Protocol Review and Optimization: Optimization of Pediatric DR

Keith J. Strauss, FAAPM, FACR
Clinical Imaging Physicist
Cincinnati Children’s Hospital
Associate Professor
University of Cincinnati School of Medicine
Introduction

• Some challenges
• Resources that assist with pediatric imaging
• Sorry state-of-the-practice
• **Equipment modifications** for pediatric imaging
  • Grid issues
  • AEC issues
• **Operational issues**
  • Measuring patient size
  • A structured program/Necessary support
• **Do you have what it takes to take on the OPERATIONAL issues?**
Fact

- Vast majority of imaging equipment sold is to adult facilities,

BUT

- Sooner or later almost all these units will perform some pediatric imaging.
Fact

- Imaging equipment is quite 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!
- Some necessary configurations may not exist!

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

- Why should your
  - Son or Daughter
  - Niece or Nephew
  - Grandson or Granddaughter

receive less care\(^2\) during imaging than that received by their parents, uncle or aunt, or grandparents?

\(^2\)Properly managed radiation dose and image quality as a function of patient size.
Fact

• I can purchase imaging equipment from a number of companies who make quality units—in all cases images will be produced,

BUT

• In addition to the equipment I want a collegial ‘relationship’ to work within to optimize equipment performance for my clinical task.
MANAGING PATIENT DOSE

Sufficient Dose to detector to manage Quantum Mottle in the image

- Dose directly affects quantum mottle
- Lack of sharpness and contrast in the image results in poor image quality despite higher doses.

Archer & Wagner
Procedures vs Effective dose contributions

US 1980*

Percent Procedures

US 2006

Effective Dose Contributions

17% of All Exams Deliver 81% of Total dose

Adapted from Mahesh
Kleinman PL, et. al. Patient size ... AJR 194, June 10, pp. 1611 – 1619.
# Pediatric Imaging Challenges


<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Anteroposterior Measurement (cm)</th>
<th>Transverse Measurement (cm)</th>
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<tbody>
<tr>
<td></td>
<td>95% Prediction Interval</td>
<td>95% Prediction Interval</td>
</tr>
<tr>
<td>Abdomen</td>
<td>Mean</td>
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<tr>
<td>0.5</td>
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<td>12.4</td>
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</tr>
<tr>
<td>20</td>
<td>22.1</td>
<td>16.3</td>
</tr>
</tbody>
</table>
AGE vs PATIENT SIZE?

Same age patients vary dramatically in size.

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

- Patient cross sectional thickness, not age, should be used.
B. Patient Ages: Neonate to 21 year and Beyond

CT: 16 yr old: 335 lb

MRI: Neonate
B. Patient Ages: Neonate to 21 year and Beyond

1 HVL @ 70 KVP

5 cm

Large Adult

Adult

5 year

1 year

3 cm

Neonate

1 HVL @ 120 KVP

1 HVL @ 70 KVP
One Pediatric Advantage?

How can I get the necessary photon flux, radiation dose rate to the image receptor while reducing the radiation dose to the entrance plane of the pediatric patient?
PEDIATRIC RADIOGRAPHIC TECHNIQUES

B. The Ugly

1. “We love CR. We can use ONE Radiographic Technique for ALL our Pediatric Exams.”

2. Dose Creep
One Patient’s Experience

Graph: Actual radiography exposures vs. target exposures: Single 16-year-old male patient.

- Actual Exposure
- Max Target Range
- Min Target Range

Image: X-ray of the abdomen.
One Patient’s Experience

Actual radiography exposures vs. target exposures:
Single 16-year-old male patient

Exposure at detector (mR)

Patient visit number

- Actual Exposure at detector
- Max Target Range
- Min Target Range

X-ray image of a 16-year-old male patient
One Patient’s Experience
Big Deal or Mountain Out of Mole Hill?

I. Radiation Induced Cancer Lifetime Risk From 1 Sv Dose

1. All Ages
   a. 6% Female
   b. 5% Male

2. First Decade
   15%

3. Middle Age
   1 - 2 %
Direct Radiography (DR) Dilemma

State-of-the-Practice of pediatric DR with respect to patient care leaves much to be desired!

Let’s look at some of the reasons. Is the current problem:

• Responsibility of end user?
• Responsibility of manufacturers?

 Properly managed radiation dose and image quality as a function of patient size.
What Have We Learned from our DR Program?

Radiologists

Cannot provide meaningful feedback on image quality until all technologists are producing controlled radiographs!

Must accept change in work patterns.

Need to accept adequate to good as opposed to great image quality!
Film Characteristic Curve Shape

- **Automatic Quality Control**

  Radiographic technique Choices outside the narrow vertical band
  - Log rel exp = 0.3
  - Exposure range > 2 at image receptor resulted in unacceptable radiograph

- **DR & CR eliminated that built in QC mechanism**
Detector Dose?

Why talk about detector dose as opposed to patient dose?

• Detector dose relatively constant despite patient size.

• Image quality driven by detector dose.

• Manufacturers provide an EI number.
  • EI number is dependent on image processing
    • Infamous ‘green’ snow
How Do We Fix This Problem?

• Technologist creates poor quality image
  • When technologist changes image processing, the EI Number changes
    • Is the image processing incorrect?
    • Is the detector dose incorrect?
      • Image acquisition is paramount
      • Radiologist’s image quality requirements.
    • Correct and carefully control detector dose
      • If image quality is substandard, the correction has to be image processing
Equipment Modifications for Pediatric CR/DR

Pediatric appropriate Anti Scatter Grids

- Removable
- Grid for 100 - 130 cm SID
- Grid for 180 cm SID
- One grid designed for 140 cm SID cannot do the job
  - Never work at 140 cm SID
Equipment Modifications for Pediatric CR/DR

Anti-Scatter Grid In/Out: When?

- Pediatric patient dose reduction with small loss of image quality
- 10 cm thick body part
  - Cross sectional area also important

- New paradigm
  - Never remove the grid!
Anti Scatter Grid vs Detector Dose

• Fixed Parameters
  • 2 pulses/sec
  • 73 kV
  • 0.4 mm Cu
  • 1.25 mag factor
  • Collimation, FoV

• Variables
  • Detector Kerma (DK)
  • Piglet thickness
  • Grid placement
Anti Scatter Grid vs Detector Dose

Five pediatric radiologists evaluated 144 DSA runs twice each to assess effectiveness of anti-Scatter Grid (ASG)

0—non-diagnostic images
fail to depict arterial structures

1—poor quality images
Diagnostic evaluation of 1st order branches

2—intermediate quality images
Diagnostic evaluation of 2nd order branches

3—high quality images
Diagnostic evaluation of 3rd order branches

4—Excellent quality images
Diagnostic evaluation of 4th order branches
ROC analysis investigated specific IQ requirements with or without Grid at minimum required vessel visibility of 2 or 3.
Anti Scatter Grid vs Detector Dose

- Grid Removal: 26% Loss of dose AND Image Quality
- Image Quality (IQ) vs patient air kerma with and without grid
- IQ score of 2.3 with grid
  - EPX6 (17.5% DK)
  - 0.23 mGy
- IQ score of 2.3 w/o grid
  - EPX2 (70% DK)
  - 0.48 mGy
- PK w grid 50% of PK w/o Grid w same IQ score!

Strauss KJ, et al. JACMP 2015
Equipment Modifications for Pediatrics DR

Pediatric appropriate Anti Scatter Grids

- **Bucky Factor:** increase in patient dose when a grid is used.
  - Ranges from 2 – 6
    - Patient size
    - Area of x-ray beam
  - Why is curve sigmoid in shape?

![Graph showing relationship between patient thickness and Bucky Factor]
AEC Sensors

Pediatric appropriate AEC sensors:

- 1 vs 3 Cell Detectors
- Designed for adults
- If cells 1 or 3 incorrectly covered by collimated x-ray field,
- One company automatically shuts off uncovered cell(s).
- Great concept, but incorrectly designed and implemented!
AEC Sensors

Pediatric appropriate AEC sensors:

- 1 and 3 Cell Detectors are completely covered by x-rays
- 1 & 3 cells remain active
- 1 & 3 not completely covered by anatomy.
- Shutdown exposure prematurely.
  - Feature as it stands cannot be used!
  - This type of problem difficult to find without a dashboard!
Centering the patient is crucial. The patient’s spine must be over the center cell.

Poor centering. Underpenetrated.

Centered. Good image.
Equipment Modifications for Pediatric DR

Pediatric AEC Calibration:

• Set **detector dose** (type of study):
  • ~ 0.3 mrad ~ 2.5 μGy for adult trunk
  • ~ 1.2 mrad ~ 10 μGy for adult extremities
  • ~ Double above for child abuse studies and DMD patients

• Why change for extremities, child abuse studies, DMD patients?
Equipment Modifications for Pediatric DR

Pediatric appropriate Automatic Exposure Control (AEC) calibration:

• Set detector dose (patient size):
  • New Born Dose $\sim 2 \times$ adult dose
  • Why?
  • Experience of radiologists?
Equipment Modifications for Pediatric DR

What has not been addressed for DR AEC?

- Energy Response
- Film-Screen combinations did not have flat energy response similar to DR detectors.
Equipment Modifications for Pediatric DR

Pediatric appropriate X-Ray Beam Filtration

- Filters with $z > 13$ (Al) allow more radiation delivery at detector with less radiation dose to the patient’s skin
  - Higher techniques required
  - Less contrast in image
    - Match Filter Thickness and kV
    - Maximize Figure of Merit $= \text{CNR}^2 / \text{Dose}$
  - Conventional understanding of appropriate technique factors obsolete
Equipment Modifications for Pediatric DR

Pediatric appropriate X-Ray Beam Filtration

• Filter and kV matched by FoM at given patient thicknesses
  • Select remaining technique factors: must select tube current and exposure time independently
    • Exposure time short enough to freeze motion
    • mAs needed for detector dose with kV/Filter by adjustment of tube current
    • Tube current dependent on focal spot size and required mAs
OPERATIONAL ISSUES

A. Comprehensive Training of Staff Fosters
   1. Full Utilization of Equipment Design
   2. Good Image Quality
   3. Reduced Radiation Dose
**Calipers**

- Centimeters are listed on the right side.

- The arrows pointing down indicate where to read the measurement.
Patient Size
Inaccurate Measurement

• Accurate thickness measurements are directly related to image quality and dose.
  • Techologist’s measurement recorded as 4 cm
  • PACS measurement shows it should have been recorded as 6 – 7 cm

• 3 cm is a Half Value Layer of Tissue
Eliminate Guesswork

- Programed parameters in generator console tied to patient thickness and exam type.
  - Measure Patient Thickness
  - Position patient
  - Select patient size and type of exam on console
  - Verify SID and use of grid
Eliminate Guesswork

- Programmed factors in generator console.
  - SID: 40, 48, 56, 72, and 102 inches
  - Grid use
  - X-ray Tube Voltage and Filter Thickness
    - Soft Tissues
    - Chest
  - Focal Spot Size: specified tube current
    - 5 msec ≤ Exposure time ≤ 15 msec
    - Patient size drives tube current
      - Manual vs AEC mode?
A Potential Useful Tool

Great idea for pediatrics

- No follow through by vendor!

<table>
<thead>
<tr>
<th>TECHNIQUE CHART</th>
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<tr>
<td></td>
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<tr>
<td>NEWBORN</td>
</tr>
<tr>
<td>EXTREMITIES</td>
</tr>
<tr>
<td>TRUNK</td>
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### Sample Technique Chart
#### Abdomen

<table>
<thead>
<tr>
<th></th>
<th>Newborn</th>
<th>Baby</th>
<th>Child</th>
<th>Small</th>
<th>Normal</th>
<th>Large</th>
<th>X-Large</th>
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<tr>
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<td>9 - 12 cm</td>
<td>13 - 17 cm</td>
<td>18 - 23 cm</td>
<td>24 - 29 cm</td>
<td>30 - 36 cm</td>
<td>37 - 44 cm</td>
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<tr>
<td><strong>KV</strong></td>
<td>64</td>
<td>77</td>
<td>79</td>
<td>83</td>
<td>85</td>
<td>89</td>
<td>95</td>
</tr>
<tr>
<td><strong>mA</strong></td>
<td>200</td>
<td>250</td>
<td>500</td>
<td>800</td>
<td>630</td>
<td>630</td>
<td>630</td>
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<tr>
<td><strong>msec</strong></td>
<td>10</td>
<td>12.5</td>
<td>12.5</td>
<td>16</td>
<td>40</td>
<td>80</td>
<td>160</td>
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<tr>
<td><strong>mAs</strong></td>
<td>2</td>
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<td>12.8</td>
<td>25.2</td>
<td>50.4</td>
<td>100.8</td>
</tr>
<tr>
<td><strong>FOCAL SPOT</strong></td>
<td>S</td>
<td>S</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td><strong>AEC</strong></td>
<td>OFF</td>
<td>OFF</td>
<td>AEC</td>
<td>AEC</td>
<td>AEC</td>
<td>AEC</td>
<td>AEC</td>
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<td>S400</td>
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<tr>
<td><strong>DENSITY</strong></td>
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<td>0</td>
<td>1.5</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>-1</td>
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<tr>
<td><strong>FILTER</strong></td>
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<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0</td>
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<td><strong>GRID</strong></td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td><strong>DOSE (µGy)</strong></td>
<td>2x</td>
<td>1.8x</td>
<td>1.5x</td>
<td>1.4x</td>
<td>1.1x</td>
<td>1.1x</td>
<td>x</td>
</tr>
<tr>
<td><strong>CELLS</strong></td>
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<td>NA</td>
<td>2</td>
<td>2</td>
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</tr>
</tbody>
</table>
ATTENUATION MODELING

Reasonable Fits: $R^2 \sim 1$

μ values differ w & w/o grid; chest vs soft tissue

- Can estimate detector air Kerma if x-ray tube output is known with Exposure factors from RDSR
Initial Feedback

- I went to school to be able to do this!
- I’m not a button pusher.
- This is going to slow us down.
- This dumbs down the process!
Feedback Today

• Our measuring program speaks volumes about our personalized care for our patients.

• It’s not a guessing game anymore. We have tools at our fingertips today that we didn’t have in the past.

• As a tech who used to set her own kV, mA, time and overexposed people, consistency in imaging is nice.
Radiology Quality Improvement Team
Great Catches

May catches brought to you by Radiology

132 ERRORS CAUGHT

<table>
<thead>
<tr>
<th>WRONG PATIENT</th>
<th>WRONG EXAM</th>
<th>WRONG SIDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>02</td>
<td>110</td>
<td>20</td>
</tr>
</tbody>
</table>

THANK YOU!

- **WRONG PATIENT**: Erin Baird caught a wrong order of STAT sheet placed on wrong patient.
- **WRONG SIDE**: Melly Durr caught a wrong US order of abdomen that was placed on a 2yr old.
- **WRONG SIDE**: Miranda Getz caught a wrong side orders in May.
- **WRONG EXAM**: Knotts Riordan caught a wrong order of ceftriaxone that was ordered instead of a cephalosporin.
- **WRONG SIDE & EXAM**: Chelsea Weave caught a wrong order of left ankle that should have been right foot.
- **WRONG EXAM**: Jen Elsen caught a wrong order of chest x-rays that should have been abdomen and a ski/fib that should have been rad/ulna.
- **WRONG EXM**: Katelyn Green caught a wrong order of what that should have been elbow.
- **WRONG SIDE**: Chelsea Robe caught a wrong side order of finger and shoulder.
- **WRONG SIDE**: Sarah Dietz & Tara Snyder caught a wrong side order of left elbow.

**February Scores**

126 ERRORS CAUGHT

<table>
<thead>
<tr>
<th>WRONG PATIENT</th>
<th>WRONG EXAM</th>
<th>WRONG SIDE</th>
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<tbody>
<tr>
<td>02</td>
<td>98</td>
<td>26</td>
</tr>
</tbody>
</table>

**Great catches!**

- **WRONG PATIENT**: Krista Segars caught a wrong US order after family questioned the order and she called ordering Dr. to verify.
- **WRONG EXAM**: Becky Barth & Kathy Leman caught a wrong order of infant/obstetric/neck that should have been head.
- **WRONG EXAM**: Kylee Jones caught a wrong order of X-ray that should have been knee.
- **WRONG EXAM**: Miranda Getz caught a wrong order of chest x-ray that should have been abdomen.
- **GREAT CATCH**: Krystal Clapper caught a wrong order of femur that should have been femur.
- **WRONG SIDE**: Robin Stewart caught a wrong side finger order on a tyloid patient.
16 Coaches
80 technologists are divided up and assigned to a coach’s list for updates
Must Monitor Performance of Program Continually

Image receptor air Kerma for each exposure

Patient air Kerma

Computer Dashboard Necessary
Here is a look at what you have achieved

Outstanding compliance

Less variability

Lower doses
What Have We Learned from our DR Program?

- Must overcome as many of the vendor’s deficiencies as possible.
  - Leverage design strengths of vendor’s equipment
  - Minimize equipment’s design deficiencies
What Have We Learned from our DR Program?

- Must overcome as many of the vendor’s deficiencies as possible.
  - Quality of control room monitor
  - Calibration of control room monitor
  - AEC Sensor Size and Configuration
Final Thought . . .

Children are not just small adults . . .

BUT

. . . most adults are big babies!!
Conclusions

• A comprehensive DR QA Program is not trivial
• Analyze your resources and your availability and
  • **DO SOMETHING** to improve pediatric DR
• Pick the low hanging fruit
  • Easier equipment modifications
  • Standardize everyone on some level of program
    • Size based technique charts
    • Measure size of pediatric patients
• Largest opportunity for dose savings is **standardization of operations**, not detector efficiencies or the use of spectral filtration.
I'd like to do something really significant with my life .... maybe become a great world leader and save the earth from nuclear devastation, feed all the hungry, or maybe even travel to far away planets .... but who am I kidding? I'm just a tiny black fly sitting on some bald guy's head.