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

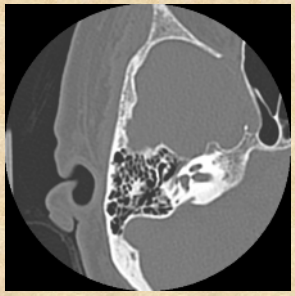
Major Clinical Considerations

- 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" are now used as pass/fail criteria for ACR CT accreditation.
  - $CTDI_{vol}$ and DLP displayed on scanner console.

Major Clinical Scan Parameters

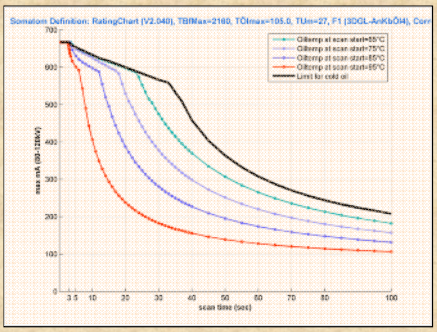
- Tube rotation time
- mA
- Pitch
- kVp
- Image thickness
- Detector configuration
- Reconstruction kernel/algorithm
- Patient size-dependent techniques

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

Tube Rotation Time

- Example: Limits are reduced by tube housing heating



mA

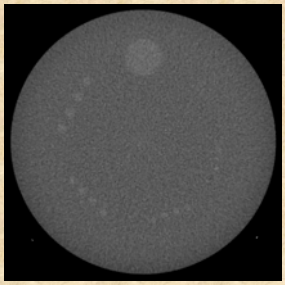
- Affects
  - Noise / Low contrast resolution
  - Dose (proportional)
- What to look out for
  - mA near tube/generator limits can be problematic (especially when dose modulation is used)

Pitch

- Affects
  - Total scan time
  - Noise / Low contrast resolution
  - Dose
- What to look out for
  - Pitches >1 may increase image thickness (vendor-specific)
  - Pitches >1 may require mA to be increased near limits

Pitch

Pitch	$CTDI_{vol}$
0.562	162



Variable pitch.

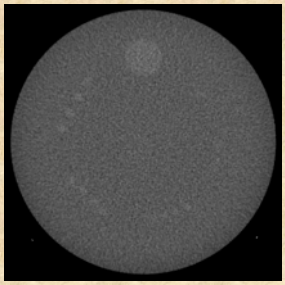
All other parameters constant.

Pitch: 0.562

$CTDI_{vol}$: 162 mGy

Pitch

Pitch	$CTDI_{vol}$
0.562	162
0.938	97



Variable pitch.

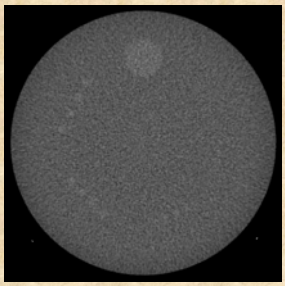
All other parameters constant.

Pitch: 0.938

$CTDI_{vol}$: 97 mGy

Pitch

Pitch	$CTDI_{vol}$
0.562	162
0.938	97
1.375	66



Variable pitch.

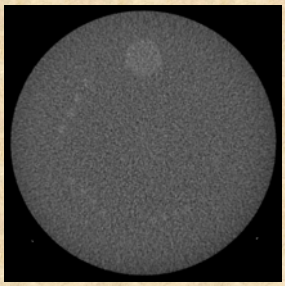
All other parameters constant.

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

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

- Same Eff. mAs => comparable image quality
- VERY helpful to achieve uniform IQ across different scanners/platforms
- Typical targets (average size patients):

  Chest ≈ 180 eff. mAs

  Abd ≈ 200 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	500
Time	Pitch	Max Eff mAs
0.33	0.5	365
	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	500
	0.6	480
	0.7	414
	0.8	363
	0.9	323
	1.0	290
	1.1	264
	1.2	242
	1.3	223
	1.4	207
	1.5	193
1.0	0.5	1000
	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

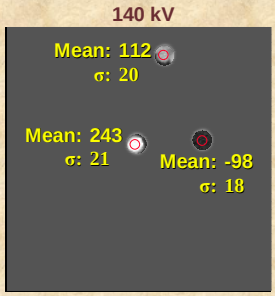
kVp

- 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

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

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

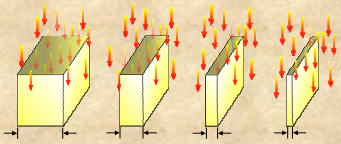
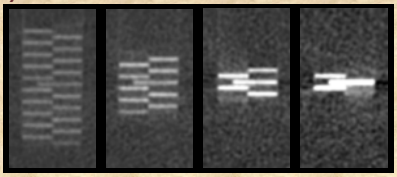


Image (mm):	5	2.5	1.25	0.625
Rel. Noise:	100%	141%	200%	283%
Req. mAs (for = noise):	100%	200%	400%	800%

- 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

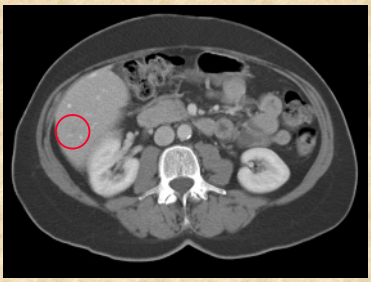


Noise (HU):	2.93	3.84	5.89	7.82

All other parameters are identical

- Thinner slices => less partial volume effect

Image Thickness



10mm image thickness

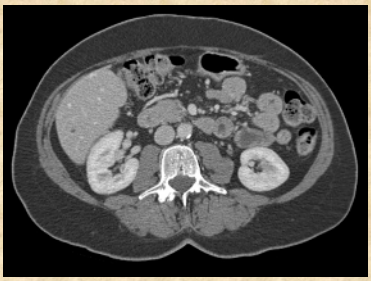
All other parameters are identical

Image Thickness

5mm image thickness

All other parameters are identical

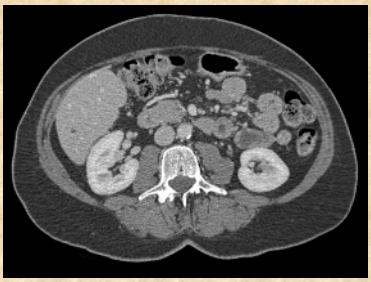
Image Thickness



2mm image thickness

All other parameters are identical

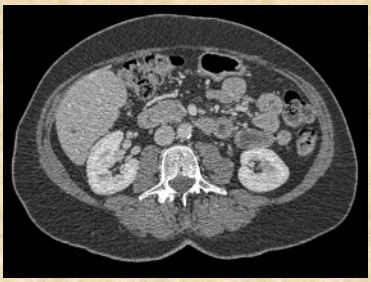
Image Thickness



1mm image thickness

All other parameters are identical

Image Thickness



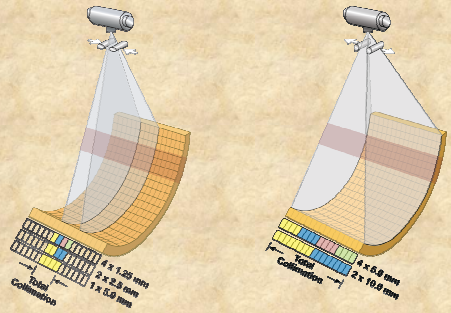
0.6mm image thickness

All other parameters are identical

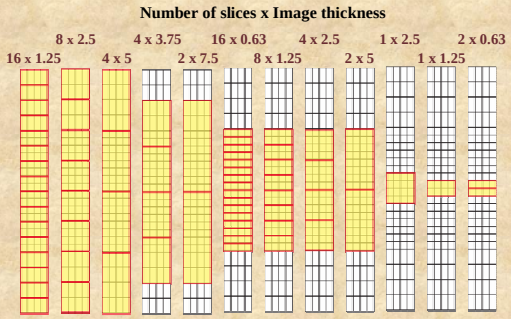
Detector Configuration

- 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

Multi-slice Detectors

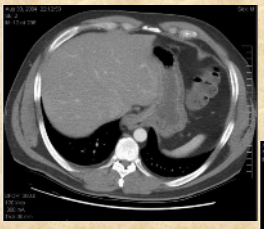


Detector Configurations - Many Options*



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

Detector Configuration

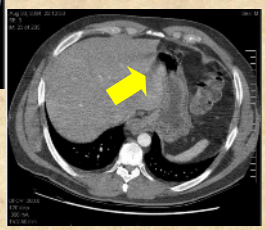


Prospective images at 5mm

Scanner: 16-channel

Detector: 8 x 2.5

Pitch = 0.875



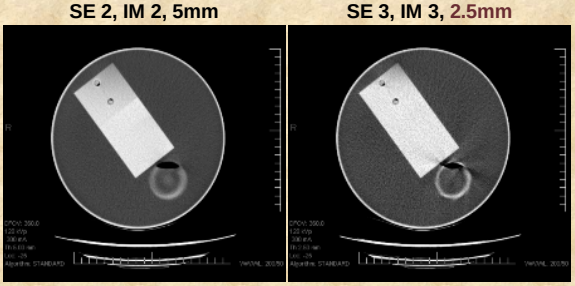
Retrospective images at 2.5mm

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



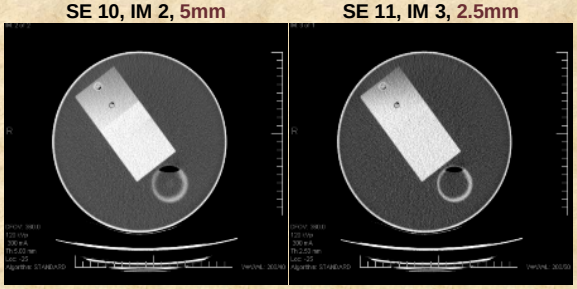
Detector Configuration

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

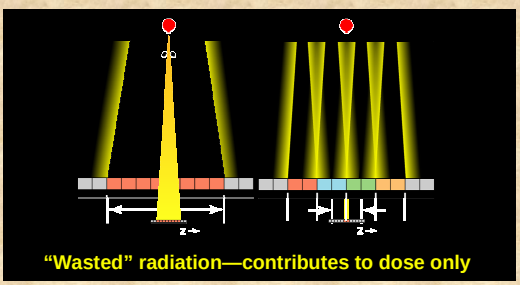


Z-axis Sampling Summary

- 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.

Multi-Slice and Dose

- MS dose is dependent on detector configuration



- Larger proportion of small beam is wasted!

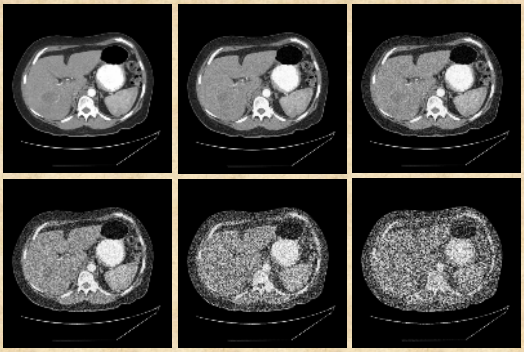
Kernel/Algorithm

- 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)

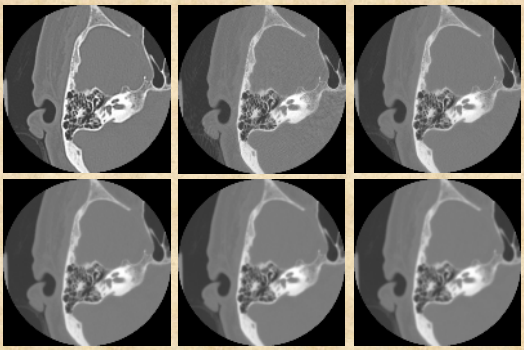
Kernel/Algorithm

- Both noise and frequency content affect "image quality"



Kernel/Algorithm

- Both noise and frequency content affect "image quality"

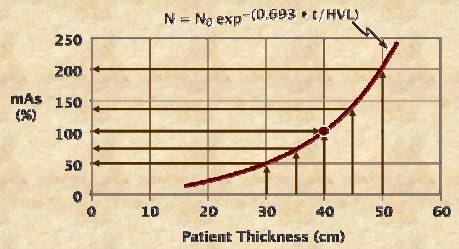


Patient Size-Dependent Techniques

- 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

CT Technique Chart Example

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 - 28	8	5	0.625:1	12.5	std (full)	2.5 3.75 7.5 10	22.1 - 28	90	120
28.1 - 30	8	5	0.625:1	12.5	std (full)	2.5 3.75 7.5 10	28.1 - 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.

Tube Current Modulation

- "AEC" approach for CT
- Final "scout" view typically used to determine mA modulation
- 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 impact of implementation (workflow, patient issues, staff issues, etc.)
  - Verifies settings in scanner
- The Radiologist
  - Provides their perspective on 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 Oversights

- Example

  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 Oversights

- Example

  Acquisition

  120 kVp

  64 x 0.625mm, pitch 0.938

  0.4 sec per rotation

  500 mA

  Construct 0.625mm images <u>every 20mm</u>

213 eff. mAs (reasonable)

For 40cm scan, 97% dose WASTED

Special Cases: Pediatric

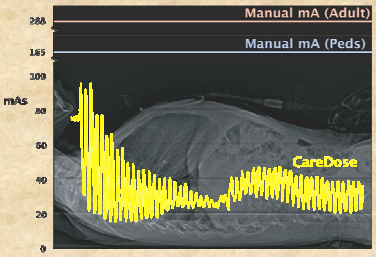
- Equal noise is not the clinical ideal, because …
  - Children don't have the fat planes between tissues and organs that adults do
  - Details of interest are smaller in children, so greater CNR required
  - Radiologists are accustomed to "reading through the noise" on large patients
  - Radiologists 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

- **Case: 6 year old, reduced-technique adult protocol**

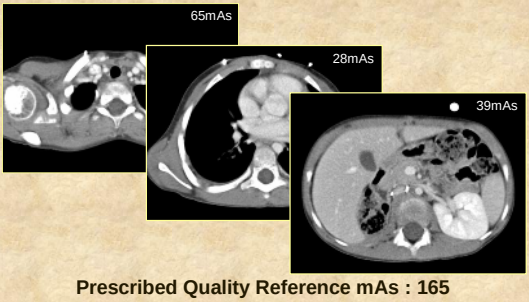


Prescribed Quality Reference mAs : 165

Average mAs used: 38

Pediatric Example

- **Case: 6 year old, reduced-technique adult protocol**



Prescribed Quality Reference mAs : 165

Average mAs used: 38

Great Resource

image gently℠

The Alliance for Radiation Safety in Pediatric Imaging

www.ImageGently.com

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!

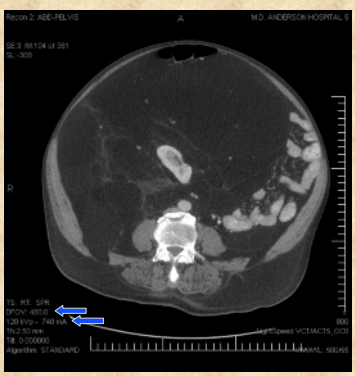
Special Cases: Heavy Patients

- 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.

Special Cases: Heavy Patients

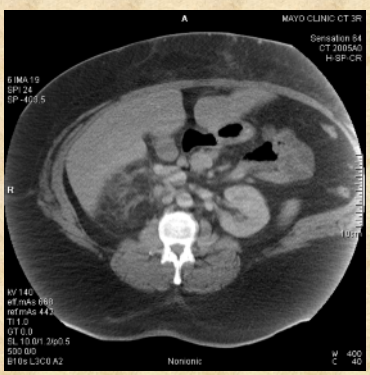


GE VCT

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

600 eff mAs

Special Cases: Heavy Patients



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

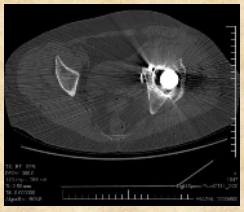
- At MDA (and Mayo), we set up 'average' patient protocols
- At MDA, a 'large patient' duplicate set
  - Patients who require ≥ 42cm DFOV
  - Increase eff. mAs by 30%
- At Mayo, a "bariatric" version and steps for heavy (but non-bariatric) patients

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 Implants Example: 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)