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 <u>all</u> 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

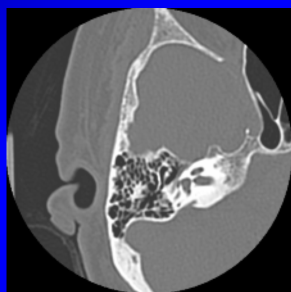
Need short scan time

- 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



Major Clinical Considerations

Need good low contrast resolution

Major Clinical Considerations

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.
- $CTDI_{vol}$ and DLP displayed on scanner console.

Technical Considerations

- Tube rotation time
- mA
- Pitch
- kVp
- Image thickness
- Detector configuration
- Reconstruction kernel/algorithm
- Patient size-dependent techniques

Tube Rotation Time

Affects

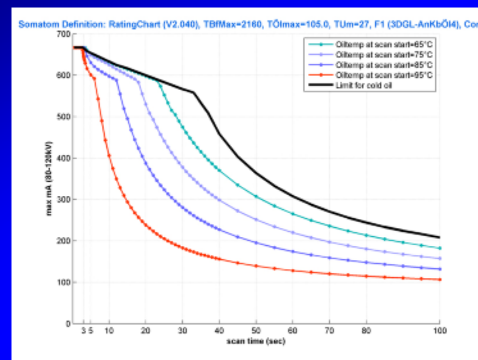
- Total scan time (proportional)
- Noise / Low contrast resolution
- Dose (proportional)

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)

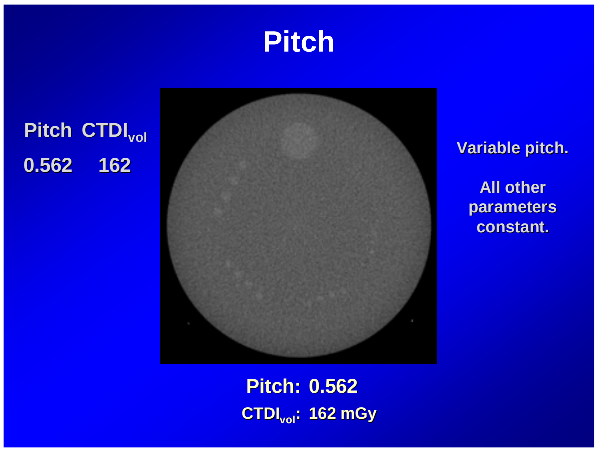
Pitch

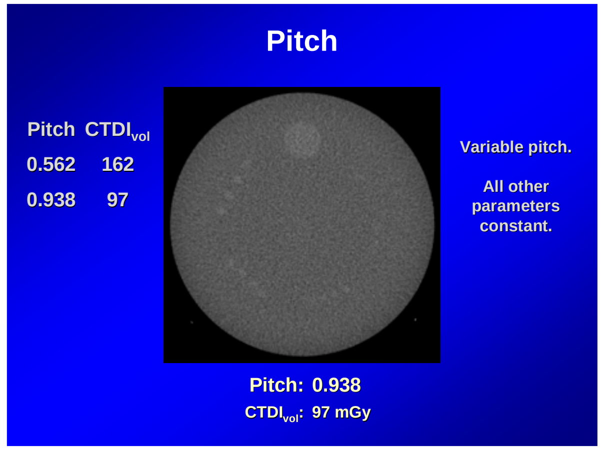
Affects

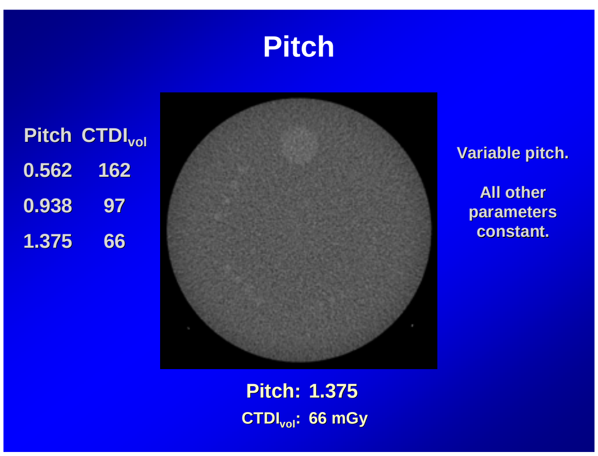
- Total scan time
- Noise / Low contrast resolution
- Dose

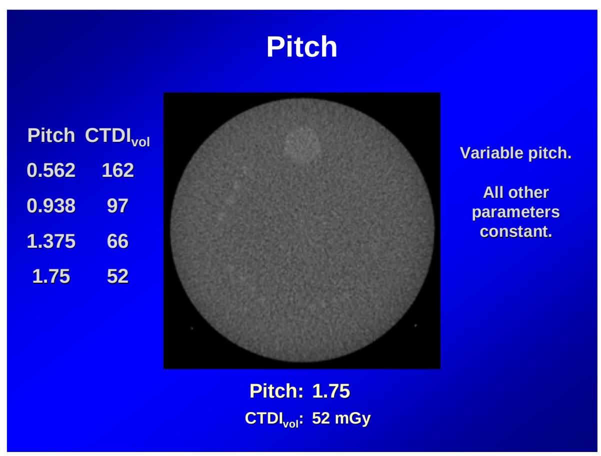
What to look out for…

- Pitches >1 may increase slice thickness (vendor-specific)
- Pitches >1 may require mA to be increased near limits


Pitch
Pitch CTDI$_{vol}$
0.562 162
Variable pitch.
All other parameters constant.
Pitch: 0.562
CTDI$_{vol}$: 162 mGy


Pitch
Pitch CTDI$_{vol}$
0.562 162
0.938 97
Variable pitch.
All other parameters constant.
Pitch: 0.938
CTDI$_{vol}$: 97 mGy


Pitch
Pitch CTDI$_{vol}$
0.562 162
0.938 97
1.375 66
Variable pitch.
All other parameters constant.
Pitch: 1.375
CTDI$_{vol}$: 66 mGy


Pitch
Pitch CTDI$_{vol}$
0.562 162
0.938 97
1.375 66
1.75 52
Variable pitch.
All other parameters constant.
Pitch: 1.75
CTDI$_{vol}$: 52 mGy

Terminology: Effective mAs

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

- 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 rotn time=0.33, p=0.6?
Gives scan time=17.6s

	kV	120
	max mA	580
Time	Pitch	Max Eff mAs
0.33	0.5	383
	0.6	319
	0.7	273
	0.8	239
	0.9	213
	1.0	191
	1.1	174
	1.2	160
	1.3	147
	1.4	137
	1.5	128
0.5	0.5	580
	0.6	483
	0.7	414
	0.8	363
	0.9	322
	1.0	290
	1.1	264
	1.2	242
	1.3	223
	1.4	207
	1.5	193
1.0	0.5	1160
	0.6	967
	0.7	829
	0.8	725
	0.9	644
	1.0	580
	1.1	527
	1.2	483
	1.3	446
	1.4	414
	1.5	387

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 $mA_2 = mA_1\,(kVp_1 / kVp_2)^2$

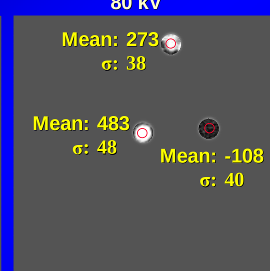
Increasing kVp may be helpful for abdominal studies in large patients.

kVp

140 kV

mAs=82

80 kV



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

Image thickness

$$\text{Noise} \propto \frac{1}{\sqrt{\#\ \text{Photons}}}$$

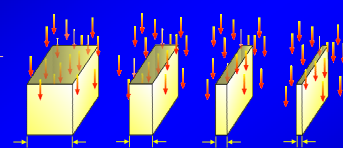
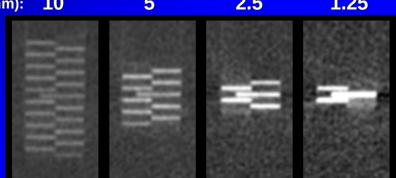


Image (mm):	5	2.5	1.25	0.625
Rel. Noise:	100%	141%	200%	283%
Req. mAs (for = noise):	100%	200%	400%	800%

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

Image thickness

Image (mm):	10	5	2.5	1.25

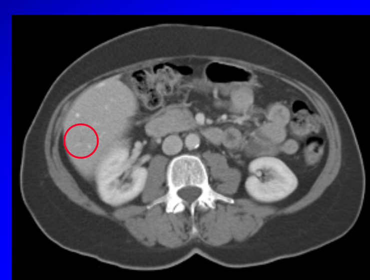


Noise (HU):	2.93	3.84	5.89	7.82

Thinner slices => less partial volume effect

Only image thickness varied, all other parameters are identical

Image thickness



10mm image thickness

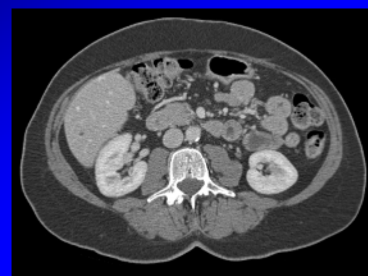
All other parameters are identical

Image thickness

5mm image thickness

All other parameters are identical

Image thickness



2mm image thickness

All other parameters are identical

Image thickness

1mm image thickness

All other parameters are identical

Image thickness

0.6mm image thickness

All other parameters are identical

Detector Configuration

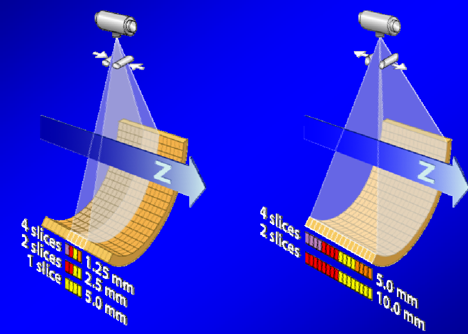
Affects

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

What to look out for…

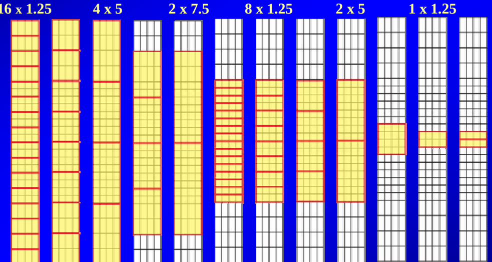
- Recommend using thinnest channel widths possible for best IQ
- Some configurations (esp. narrow collimations) are less dose efficient (vendor-specific)
- Compare relative dose using $CTDI_{vol}$ on console.

Detector Configuration

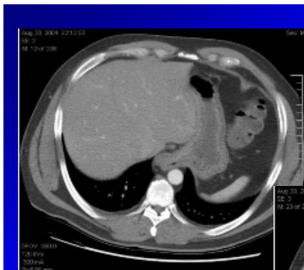


Many options*

Number of slices x Slice thickness



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

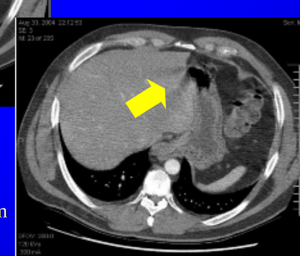


Prospective images at 5mm

Scanner: 16-channel

Detector: 8 x 2.5

Pitch = 0.875

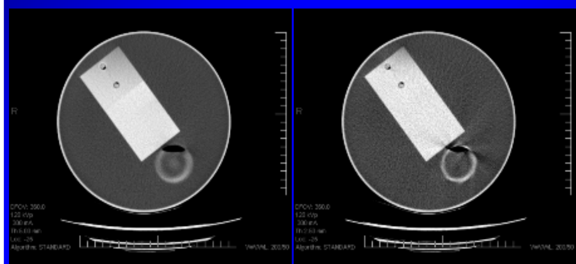


Retrospective images at 2.5mm

Same as patient study

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

SE 2, IM 2, 5mm — SE 3, IM 3, **2.5mm**

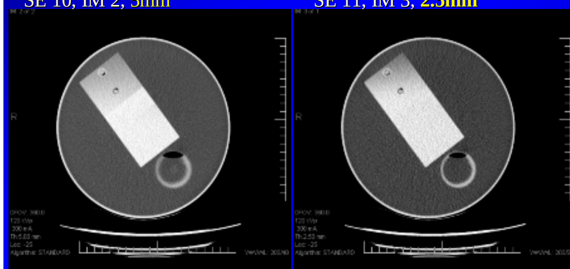


Change detector (incr. Z sampling), retain beam width

Pitch: 1.375, Detector: 16×**1.25mm**, Beam: **20mm**

Effective mAs = 109 (decreased from 171)

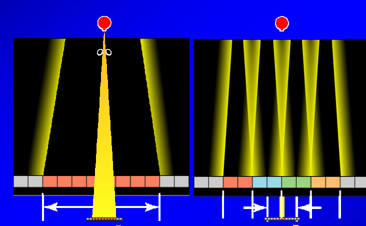
SE 10, IM 2, 5mm — SE 11, IM 3, **2.5mm**



Z-axis Sampling Summary

- **Detector (output channel) size <u>should</u> 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

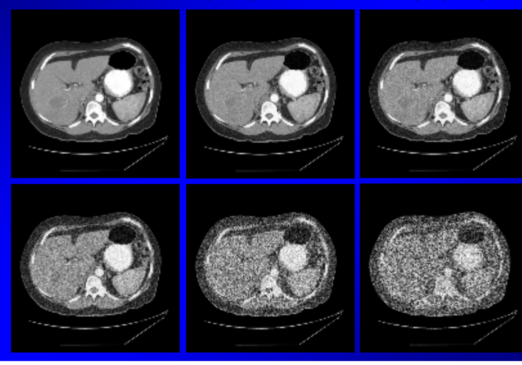
What to look out for…

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

Reprocessing using different kernel is FREE (no dose cost)

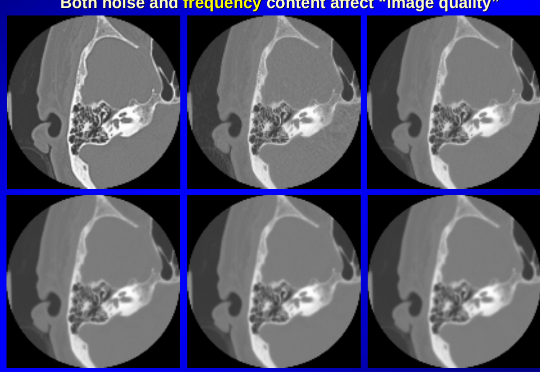
Kernel/Algorithm

Both noise and frequency content affect “image quality”



Kernel/Algorithm

Both noise and frequency content affect “image quality”



Patient Size-Dependent Techniques

Dose Modulation

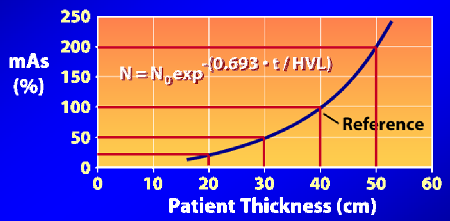
- Technique determined automatically based on reference level of noise or image quality.
- Can reduce dose in x,y and z-directions (small pts).

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



Mayo "Imaging" HVLs

Abd/Pelvis: 10 cm
Chest: 13 cm

Example CT Size Technique Chart

ABD & PELVIS - ROUTINE Technique Chart (pediatric and adult) **LightSpeed Ultra**

Lateral patient width (cm)	Rows used	Primary slice thickness (mm)	Pitch	Table speed (mm/rot)	Recon Algorithm	Retro recon thickness' available (mm)	Lateral patient width (cm)	mA (at 0.5s)	kVp (at 0.5s)
up to 14	8	3.75	0.625:1	12.5	std (full)	2.5 5 7.5 10	up to 14	60	120
14.1 - 18	8	3.75	0.625:1	12.5	std (full)	2.5 5 7.5 10	14.1 - 18	80	120
18.1 - 22	8	3.75	0.625:1	12.5	std (full)	2.5 5 7.5 10	18.1 - 22	110	120
22.1 - 26	8	5	0.625:1	12.5	std (full)	2.5 3.75 7.5 10	22.1 - 26	90	120
26.1 - 30	8	5	0.625:1	12.5	std (full)	2.5 3.75 7.5 10	26.1 - 30	130	120
30.1 - 35	8	5	0.625:1	12.5	std (full)	2.5 3.75 7.5 10	30.1 - 35	180	120
35.1 - 40	**8**	**5**	**0.625:1**	**12.5**	**std (full)**	**2.5 3.75 7.5 10**	**35.1 - 40**	**250**	**120**
40.1 - 45	8	5	0.625:1	12.5	std (full)	2.5 3.75 7.5 10	40.1 - 45	350	120
45.1 - 50	8	5	0.625:1	12.5	std (full)	2.5 3.75 7.5 10	45.1 - 50	370	140

For scanner default protocol use 35.1 - 40 cm settings

 last modified May-27-03

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…

- Final scout acquired is typically used to assess size and should included entire scan area

  P-A instead of A-P for ALL patients

  If scout not adequate, repeat
  Scout dose ≈ 1-5 chest x-rays << spiral acquisition
- Patient centering is CRITICAL

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

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.

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.).

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

Acquisition

- 120 kVp
- 64 x 0.625mm, 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

Acquisition

- 120 kVp
- 64 x 0.625mm, 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

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 peds
- 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)

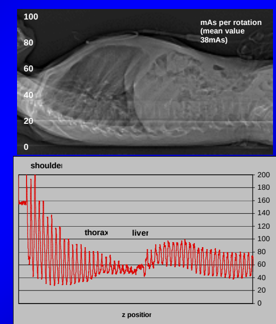
Pediatric Example

6 year old child

Scanned with adult protocol using Dose Modulation

Reference eff. mAs = 165

Mean eff. mAs = 38



Pediatric Example

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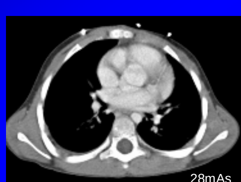


Special Cases: Heavy Patients

- 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!

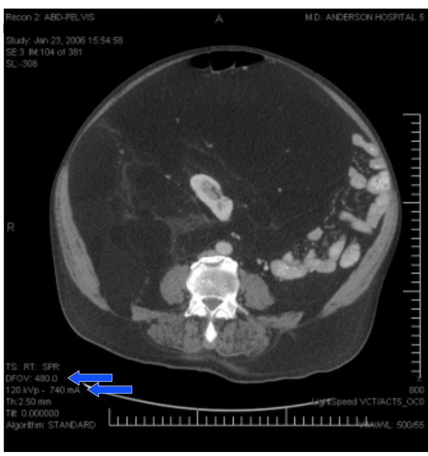
Special Cases: Heavy Patients

Post-Acquisition options

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

Reprocessing is FREE (no dose cost)

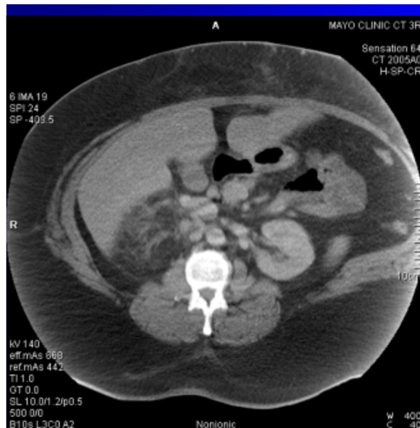
Hoping for adequate, not exquisite, images.



GE VCT

DFOV 48cm
120 kV
740 mA
0.8 sec/rotn
Pitch .984

600 eff mAs



Siemens
Sens-64

DFOV 50cm
140 kV
334 mA
1.0 sec/rotn
Pitch 0.5
10mm images

668 eff mAs

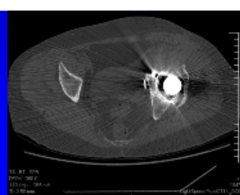
Combo Protocol & Technique Chart

- 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



<u>Prospective axial series:</u>
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).

0% 1. Changing the mAs setting.

0% 2. Changing the detector configuration/beam collimation.

0% 3. Using mA modulation.

0% 4. Changing the reconstruction kernel/algorithm.

0% 5. Changing the pitch.

10

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.

H.D. Nagel, *Radiation Exposure in Computed Tomography (4th edition)*, CTB Publications, D-21073 Hamburg, Germany, 2002.

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

0% 1. X-ray tube rotation time.

0% 2. Radiation dose.

0% 3. Pitch.

0% 4. Low-contrast resolution.

0% 5. Cannot determine.

10

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.**

C.H. McCollough, M. R. Bruesewitz, JM Kofler, *CT Dose Reduction and Dose Management Tools: Overview of Available Options*, RadioGraphics 2006; 26:503–512.

Which of the following statements is false?

0%	1. X-ray tube current modulation always results in less dose compared to using no dose-reduction technique.
0%	2. Using thinner slices may result in higher doses.
0%	3. Relative doses of different scan parameters can be compared using the $CTDI_{vol}$ displayed on the scanner.
0%	4. A minimal scan protocol “team” consists of a radiologist, a medical physicist, and a technologist.
0%	5. Thinner x-ray beam widths yield less scatter but can be less dose-efficient.

10

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 $CTDI_{vol}$ 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.

N Keat, *Automated Dose Control in Multi-slice CT*, UK Radiological Congress (UKRC), Birmingham, UK, May, 2006. Presentation available at www.impactscan.org.

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

0%	1. Centering the patient in the gantry is often critical to achieving reliable results.
0%	2. X-ray tube capacity can limit the usefulness of x-ray tube current modulation in practice.
0%	3. Generally, the last (or final) scout or topogram view acquired is used for x-ray tube current modulation purposes.
0%	4. Calculating radiation dose is more challenging when x-ray tube current modulation is implemented.
0%	5. All of the above statements are true.

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

0%	1. About half as much.
0%	2. About 1-5 times more.
0%	3. About 10 times more.
0%	4. About 50-100 times more.
0%	5. >100 times more

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O'Daniel J.C., Stevens D.M., Cody D.D. Reducing radiation exposure from projection CT Scans. American Journal of Roentgenology. *185*: 509-515;2005