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

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Scan 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.
  - Consult with radiologist

All protocol decisions must consider clinical task

Major Clinical Considerations

Need short scan time

- Single breath-hold (<15 seconds)
- Less patient motion
  - Especially peds, ER patients
- Scan time also affects contrast timing

Breathing motion in upper portion of image
Major Clinical Considerations

**Need high spatial resolution**

**Radiation Dose**
- Should be as low as possible without sacrificing diagnostic content.
- Dose “ceilings” will potentially be used as pass/fail criteria for ACR CT accreditation.
- CTDI<sub>vol</sub> and DLP displayed on scanner console.

**Technical Considerations**
- Tube rotation time
- mA
- Pitch
- kVp
- Image thickness
- Detector configuration
- Reconstruction kernel/algorithim
- Patient size-dependent techniques
Tube Rotation Time

Affects
- Total scan time (proportional)
- Noise / Low contrast resolution
- Dose (proportional)
  Generally want to minimize rotation time

What to look out for...
- IV contrast timing may need adjustment
- mA needed may exceed tube/generator limits

Example: Limits are reduced by tube housing heating

mA

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

What to look out for...
- mA near tube/generator limits can be problematic (especially when dose modulation is used)

Pitch

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

What to look out for...
- Pitches >1 may increase slice thickness (vendor-specific)
- Pitches >1 may require mA to be increased near limits
Pitch

Pitch: 0.562
CTD{sub}vol: 162 mGy
All other parameters constant.

Pitch: 0.938
CTD{sub}vol: 97 mGy
All other parameters constant.

Pitch: 1.375
CTD{sub}vol: 66 mGy
All other parameters constant.

Pitch: 1.75
CTD{sub}vol: 52 mGy
All other parameters constant.
**Terminology: Effective mAs**

Effective mAs = \( \frac{mA \cdot s}{pitch} \)

- Same Eff. mAs => comparable image quality
- VERY helpful to achieve uniform IQ across different scanners/platforms
- Typical targets (average size pts):
  - Chest ~ 180 eff. mAs
  - Abd ~ 200 eff. mAs

**Pitch, Rotation Time, 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 rot time=0.33, p=0.67?
Gives scan time=17.6s

**kVp**

Affects
- Noise / Low contrast resolution
- Dose

What to look out for...
- Low kVp may require mA values to exceed limits
- Confirm scanner is calibrated for proposed kVp
- Set mA by matching noise using a phantom  
  *For small kVp changes (e.g., 120 to 140 kVp) can estimate \( mA_2 = mA_1 \left( \frac{kVp_1}{kVp_2} \right)^2 \)*

Increasing kVp may be helpful for abdominal studies in large patients.

<table>
<thead>
<tr>
<th>kVp</th>
<th>Mean</th>
<th>( \sigma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>140 kV</td>
<td>112</td>
<td>20</td>
</tr>
<tr>
<td>80 kV</td>
<td>273</td>
<td>38</td>
</tr>
</tbody>
</table>

mAs=82  
mAs=240

All other parameters are identical
**Image thickness**

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

**What to look out for...**
- Potential to dramatically increase mA (and dose)
  to compensate for increased noise with thinner images

**Noise**
\[ \text{Noise} \propto \frac{1}{\text{# Photons}} \]

**Image (mm):**
- 5
- 2.5
- 1.25
- 0.625

**Rel. Noise:**
- 100%
- 141%
- 200%
- 283%

**Req. mAs (for noise):**
- 1000
- 2000
- 4000
- 8000

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

**Thinner slices => less partial volume effect**

- Only image thickness varied, all other parameters are identical

**Image thickness**

- Image (mm): 10, 5, 2.5, 1.25
- Noise (HU): 2.93, 3.84, 5.89, 7.82

**10mm image thickness**

- All other parameters are identical
Image thickness

5mm image thickness
All other parameters are identical

2mm image thickness
All other parameters are identical

1mm image thickness
All other parameters are identical

0.6mm image thickness
All other parameters are identical
Detector Configuration

Affects
- Total scan time
- Noise / Low contrast resolution
- Thinnest available recon
- Dose

What to look out for...
- Recommend using thinnest channel widths possible for best IQ
- Some configurations (esp. narrow collimations) are less dose efficient (vendor-specific)
- Compare relative dose using CTDI_{vol} on console.

Many options*

<table>
<thead>
<tr>
<th>Number of slices x Slice thickness</th>
<th>16 x 1.25</th>
<th>8 x 2.5</th>
<th>4 x 3.75</th>
<th>4 x 5</th>
<th>8 x 1.25</th>
<th>4 x 2.5</th>
<th>2 x 3</th>
<th>1 x 2.5</th>
<th>2 x 0.63</th>
</tr>
</thead>
</table>

* Doesn’t consider recons, not all available in helical

Prospective images at 5mm
Scanner: 16-channel
Detector: 8 x 2.5
Pitch = 0.875

Retrospective images at 2.5mm
Same as patient study
Pitch: 0.875, Detector: 8×2.5mm, Beam: 20mm
SE 2, IM 2, 5mm
SE 3, IM 3, 1.5mm

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

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.

Narrow Collimation Dose Inefficiency
"Wasted" radiation—contributes to dose only
Larger percentage of small beam is wasted!
Kernel/Algorithm

Affects
- Noise / Low contrast resolution
- Spatial resolution

What to look out for...
- Kernels/algorithms can have obvious-to-subtle differences—get consensus from radiologists.

Reprocessing using different kernel is FREE
(no dose cost)

Kernel/Algorithm

Both noise and frequency content affect “Image quality”

Patient Size-Dependent Techniques

Dose Modulation
- Technique determined automatically based on reference level of noise or image quality.
- Can reduce dose in x, y and z-directions (small pts).

Technique Charts
- Pre-determined techniques based on patient size.
- Physicist needs to construct chart.
- Tech must measure patient size and manually enter technique.
- Not as eloquent or efficient as modulation but can save significant dose.
Technique Charts

Use known relationships to predict the mAs required to keep image noise/quality constant as thickness changed.

Example CT Size Technique Chart

Tube Current Modulation

- “AEC” approach for CT
- “Scout” view typically used to set mA
- For SMALL patients can result in dose DECREASE (peds)
- For LARGE patients can result in dose INCREASE
**Tube Current Modulation**

**What to look out for...**

- Set mA FLOOR and mA CEILING (vendor-specific)
  - Min. mA too low can cause high noise
  - Max. mA too high can cause scary dose
- Set Quality Reference mAs (vendor-specific)
  - Build in scanner using appropriate base protocol
- Calculating delivered dose challenging
  - Changes per image and during tube rotation
  - Can used exam-averaged mAs for dose estimate

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**Protocol Development**

**Who should be involved?**

- Medical Physicist: Technical issues
- Radiologist: Clinical issues
- Technologist: Implementation issues

**Others to consult...**

- Nurses, Schedulers, Billing, Vendor Apps, etc.

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

**The Radiologist**

- Provides their perspective on the impact of implementation (workflow, patient issues, staff issues, etc.).

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**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 reformat
0.625mm images spaced at 10mm for high res

Does this seem reasonable to you?

General Tips: Watch for no-brainers

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

For 40cm scan, 97% dose WASTED 😞

Special Cases: Pediatric

Equal noise is not the clinical ideal, because ...

- Children don’t have the fat planes between tissues and organs that adults do
- Details of interest are smaller in children, so greater CNR required
- Radiologists are accustomed to “reading through the noise” on large patients
- Radiologists require higher image quality in children to ensure high diagnostic confidence
**Special Cases: Pediatric**

**Approach**
- Scale down from a standard adult technique
- Adjust by ratio of image thickness for adult vs pediatrics
- Tweak as necessary after review

**What to look out for…**
- Want shortest possible scan time (kids squirm)
- Build scanner protocol using pediatric base (if available)

**Pediatric Example**

6 year old child
Scanned with adult protocol using Dose Modulation
Reference eff. mAs = 165
Mean eff. mAs = 38

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**Special Cases: Heavy Patients**

- Growing issue across USA
  - At MDA: ~50% 'large,' ~30% 'average,' ~20% 'small'
- Challenge to cross-sectional imaging
- Obligated to deliver diagnostic images

**First Considerations**
- Is table safe for heavy patient (load limit)?
- Can patient fit into gantry?
- Can staff get patient on table?
Special Cases: Heavy Patients

Approach (prioritize according to clinical task)

- (1) Increase ceiling level on current modulation protocols.
- (2) Quality Reference mAs remains unchanged.
- Increase tube rotation time.
- Decrease pitch.
- Use larger collimation (e.g., 32x0.6 => 24x1.2) then decrease pitch.
- Increase kVp.

May only need some options—listen to your scanner!

Post-Acquisition options

- Recon using a smoother kernel (or special kernels, if available).
- Recon to thicker images.

Reprocessing is FREE (no dose cost)

Hoping for adequate, not exquisite, images.
Combo Protocol & Technique Chart

- At MDA (and Mayo), we set up ‘average’ patient protocols
- At MDA, a ‘large patient’ duplicate set
  Patients who require > 42cm DFOV
  Increase eff. mAs by 30%
- At Mayo, a “bariatric” version and steps for heavy (but non-bariatric) patients

Special Cases: Metal Implants

- Thinner images prospectively
- Thicker images built from reformats
- Reformat into sagittal and/or coronal planes
- Scan with higher kVp
  More photons produced at same mAs
  Photons are more penetrating

Metal Hip

Prospective axial series:
140kV
265 mA, 0.5 sec, pitch 1.5
Effective mAs = 88 mAs
2.5 mm image thickness
4 x 2.5 mm detector config.

Special Cases: Metal Implants

- Cannot completely eliminate artifact
- Increasing mAs (dose) has diminishing returns
- Dose modulation should behave properly
  (i.e., not automatically max-out in metal)
Which of the following affects image quality but not dose? (Assume all other parameters remain constant).

1. Changing the mAs setting.
2. Changing the detector configuration/beam collimation.
3. Using mA modulation.
4. Changing the reconstruction kernel/algorithm.
5. Changing the pitch.

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Which of the following is the most important consideration for optimizing scan protocols?

1. X-ray tube rotation time.
2. Radiation dose.
3. Pitch.
4. Low-contrast resolution.
5. Cannot determine.

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5. Cannot determine.
Which of the following statements is false?

1. X-ray tube current modulation always results in less dose compared to using no dose-reduction technique.
2. Using thinner slices may result in higher doses.
3. Relative doses of different scan parameters can be compared using the CTDIvol displayed on the scanner.
4. A minimal scan protocol “team” consists of a radiologist, a medical physicist, and a technologist.
5. Thinner x-ray beam widths yield less scatter but can be less dose-efficient.


Which statement is true regarding x-ray tube current modulation implementation?

1. Centering the patient in the gantry is often critical to achieving reliable results.
2. X-ray tube capacity can limit the usefulness of x-ray tube current modulation in practice.
3. Generally, the last (or final) scout or topogram view acquired is used for x-ray tube current modulation purposes.
4. Calculating radiation dose is more challenging when x-ray tube current modulation is implemented.
5. All of the above statements are true.

Compared to a chest x-ray, the entrance exposure from a single A/P scout scan (or topogram) is...?

<table>
<thead>
<tr>
<th></th>
<th>1. About half as much.</th>
<th>2. About 1-5 times more.</th>
<th>3. About 10 times more.</th>
<th>4. About 50-100 times more.</th>
<th>5. &gt;100 times more</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>0%</td>
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