = X
Patient Exp Rate Reduced 4X
Images courtesy of Phil Rauch
AUFRICHTIG PRINCIPLE

IR Exp/frame = X vs 2X

Patient Exp Rate Reduced 2X

Images courtesy of Phil Rauch
AMMENDED AUFRICHTIG PRINCIPLE

IR Exp/frame = 2X vs 2X
Patient Exp Rate Reduced 7.5X

Images courtesy of Phil Rauch
Technique Optimization

• Control of air KERMA rate at Image Receptor (AKIR)
  • During Variable Rate Pulsed Fluoroscopy
    • Exposures Relative to “Normal”: 30 p/s
      • AKIR / Frame $\alpha$ $(30/$Pulse Frequency$)^{1/2}$
        • Different relationship for < 7.5 pulses/second
        • AKIR / Frame $\alpha$ Constant
  
• Aufrichtig Principle classic example or dose management as opposed to pure reduction
Successful Reconfigurations

• Triple as opposed to dual focused x-ray tubes provide more control of x-ray production as a function of patient size
  • Smaller focal spot matched to a small body minimizes geometric unsharpness
  • 0.3 mm focal spot allows use of geometric magnification without a grid for smallest patients
  • 0.3 mm focal spot provides adequate kW for cardiac catheterizations of infants and babies < 1 year of age

• Manufacturer may still have triple focus angiographic tube designed for neuro work which is a better cath lab choice!
Conclusions

• Configuration and design changes of imaging equipment can improve image quality and/or better manage patient dose of pediatric patients.

• Tailored equipment configurations to the patient’s imaging needs are essential and only result from teamwork.

Max Benefit/Risk = managed image quality/managed patient dose

• END USERS NEED AN EFFECTIVE WORKING RELATIONSHIP WITH THEIR EQUIPMENT VENDOR & MEDICAL PHYSICIST.
Thank you

Keith.strauss@cchmc.org