Radiation Dose Informatics: Using the Tools of Six Sigma to Improve Radiation Exposure Prescription

Lots of Commercial Dose Management Software!

Image Quality and Dose

Increasing Image Quality

Increasing Radiation Dose

Problem: Good IQ with high (or even too high) dose

Too high dose prescription must be avoided

Narrow the range of x-ray prescriptions!
“Inventor” of Six Sigma
W. Edwards Deming

- Physicist PhD (Yale, 28)
- Taught engineering, physics in the 1920s
- Long career in government statistics, USDA, Bureau of the Census
- Worked with Japan post war.

Toyota reduced Variation .. Improved Quality 1960s


The Motorola Six-Sigma Concept 1980: pagers

- Motorola found process subject to disturbances that could cause it to shift by as much as 1.5 standard deviations off target.
- No process or system is ever truly stable!
- Thus 3.4 parts per million for this system

* From Montgomery

What diagnostic medical physicists measure?

$$\sigma^2_{\text{Measurement}} = \sigma^2_{\text{Repeatability}} + \sigma^2_{\text{Reproducibility}}$$
These devices were repeatable with accurate output, ......!!

Reproducibility!!!

Different Procedures/Protocols, Operator Training, Patients!

Six Sigma Process Improvement with an Emphasis on Achieving Significant Impact!

- All work is performed in (interconnected) processes
  - Easy to see in some situations (manufacturing)
  - Harder in others
- Any process can be improved
- An organized approach to improvement is necessary

Reduce System Variability DMAIC (duy–may–ick)

Basic Tenets of Quality

- It is the process that creates variability
- Belief that things can be improved
- A blameless environment is needed for team solutions
- People closest to the product are most able to affect quality
- Everyone has responsibility for quality
The Primary Six Sigma Tools

- Process map
- Cause and effect analysis
- Measurement systems analysis*
- Capability study*
- Failure mode and effects analysis
- Observational study (regression)*
- Designed experiments*
- Control charts and out-of-control-action-plans*

Statistical Tools

Measure, Analyze and Improve!
Reduce Exam Prescription Variability....

Six Sigma/Informatics and Fluoroscopy

GE ‘Dose Watch’

Executive Summary
Exams are grouped by the dose range in 1 Gy increments.
The number of cases exceeding the Dose Threshold set by the customer are shown to the right.

Three ‘steps’ to improve fluoroscopy x-ray prescriptions
1. Adding Copper filtration
2. Lower pulse and frame rates
3. Table-Detector positioning
ANALYZE: Lucite 15 cm to 35 cm 20% iodine solution for CNR measures

Slightly (~8-10%) reduced CNR 0.1 mm copper

BUT ~40% Lower Skin Dose 0.1 mm Cu!

Step 1: EASY IMPROVEMENT!
- 0.1 mm Copper minimum ADDED TO:
- 100% Stationary Fluoroscopy devices
- 100% protocols
- 100% Patients have 40% reduced exposure!

Step 2: Operator Frame Rate Behaviors
- Lowering pulse and frame rates
- Important! Can you see what is needed?
- Tool 1: Collect pilot examples
- Tool 2: Share results (data - Shine a light)
- Tool 3: Educate
NewFS Dose  vs  OldFS Dose

(70-75 bpm, II)  
(70-75 bpm, flat panel)

Tool 2
Data can Shine a light!

Skin Exposure Per Physician

Names blurred out
Physiologic

Shine a light!

Ufors RaySafe

GE ‘Dose Watch’

Cumulative Dose (ESAK) Incidence Map

Shows Cumulative Dose (ESAK) with respect to gantry angulations. The dose with respect to 200 KVP patient positioning, including patient positioning, includes both 200 KVP positions. This dose calculation is performed with the patient in the diagnostic position without rotating the gantry to the patient with respect to the gantry in 30 degree increments.

For purposes of reporting high skin dose events, adding the dose from any four contiguous blocks that exceed a specific threshold. This represents the highest possible skin dose, which produces a ‘hot spot’ that the potentially higher dose from any one of the blocks.

Highest Average Skin Exposure

From: 1/1/2012  To: 1/1/2013
Exams: 541  Procedures: 28

<table>
<thead>
<tr>
<th>Procedure Name</th>
<th>Max Dose</th>
<th>Min Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van Justin</td>
<td>2.0</td>
<td>1.6</td>
</tr>
<tr>
<td>Van Russell</td>
<td>2.3</td>
<td>1.1</td>
</tr>
<tr>
<td>Mammography</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>Van Pulemony</td>
<td>0.6</td>
<td>0.7</td>
</tr>
<tr>
<td>Van Pulsed</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Van Angiogram</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Van IVC</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Van PIC</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Van ECG</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

There are 234 exams with skin exposure less than 0.9 GY.
NEED TOOL!

- Was the 3.8 Gy skin exposure optimized?
- Analyze what happened!
- Educate to improve behaviors

Post Procedure (Informatics)

- Good geometry?
- When was DSA or cine used?

DMAIC - Improve: Informatics Tool
ALARA Review

3.8 Gy Total

- Detector too high!
- Acq. medium mag.
- Table too low! Below IRP!

DMAIC - Improve: Informatics Tool
ALARA Review

3.8 Gy Total

- Detector too high!
- Acq. medium mag.
- Max mag needed?
NOW!

Six Sigma/Informatics and Computed Tomography

CT Value Stream (Process Map)

- Value is created via efforts of people as product created (knowledge).
- Relentless pursuit of waste elimination as competitive leverages

Dose Informatics and Analytics

Clinician needs a CT

- Value to Patient/Physician customer is knowledge for optimal next action

Clinician Orders a CT

- Value to Patient/Physician customer is knowledge for optimal next action - 'medical, surgical or interventional'
Clinician Orders NEW CT

MEANWHILE... Technologist manages the Protocol Book - the CT Exam 'Scripts'

- Is this efficient?

What set of acquisitions are on the scanner?
On ALL scanners?
All the SAME?

Protocol Manager Tool

Support for multiple scanners in a single protocol

Full document control including
- Track revisions to protocols
- Review reminders
- Web-based access
- Customizable style sheets and entry forms

Order in EMR transfers to RIS – generates Order

Protocol Manager Tool
Radiologists selects a CT ‘Script’

- Prescribing an optimal CT exam

CT tech and Nurse: Closest to Prescription can highly affect quality!

Protocol  ➔  Scanner

- Scanners are NOT a node on the network!
- Scanner settings differ from Protocol Book!
- Differ between scanners
- Established console settings – **good**!
- On the fly changes – variability in exams
- Console settings complicated – need virtual scanner
Individuals closest to ‘product’ most able to affect quality

- Toyota Assembly Line worker STOPS the Line!
- Procedural Pause – Operating Room

**Dose Check!**

### GE: Establish Dose Check Values by Protocol

#### Detail Tables

<table>
<thead>
<tr>
<th>Study Description</th>
<th>Permissible (mAs)</th>
<th>Number of Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT angiography</td>
<td>220</td>
<td>20</td>
</tr>
<tr>
<td>CT brain imaging</td>
<td>130</td>
<td>10</td>
</tr>
<tr>
<td>CT abdomen</td>
<td>130</td>
<td>10</td>
</tr>
<tr>
<td>CT body section</td>
<td>130</td>
<td>10</td>
</tr>
<tr>
<td>CT extremities</td>
<td>130</td>
<td>10</td>
</tr>
<tr>
<td>CT abdomen, liver</td>
<td>130</td>
<td>10</td>
</tr>
<tr>
<td>CT chest, abdomen</td>
<td>130</td>
<td>10</td>
</tr>
<tr>
<td>CT chest, heart</td>
<td>130</td>
<td>10</td>
</tr>
<tr>
<td>CT spine</td>
<td>130</td>
<td>10</td>
</tr>
</tbody>
</table>

#### Process Variability

1. Magnification Errors
2. FOV Cut-off AP
3. FOV Cut-off Z-axis

### Centering the Patient in the Gantry

- Lateral Laser Lights – Table Height
- Table Height – affects mAs modulation
- Table more LIKELY to be too LOW
Configure x-ray tube at top!

1. Mag Error - mA modulation

<table>
<thead>
<tr>
<th>PA Scout</th>
<th>AP Scout</th>
<th>AP Scout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table Low</td>
<td>Table Center</td>
<td>Table High</td>
</tr>
<tr>
<td>52 cm</td>
<td>45 cm</td>
<td>47 cm</td>
</tr>
<tr>
<td>Tube: below</td>
<td>above</td>
<td>above</td>
</tr>
</tbody>
</table>

2. FOV Cut-off AP

Patient low on lateral scout.
Raise table in gantry.
Acquire AP scout.
Scout misrepresents patient position for FOV.

Patient low on lateral scout.
Raise table in gantry.
Re-acquire lateral scout.
Acquire AP scout.
Scout represents patient position for FOV.

3. FOV Cut-off Zaxis

Exam 1
Properly Centered – No Mag
FOV INSIDE of CT Radiograph!
Auto mA is working!

Exam 3
Patient LOW – CT Radiograph is Magnified!
Patient LOW – CT Radiograph is Magnified!

Exam 4
Patient LOW – CT Radiograph is Magnified!
FOV OUTSIDE of CT Radiograph!
Auto mA is confused!
Quality Review of CT Dose

- ACR National Radiation Dose Registry
- ACR CT Accreditation - Medical Physics Review
- Joint Commission SE #47
- California SB 1237

New Requirements for CT ACR Accreditation

2. Institute a regular review process of all protocols to be sure that no unintended changes have been applied that may degrade image quality or unreasonably increase dose. Review at least 6 clinical protocols (more if required by state or local regulatory body), including:
   a. Pediatric head (1 year old)
   b. Pediatric abdomen (5 years old; 40–50 lb or approx. 20 kg)
   c. Adult head
   d. Adult abdomen (70 kg)
   e. High-Resolution chest
   f. Brain perfusion (if performed at the facility)
JC: Investigate Doses outside the range

- 6030_Abdomen_Pelvis scan length 40-60 cm