Optimizing CT Image Protocols With Respect To Image Quality and Radiation Dose

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Disclosures

Dianna D. Cody, Ph.D
MTMI (speaker), Fulbright & Jaworski

James M. Kofler, Ph.D.
Nothing to disclose
Learning Objectives

1. Appreciate the clinical aspects that drive protocol parameters

2. Appreciate the technical aspects behind protocol parameter choices

3. Appreciate the importance of protocol review & management
Overview: Protocols

• Influence the image quality and radiation dose of EVERY CT scan
• Provide consistency within and among scanners
  – Especially important in longitudinal exams
  – And in clinics with many technologists
• Improves throughput and tech efficiency
• Should include all instructions to complete exam
Where to begin?

• **New Protocol**
  - Use manufacturer’s suggested protocol
  - Model after existing similar protocol
  - Literature review for guidelines
  - Ask your colleagues to share theirs

• **Existing Protocol**
  - Determine SPECIFIC weakness of protocol
    • Poor contrast, too noisy, dose seems high, etc.

• **All protocol decisions must consider clinical task**
Clinical Considerations

Need short scan time

- **Single breath-hold** (<15 seconds)
- **Less patient motion**
  - Especially peds
  - Emergency room
- **Scan time also affects contrast timing**

Breathing motion in upper part of image
Clinical Considerations

Need high spatial resolution?

- Fine detail
- Thin images
Clinical Considerations

Need good low contrast resolution?

- Low noise
- Organ boundaries & structures
Clinical Considerations

• **Dose**
  - Not too high
  - Not too low
  - Matched to clinical task & patient size
Technical Considerations

- Tube rotation time
- mA
- Pitch
- kVp
- Image thickness
- Detector configuration
- Reconstruction kernel/algorith
Tube Rotation Time

• Affects
  – Total scan time (proportional)
  – Noise / Low contrast resolution
  – Dose (proportional)

  Generally want to minimize rotation time

• Note:
  – IV contrast timing may need adjustment
  – mA needed may exceed tube/generator limits
mA

• **Affects**
  - Noise / Low contrast resolution
  - Dose (proportional)

• **Note:**
  - mA near tube/generator limits can be problematic (especially when dose modulation is used)
Pitch

• **Affects**
  - Total scan time
  - Noise / Low contrast resolution
  - Dose

• **Note:**
  - Pitches >1 may increase image thickness (vendor-specific)
  - Pitches >1 may require mA to be increased near limits
Variable pitch.

All other parameters constant.

Pitch

<table>
<thead>
<tr>
<th>Pitch</th>
<th>CTDI\textsubscript{vol}</th>
</tr>
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<tbody>
<tr>
<td>0.562</td>
<td>162 mGy</td>
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Pitch: 0.562

CTDI\textsubscript{vol}: 162 mGy
Pitch

Pitch: 0.562  
CTDI
vol: 162 mGy

Variable pitch.

All other parameters constant.
Variable pitch.

All other parameters constant.

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<th>CTDI$_{vol}$</th>
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<td>0.938</td>
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Pitch: 0.938
CTDI$_{vol}$: 97 mGy
## Pitch

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<tr>
<td>1.375</td>
<td>66</td>
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</table>

Variable pitch. All other parameters constant.

Pitch: 1.375  
CTDI$_{vol}$: 66 mGy
### Pitch

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**Variable pitch.**

**All other parameters constant.**

Pitch: 1.75  
CTDI$_{\text{vol}}$: 52 mGy
Terminology: Effective mAs

$$\text{Effective mAs} = \frac{\text{mA} \cdot \text{s}}{\text{pitch}}$$

- Same Effective mAs => comparable image quality
- Very useful to achieve uniform IQ across different scanners/platforms
- Typical targets (average size patients)
  - Chest $\approx 180$ eff. mAs
  - Abd $\approx 200$ eff. mAs
Eff mAs = 280
Rotn time: 0.5s, Pitch: 0.8
Total scan time: 20s

Want scan time to be 15s
Change pitch to 1.1 (scan time=14.5s)
But max eff. mAs=264 (need 280)

Maybe use p=1.0 (scan time=16s)?

How about rotn time=0.33, p=0.6?
Gives scan time=17.6s
Image Thickness

• **Affects**
  - Noise / Low contrast resolution
  - Dose (?)

• **Note:**
  - Potential to dramatically increase mA (and dose) to compensate for increased noise with thinner images
Noise $\propto \frac{1}{\sqrt{\text{# Photons}}}$

- Better z-resolution (less partial vol. averaging)
- Increased image noise
- Potential for increased radiation dose

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<th>Image (mm)</th>
<th>Rel. Noise</th>
<th>Req. mAs (for = noise)</th>
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<td>0.625</td>
<td>283%</td>
<td>800%</td>
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Image Thickness

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<th>1.25</th>
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<td>2.93</td>
<td>3.84</td>
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Thinner images => less partial volume effect

Only image thickness varied, all other parameters are identical
Image Thickness

10 mm image thickness
All other parameters are identical
Image Thickness

5 mm image thickness
All other parameters are identical
Image Thickness

2 mm image thickness
All other parameters are identical
Image Thickness

1 mm image thickness
All other parameters are identical
Image Thickness

0.6 mm image thickness
All other parameters are identical
Detector Configuration
Detector Configuration

• Potentially many possible configurations
  – Not all available under all circumstances

• Narrow Beam width
  – Less scatter
  – Less coverage
  – Less dose efficiency (potentially)
Detector Configuration

- **Affects**
  - Total scan time
  - Noise / Low contrast resolution
  - Thinnest available recons

- **Note:**
  - Recommend using thinnest channel widths for best IQ
  - Some configurations (esp. narrow collimations) are less dose efficient (vendor-specific)
  - Compare relative dose using CTDI$_{vol}$ on console
Detector Configuration

Scanner: 16-channel, Detector: 8 x 2.5, Pitch = 0.875

Prospective images at 5 mm

Retrospective images at 2.5 mm
Detector Configuration

Same as patient study

Pitch: 0.875, Detector: 8×2.5mm, Beam: 20mm

SE 2, IM 2, 5mm

SE 3, IM 3, 2.5mm
Detector Configuration

Change detector (incr. Z sampling), retain beam width
Pitch: 1.375, Detector: 16×1.25mm, Beam: 20mm
Effective mAs = 109 (decreased from 171)

SE 10, IM 2, 5mm
SE 11, IM 3, 2.5mm
Detector Configuration

Increased z-sampling, same coverage (20 mm)

Detector: 8 x 2.5mm → 16 x 1.25mm
Pitch: 0.875 → 1.375 (less dose!)

5 mm

2.5 mm

DUPLICATE SAMPLE of Previous Slide
Z-axis Sampling Summary

- Detector (output channel) size should be less than thinnest retro desired.
- Beam width may change with detector configuration.
- Changes in beam width and/or pitch will affect total scan acquisition time.
- Narrow collimations => less scatter, but less dose efficient.
- Compare relative dose using CTDI$_{vol}$ on console.
“Wasted” radiation—contributes to dose only

Larger percentage of small beam is wasted!
kiloVoltage

- **Affects**
  - Noise/ Low Contrast resolution
  - Dose

- **Note:**
  - Optimum mA varies with kV
  - Low kVp may require mA values to exceed limits
  - Bolus tracking thresholds are different at different kVs
  - Make sure scanner is calibrated for all clinical kVs
kiloVoltage

100 kV
(CTDI\textsubscript{vol}=3.98 mGy)

120 kV
(CTDI\textsubscript{vol}=5.18 mGy)
Reconstruction Algorithm

• Affects
  – Noise / Low contrast resolution
  – Spatial resolution

• Note:
  – Kernels/algorithms can have obvious-to-subtle differences—get consensus from radiologists.
  – Reprocessing using different kernel is FREE (no dose cost)
Reconstruction Algorithm ~ Noise
Reconstruction Algorithm ~ Frequency
Protocol Review & Management

• Who should be involved?
  − Medical Physicist: Technical expert
  − Radiologist: Clinical expert
  − Technologist: Implementation expert

• Others to consult
  − Nurses, schedulers, billing, vendor apps, etc.
    • Any one with expertise on any aspect of protocol
Planning

• **The Physicist**
  - Assess which parameter(s) address the weakness of the protocol.
  - Provide options for optimizing the protocol (including minimizing dose and compromises to other parameters).

• **The Technologist**
  - Provides perspective on the impact of implementation (workflow, patient issues, staff issues, etc.).
  - Verifies settings in scanner.

• **The Radiologist**
  - Defines clinical task.
  - Provides perspective on the impact of implementation (workflow, patient issues, staff issues, etc.).
General Protocol Tips

- Dedicated “team” for protocol work
  - Don’t frequently rotate members

- Define structure/processes in detail – Set Rules!
  - Protocol change process
  - Protocol and file naming conventions
  - Protocol layout and components
  - Approval process (critical)!

- Support from administration essential
  - Time and resources are non-trivial

- Ongoing effort
Clinical Evaluation and Implementation

• Case-by-case, with radiologist review after each case. Ideally, get consensus of radiologists.

• If changes unacceptable, repeat planning phase.

• If changes acceptable…
  – Change scanner program
  – Change written protocol
  – Notify all techs & radiologists of major changes
  – Document changes, justifications, and people involved
General Tips: Watch for “two-fers”

- Become more savvy about using a dense helical data set for more than one purpose.

Example:
One chest acquisition on 64-channel scanner
- 5mm transverse images
- 2.5mm transverse images
- 0.625mm images used for coronal & sagittal reformats
- 0.625mm images spaced at 10mm for high res
General Tips: Watch for “no brainers”

Example:

Acquisition

- 120 kVp
- 64 x 0.625mm, spiral scan, pitch 0.938
- 0.4 sec per rotation
- 500 mA

Construct 0.625mm images every 20mm

Does this seem reasonable to you?
General Tips: Watch for “no brainers”

Example:
Acquisition
  120 kVp
  64 x 0.625mm, spiral scan, pitch 0.938
  0.4 sec per rotation
  500 mA
Construct 0.625mm images every 20mm

213 eff. mAs (reasonable)

For 40cm scan, 97% dose WASTED 😞
General focus on more consistency

- More reliable to design desired protocol parameter combinations
- Lock them down on scanners
- Discourage “on-the-fly” adjustments
- Rely instead on protocol inventory
CT Protocol Review

• Regular frequency (annual?)

• Team reviews EVERY protocol
  – Needed and used? If not, remove from protocol book & from scanner(s)!
  – Consolidate several similar protocols?
  – Look for protocols where useful technology (TCM) has not been incorporated yet
  – Have a revision date in the protocols.
What to review?

• Acquisition parameters
• Reconstruction parameters (including reformats)
• Dose reduction techniques (TCM, Iterative)
• Adjustment for patient size?
• Dose management tools? (CT Dose Check)

• AAPM Task Group – Professional Guideline
CT Protocol Management Tool - MDA

- Homegrown software (3rd try)
- Database structure
- Define reference protocol settings (used to populate protocol description sheet)
- Compares those parameters to each scanners’ settings, shows mismatches
- Can confirm protocol matches intended settings prior to each exam
- Helps track and fix incorrect settings
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**AAPM 2012 Summer School on Medical Imaging using Ionizing Radiation**

**Scanner Type:** LS_64
**GI Contrast:** 2% Barium Sulfate or Omnii 320 or Water (Oral)
**IV Contrast:** Optiray 320
**Volume:** 2 ml per Kg. (Do Not Exceed 150 ml)

**Patient Orientation/Position:** FeetFirst / Supine

**Injection Rate:** See Radiologist's protocol

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<th>kVp</th>
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<th>NI</th>
<th>TCM</th>
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<td>5.0 mm (Plus)</td>
<td>Soft DLP=210 At POS</td>
<td>2.5 mm (Plus)</td>
<td>Soft 30% ASIR Slice DLP=210 At POS</td>
</tr>
<tr>
<td>2</td>
<td>Helical 0.4 s</td>
<td>Top of Liver to Bottom of Liver</td>
<td>50 / 39.375 / 0.984</td>
<td>5.0</td>
<td>PedBody</td>
<td>80</td>
<td>35 / 145 (120)</td>
<td>10.0</td>
<td>auto mA + smart mA</td>
<td>3.4 (max)</td>
<td>7.6</td>
<td>5.0 mm (Plus)</td>
<td>Soft DLP=210 At POS</td>
<td>2.5 mm (Plus)</td>
<td>Soft 30% ASIR Slice DLP=210 At POS</td>
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**PRE CONTRAST (ONLY IF NEEDED OR REQUESTED)**

<table>
<thead>
<tr>
<th>Series</th>
<th>Scan Type</th>
<th>Area</th>
<th>Thick / Speed / Pitch</th>
<th>Interval</th>
<th>SFOV</th>
<th>kVp</th>
<th>mA (min / max)</th>
<th>NI</th>
<th>TCM</th>
<th>CTDDI</th>
<th>Delay</th>
<th>Recon 1</th>
<th>Recon 2</th>
<th>Recon 3</th>
<th>Recon 4</th>
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<tbody>
<tr>
<td>3</td>
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<td>Top of Liver to Symphysia Pubis</td>
<td>50 / 39.375 / 0.984</td>
<td>5.0</td>
<td>PedBody</td>
<td>80</td>
<td>100 / 180 (50)</td>
<td>9.5</td>
<td>manual</td>
<td>1.6 (manual)</td>
<td>90.0</td>
<td>5.0 mm (Full)</td>
<td>Soft DLP=210 At POST</td>
<td>2.5 mm (Full)</td>
<td>Soft 30% ASIR Slice DLP=210 At POST</td>
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<tr>
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<td>PedBody</td>
<td>80</td>
<td>100 / 180 (50)</td>
<td>9.5</td>
<td>manual</td>
<td>1.6 (manual)</td>
<td>180.0</td>
<td>5.0 mm (Full)</td>
<td>Soft DLP=210 At POST</td>
<td>2.5 mm (Full)</td>
<td>Soft 30% ASIR Slice DLP=210 At POST</td>
</tr>
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</table>

**POST CONTRAST**

**DR auto Transfer:** STENTOR, ACR, PEMNET

**Auto Transfer:** STENTOR

**Comments:** Scanning direction from superior to inferior

Do coronal & sagittal reformation
<table>
<thead>
<tr>
<th>Protocol Nr</th>
<th>Patient</th>
<th>Cat</th>
<th>Description</th>
<th>Last modification</th>
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<th>ct5</th>
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</tbody>
</table>
## AAPM 2012 Summer School on Medical Imaging using Ionizing Radiation

GI Contrast: 2% Barium Sulfate or Omni 320 or Water (Oral)
IV Contrast: Optiray 320
Volume: 2 ml per Kg. (Do Not Exceed 150 ml)
Patient Orientation/Position: FeetFirst / Supine
Injection Rate: See Radiologist's protocol

### Series Scan Type

<table>
<thead>
<tr>
<th>Series</th>
<th>Scan Type</th>
<th>Description</th>
<th>Area</th>
<th>Thick / Speed / Pitch</th>
<th>Interval</th>
<th>SFOV</th>
<th>mA min / max (manual)</th>
<th>NI</th>
<th>TCM</th>
<th>CTDI vol</th>
<th>Delay</th>
<th>Recon 1</th>
<th>Recon 2</th>
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<td>Scout</td>
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<td>AL-AP AL-AP</td>
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### PRE CONTRAST (ONLY IF NEEDED OR REQUESTED)

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<tr>
<th>Series</th>
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<th>Interval</th>
<th>SFOV</th>
<th>mA min / max (manual)</th>
<th>NI</th>
<th>TCM</th>
<th>CTDI vol</th>
<th>Delay</th>
<th>Recon 1</th>
<th>Recon 2</th>
<th>Recon 3</th>
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<tr>
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<td>Top of Liver to Bottom of Liver</td>
<td>5.0 / 39.375 / 0.984</td>
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<td>PedBody</td>
<td>80</td>
<td>35 / 145 (120)</td>
<td>10.0</td>
<td>auto mA + smart mA</td>
<td>3.4 (max)</td>
<td>7.6</td>
<td>AL-AP AL-AP</td>
<td>SCOT</td>
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### POST CONTRAST

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<th>Scan Type</th>
<th>Description</th>
<th>Area</th>
<th>Thick / Speed / Pitch</th>
<th>Interval</th>
<th>SFOV</th>
<th>mA min / max (manual)</th>
<th>NI</th>
<th>TCM</th>
<th>CTDI vol</th>
<th>Delay</th>
<th>Recon 1</th>
<th>Recon 2</th>
<th>Recon 3</th>
<th>Recon 4</th>
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<tbody>
<tr>
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<td>Axial</td>
<td>1 Slice Middle of Kidneys</td>
<td>5.0 / 39.375 / N/A</td>
<td>5.0</td>
<td>PedBody</td>
<td>80</td>
<td>100 / 180 (50)</td>
<td>9.5</td>
<td>manual</td>
<td>1.6 (manual)</td>
<td>90.0</td>
<td>AL-AP AL-AP</td>
<td>SCOT</td>
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<td>1 Slice Middle of Bladder</td>
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<td>SCOT</td>
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</tbody>
</table>

DR auto transfer: STENTOR, ACR, PEMNET
Auto Transfer: ""ACR, ""STENTOR

Comments: Scanning direction from anterior to inferior

Do coronal & sagittal reformation
mA Modulation Scout Scans

Jim Kofler, Ph.D.

Same patient – vertical table height can affect size-shape model!
Predicted CTDIvol vs table height (Multiple Vendors)

Percent Change in CTDIvol (mGy) from isocenter.

Change in SSD from isocenter (cm)

-60% -40% -20% 0% 20% 40% 60%
Conclusions

• Not always a “perfect” answer
• “Best” parameters for standard conditions
  – Strategies presented in other sessions
  – AAPM website, manufacturers
• Protocol Management Important
  – Have a system/procedure in place
  – Techs, physicists, radiologists
  – Consider regular review process