Dose Optimization:
Past, Present, and Future

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LANDAUER Medical Physics
Clinical Dose Optimization Symposium 2016
Part I: The Past

“The only source of knowledge is experience.”

–Albert Einstein
Early history of x-ray imaging

1895
Growing understanding of the effects of radiation

“I wish to suggest that more be understood regarding the action of the x rays before the general practitioner adopts them in his daily work.”

-Dr. D. W. Gage notes cases of hair loss, reddened skin, skin sloughing off, and lesions. (1896)
Timeline of radiation limits

- Vernon Wagner introduced the first film badge
- American Roentgen Society: "A dose rate that could be tolerated indefinitely without harmful effects."
- Data from atomic bomb survivors. Introduction of ALARA concept.

What about the patients?

Radiation exposure to the US population

Early 1980s
- Background (83%)
- Occupational / industrial (0.3%)
- Consumer (2%)
- Medical (15%)

NCRP Report 160

2006
- Background (50%)
- Occupational / industrial (0.1%)
- Consumer (2%)
- Medical (48%)
Growth of CT

A Growing Practice
The use of CT scans in the U.S. has more than quadrupled since the early 1990s.

2011
85.3 million

Note: Figures are not available for 2008-09.
Source: IMV Medical Information Division

The Wall Street Journal

http://www.wsj.com/articles/SB126082398582691047
The need for dose optimization

- “For a year or more, doctors and hospitals failed to detect the overdoses...”
- “But there are no hard standards for how much radiation is too much.”

CT risks in the scientific literature

Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study

Mark S Pearce, Jane A Salotti, Mark P Little, Kieran McHugh, Choonsik Lee, Kwang Pyo Kim, Nicola L Howe, Cecile M Ronckers, Preetha Rajaraman, Sir Alan W Craft, Louise Parker, Amy Berrington de González

Cancer risk in 680 000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians

OPEN ACCESS

John D Mathews epidemiologist⁴, Anna V Forsythe research officer⁴, Zoe Brady medical physicist¹², Martin W Butler data analyst³, Stacy K Goergen radiologist⁴, Graham B Byrnes statistician⁵, Graham G Giles epidemiologist⁶, Anthony B Wallace medical physicist⁷, Philip R Anderson epidemiologist⁸⁹, Tenniel A Guiver data analyst⁸, Paul McGale statistician¹⁰, Timothy M Gain radiologist¹¹, James G Dowty research fellow¹, Adrian C Bickerstaffe computer scientist¹, Sarah C Darby statistician¹⁰
AAPM Medical Physics Practice Guideline 1.a: CT Protocol Management and Review Practice Guideline

The American Association of Physicists in Medicine (AAPM) is a nonprofit professional society whose primary purposes are to advance the science, education, and professional practice of medical physics. The AAPM has more than 8,000 members and is the principal organization of medical physicists in the United States.

The AAPM will periodically define new practice guidelines for medical physics practice to help advance the science of medical physics and to improve the quality of service to patients throughout the United States. Existing medical physics practice guidelines will be reviewed for the purpose of revision or renewal, as appropriate, on their fifth anniversary or sooner.

Each medical physics practice guideline represents a policy statement by the AAPM, has undergone a thorough consensus process in which it has been subjected to extensive review, and requires the approval of the Professional Council. The medical physics practice guidelines recognize that the safe and effective use of diagnostic and therapeutic radiology requires specific training, skills, and techniques, as described in each document. Reproduction or modification of the published practice guidelines and technical standards by those entities not providing these services is not authorized.

1. Introduction

The review and management of computed tomography (CT) protocols is a facility’s ongoing mechanism of ensuring that exams being performed achieve the desired diagnostic image quality at the lowest radiation dose possible while properly exploiting the capabilities of the equipment being used. Therefore, protocol management and review are essential activities in ensuring patient safety and acceptable image quality. These activities have been explicitly identified as essential by several states[1][2] regulatory and accreditation groups such as the American College of Radiology (ACR) CT Accreditation program,[3] as well as the Joint Commission in its Sentinel Event Alert,[4] among others. The AAPM considers these activities to be essential to any quality assurance (QA) program for CT, and as an ongoing investment in improved quality of patient care.
NEMA XR-29

- All CT scanners must have:
  - Radiation dose structured reporting (RDSR)
  - Automatic exposure control (AEC)
  - Dose Check
  - Reference adult and pediatric protocols

- 5% penalty on outpatient imaging starting Jan 1, 2016

- 15% penalty on outpatient imaging starting Jan 1, 2017
### TJC requirements related to dose optimization

#### Element of Performance and Summary Phrase

<table>
<thead>
<tr>
<th>Element of Performance</th>
<th>Summary Phrase</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC.01.02.15; C5</td>
<td>Document the CT radiation dose index in a retrievable format.</td>
</tr>
<tr>
<td>PC.01.03.01; A25</td>
<td>Establish CT protocols including indication, contrast, age, size, and expected dose index range.</td>
</tr>
<tr>
<td>PC.01.03.01; A26</td>
<td>Review CT protocols with input from a radiologist, medical physicist, and technologist.</td>
</tr>
<tr>
<td>PI.02.01.01; A6</td>
<td>Review incidents where the CT radiation dose index exceeded expected dose ranges.</td>
</tr>
</tbody>
</table>
Challenges meeting the TJC

1. How should we establish expected dose index ranges?
2. How should we identify incidents that exceed the expected dose index range?
3. What should we do when an incident exceeds the expected dose index range?
4. How should we set up a patient dose review committee?
5. How can we reduce the dose without risking loss of diagnostic quality?
Part II: The Present

“How wonderful that we have met with a paradox. Now we have some hope of making progress”

–Niels Bohr
Part II: The Present

• Tools for dose optimization
• Patient Dose Review Committee (PDRC)
• Expected dose index ranges
• Reviewing and optimizing imaging protocols
Tools for dose optimization
Data flow

Modality

Images

Acq. Settings

RDSR

PACS

Protocol
Modifications

Patient Dose
Review Committee

Alerts/Notif.

Aggregate data

Dose estimates

Dose tracking tool
Dose Tracking Software (DTS)

- Aware
- Care Analytics
- DOSE M 2.0
- Dose Monitor
- Dose Watch
- Imalogix
- Nexo Dose
- Nova Dose
- Radimetrics
- Safe CT
- Sectra Dose Track

Screenshots from Dose Tracking Software packages and are meant only for example purposes and should not be interpreted as endorsement from LANDAUER.
American College of Radiology Dose Index Registry

Comparison to internal DTS
- Comparison to national benchmarks
- No real-time alerts/notifications
- Data is anonymized
Dose Check

- Notification value
  - Series level
  - Protocol specific

- Alert value
  - Sums across series
  - Global value
# Building an effective dose optimization program

<table>
<thead>
<tr>
<th>NEMA XR-29 Dose Check</th>
<th>ACR DIR</th>
<th>DTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collects patient dose indices (TJC)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Real-time alerts when incidents exceed dose index thresholds</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Keeps a record of incidents exceeding dose index thresholds</td>
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<tr>
<td>Provides external benchmarks for comparison</td>
<td>✓</td>
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<tr>
<td>Selects appropriate external benchmarks</td>
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<td></td>
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<tr>
<td>Establishes expected dose index ranges (TJC)</td>
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<td>Review of all CT protocols (TJC)</td>
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<tr>
<td>Optimize imaging protocols</td>
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Patient Dose Review Committee (PDRC)
Role of the PDRC

Dose tracking tools

PDRC
PDRC membership

- **Radiologist (required)**
  - Expertise: Clinical indication, limits on resolution and noise for diagnosis
  - Champion of image quality
  - Ultimately responsible for making diagnosis from images

- **Technologist (required)**
  - Expertise: Scanner settings and function, patient positioning and movement, and clinical workflow
  - Responsible for implementing changes to imaging protocols
  - Primary investigation of patient dose alerts

- **Medical physicist (required)**
  - Expertise: Radiation dose, image acquisition, and image reconstruction
  - Understand dose and image quality metrics
  - Develop appropriate benchmarks and expected dose ranges
  - Understands the tradeoffs in image quality and radiation dose required for protocol optimization
PDRC membership

• Imaging Director (optional)
  – Oversee all imaging operations
  – Compliance with regulations and accrediting bodies
  – New equipment purchases
• Radiation Safety Officer (optional)
  – Oversee issues related to radiation dose at the hospital
  – May be involved in dose alert investigations
  – Often serves many roles at the hospital
# Building an effective dose optimization program

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Expected dose index ranges

Thresholds too high

Thresholds too low

Content should not be re-distributed without the expressed consent of LANDAUER.
What causes outliers?

1. False positives
   - Incorrect protocol name
   - Combo study

2. Justified
   - Large patient size
   - Repeat due to patient motion

3. Actionable
   - Incorrect scan parameters
   - Scan length
   - Patient positioning
     • Table height
     • Orientation
Importance of patient size

Samei and Christianson, “Dose index analytics: More than a low number”, JACR, 2014
Is the protocol good?

![CTDI (mGy) Frequency Chart](image)

- **Possible Threshold**
Is the protocol good?

Short rotation time

Long rotation time

Possible Threshold

CTDI (mGy) vs. Effective Diameter (cm)
Is the protocol good?

Short rotation time (small patients)

Long rotation time (large patients)

CTDI (mGy) vs Effective Diameter (cm)

Improved Threshold
Reviewing and optimizing imaging protocols

...AND I HAVE FOUND THIS ONE WORKS A LOT BETTER.
What does protocol review mean?

1. Diagnostic image quality?
2. Dose comparable with external benchmarks?
3. Dose and image quality consistent for all patients?
   - Patient size
   - Patient motion
   - Adult and pediatric patients

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>Mean CTDI</th>
<th>CTDI (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.3 l-spine</td>
<td>8.7 l-spine</td>
<td>6.13 gi blee...</td>
</tr>
<tr>
<td>5.15 low dos...</td>
<td>6.9 l-spine</td>
<td>6.7 3 phase...</td>
</tr>
<tr>
<td>5.10 chestw/...</td>
<td>8.1 pelvis w...</td>
<td>5.5 pulmonar...</td>
</tr>
<tr>
<td>6.14 runoff...</td>
<td>6.10 urogram</td>
<td>5.7 chest ab...</td>
</tr>
<tr>
<td>8.2 pelvis w...</td>
<td>6.13 runoff...</td>
<td>4.1 shoulder</td>
</tr>
<tr>
<td>6.6 renal st...</td>
<td>5.2 routine...</td>
<td>2.5 facial b...</td>
</tr>
<tr>
<td>5.1 routine...</td>
<td>3.5 c-spine</td>
<td>1.1 brain po...</td>
</tr>
<tr>
<td>3.3 soft tis...</td>
<td>3.2 soft tis...</td>
<td>3.1 soft tis...</td>
</tr>
<tr>
<td>8.4 pelvis f...</td>
<td>5.6 chest ab...</td>
<td>6.8 abdomen...</td>
</tr>
<tr>
<td>6.2 abdomen...</td>
<td>3.10 neck/ch...</td>
<td>3.1 soft tis...</td>
</tr>
</tbody>
</table>
Protocol optimization example: L-spine

<table>
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<tr>
<th>Scan parameter</th>
<th>Existing Protocol</th>
</tr>
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<tbody>
<tr>
<td>Scan mode</td>
<td>Helical</td>
</tr>
<tr>
<td>Rotation time (s)</td>
<td>1</td>
</tr>
<tr>
<td>Slice thickness (mm)</td>
<td>2.5</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.52</td>
</tr>
<tr>
<td>kVp</td>
<td>140</td>
</tr>
<tr>
<td>NI</td>
<td>12.73</td>
</tr>
<tr>
<td>Min mA</td>
<td>75</td>
</tr>
<tr>
<td>Max mA</td>
<td>500</td>
</tr>
<tr>
<td>CTDI NV (mGy)</td>
<td>N/A</td>
</tr>
<tr>
<td>Avg CTDI (mGy)</td>
<td>45</td>
</tr>
<tr>
<td>Max CTDI (mGy)</td>
<td>109</td>
</tr>
</tbody>
</table>
### Protocol optimization example: L-spine

<table>
<thead>
<tr>
<th>Scan parameter</th>
<th>Existing Protocol</th>
<th>New L-Spine Small-Med</th>
<th>New L-Spine Large</th>
</tr>
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<tr>
<td>Scan mode</td>
<td>Helical</td>
<td>Helical</td>
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<td>70</td>
<td>115</td>
</tr>
<tr>
<td>Avg CTDI (mGy)</td>
<td>45</td>
<td>26</td>
<td>69</td>
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<tr>
<td>Max CTDI (mGy)</td>
<td>109</td>
<td>62</td>
<td>78</td>
</tr>
</tbody>
</table>
Medium Sized Community Hospital

CTDI (mGy)

- Chest PE
- Sinus
- Neck
- Orbits
- L-Spine
- Abdomen Pelvis
- C-Spine
- FACE
- TEMPORAL BONE
- CHEST ABDOMEN PELVIS

After Review  Before Review
Example dose alert investigation

CTDI = 8.2 mGy

CTDI = 2.6 mGy
Protocol optimization examples

Screenshots from Dose Tracking Software packages and are meant only for example purposes and should not be interpreted as endorsement from LANDAUER.

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Protocol optimization examples

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6/8/2016
Part III: The Future

“Physicists like to think that all you have to do is say, these are the conditions, now what happens next?”

–Richard Feynman
Quantity to quality

- ACR Imaging 3.0
- Accountable Care Organizations
- Participation in quality registries
- Increased patient awareness
The next big thing: Fluoroscopy dose optimization

- High risk to the patient
- Risk to operators
  - Threshold for cataracts lower than previously thought
  - Concern over other effects
- Expected additions to TJC
- Expected additions ACR DIR

A new frontier: Image quality monitoring

• What metrics to use?
  – Noise
  – Resolution
  – Texture

• Incorporate into commercially available tools

• Develop national benchmarks
Thank You!

Olav Christianson, MS, DABR
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Practice Manager – Clinical Dose Optimization Service
LANDAUER Medical Physics
Clinical Dose Optimization Symposium 2016