Translating Protocols Across Patient Size: Babies to Bariatric

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Disclosures

Research Support:

NIH: EB 079861
DK 083007
DK 059933
EB 004898
RR 018898

Siemens Healthcare

Off Label Usage

None

Since no CT image looked “over-exposed,”

the community lost the sense of needing to

adjust the mAs or kVp for patient size,

as was inherent to film/screen imaging.

FDA Public Health Notification:

Reducing Radiation Risk from Computed Tomography for Pediatric and Small Adult Patients

November 2, 2001

While the benefits of computed tomography are well known … those benefits are not without risks.

... emphasize the importance of keeping radiation doses ... as low as reasonably achievable, especially for pediatric and small adult patients, who may sometimes receive more radiation than needed to obtain diagnostic images.

... stress the importance of adjusting CT scanner parameters appropriately for each individual's weight and size, and for the anatomic region being scanned.

Dose management is about getting the

right dose

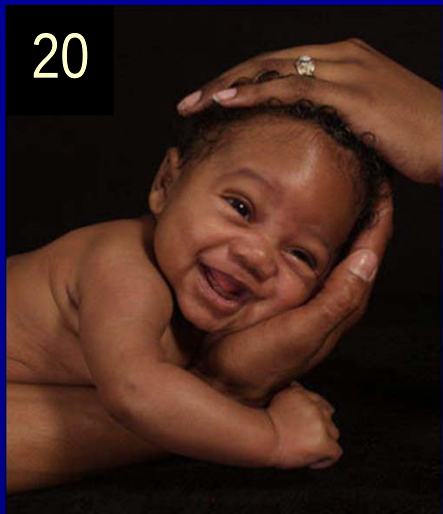
for the *specific patient* and

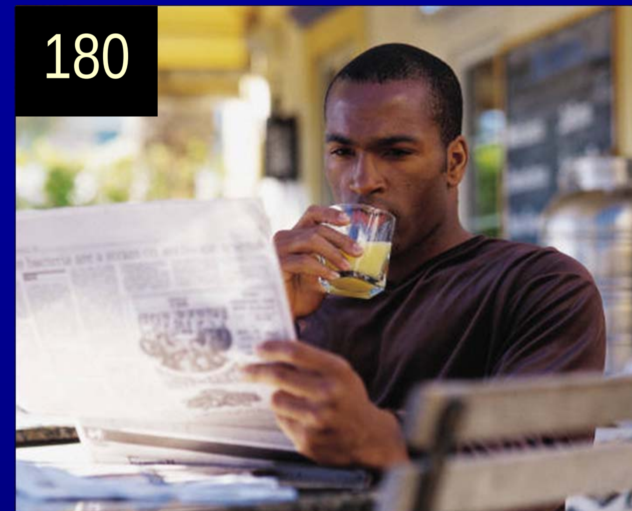
the *specific diagnostic task*.

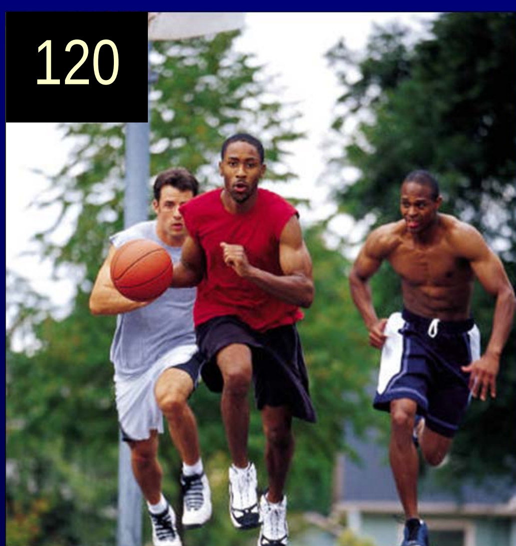
For large patients,

this can indeed mean a dose* increase.

*Doubling the mAs on an obese patient to achieve the same image noise as standard patient results in only an approximately 30% increase in effective dose due to the extra layers of fat tissue “shielding” many of the sensitive internal organs







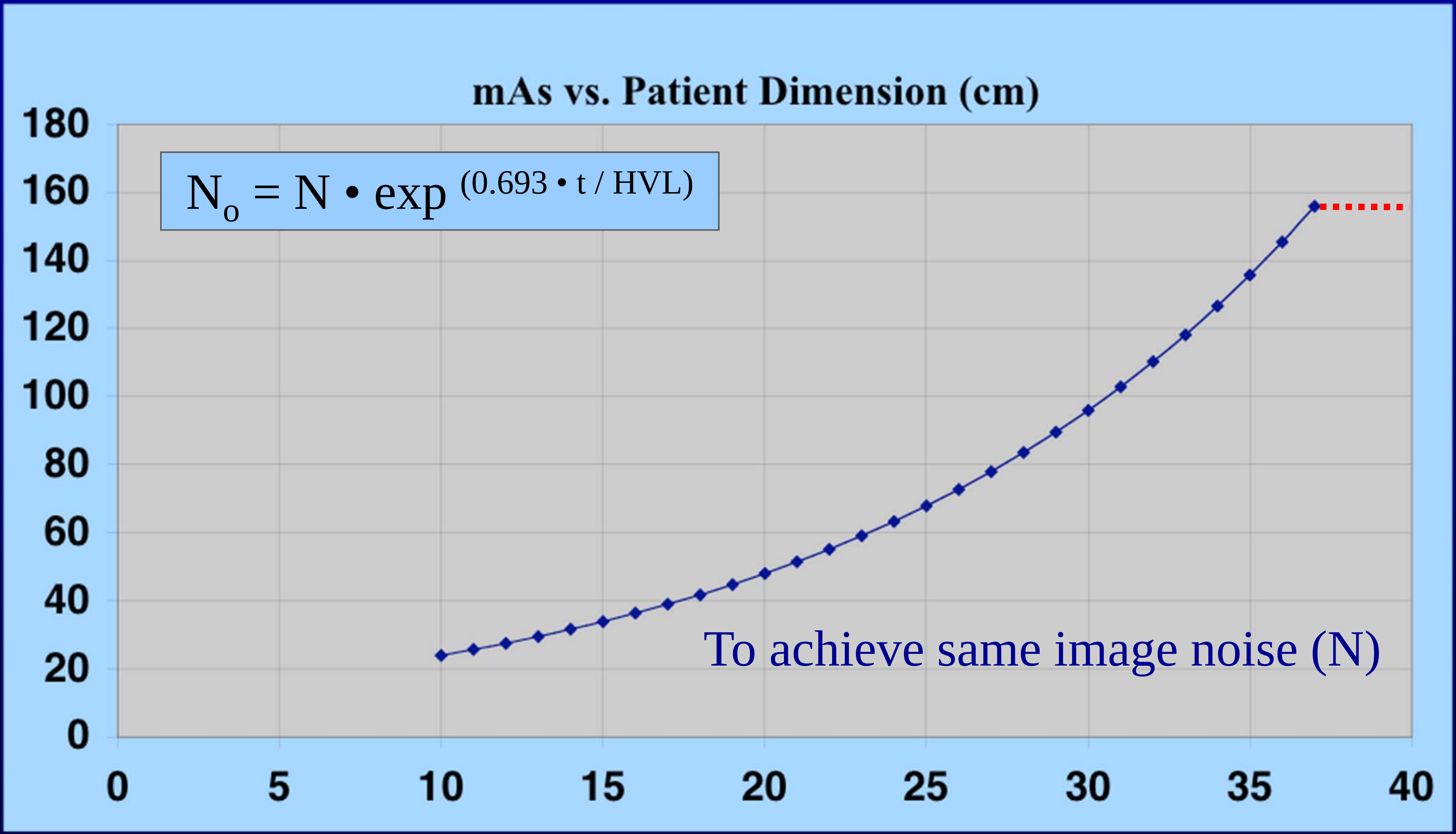
"Right-sizing" the dose

mAs works - IF all else constant

Technique charts

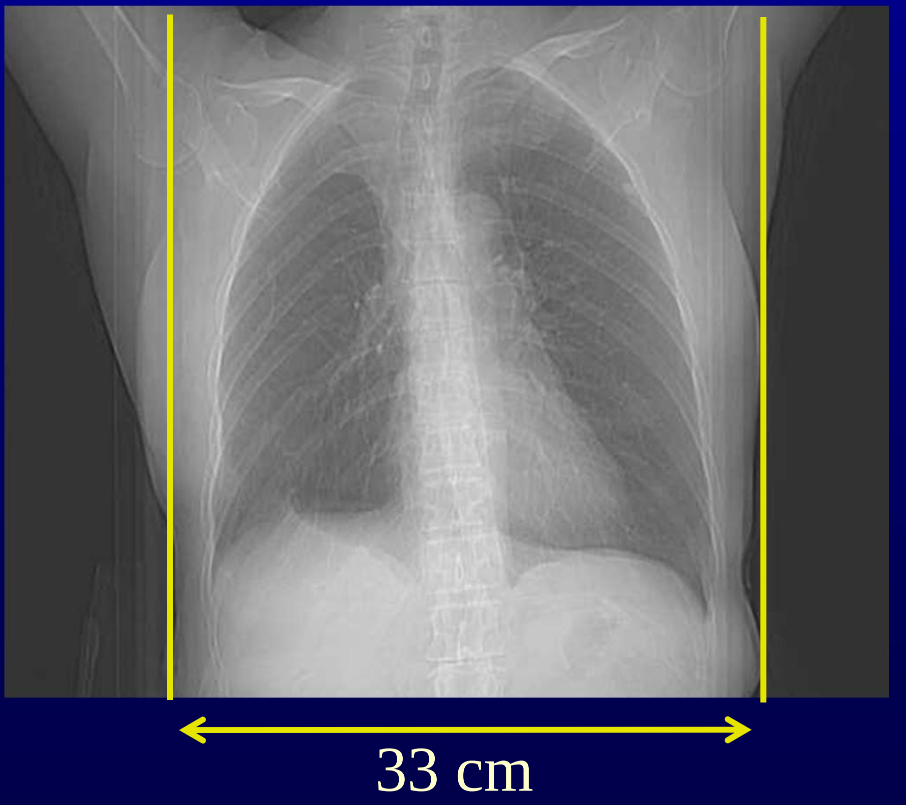
- Adapt the scan parameters to
  - specific patient
  - specific diagnostic task
- Reduce dose for pediatric and small patients
- Improve image quality for large patients
- Ensure consistency across practice
  - dose and image quality

Exponential relationship between patient thickness, mAs, and measured photons



Estimating Patient Attenuation

- Lateral width (skin to skin) at the level of the liver
  - from the A/P CT radiograph
- For patients with very large upper chest or hips
  - use measurement from the level of the liver
  - If in doubt, go up up a size
- Reconstruction (display) FOV chosen as usual
  - may be different from the width used to determine mAs.



Generalized Technique Chart
(fixed image thickness)

Abdomen & Pelvis technique for Adults

Lateral patient width (cm)	mAs (relative to standard Adult protocol)
22.1 - 26	0.4
26.1 - 30	0.5
30.1 - 35	0.7
35.1 - 40	1.0
40.1 - 45	1.4*
45.1 - 50	2.0*

Image Gently Protocol Recommendations

PA Thickness (cm)	Approx Age	Abdomen	Thorax
		mAs Reduction Factor (RF)	mAs Reduction Factor (RF)
9	newborn	0.43	0.42
12	1 yr	0.51	0.49
14	5 yr	0.59	0.57
16	10 yr	0.66	0.64
19	15 yr	0.76	0.73
22	small adult	0.90	0.82
25	med adult	**1.0**	0.91
31	large adult	1.27	1.16

Guiding principles

- All decisions made in the direction of conservative dose reduction
  - wanted no non-diagnostic exams
  - can iteratively reduce further as staff gain comfort
- Involve pediatric and adult radiologists and lead techs
- ER, inpatient and outpatient scans
- Get leadership buy-in
- Provide mandatory education with roll out
- Aim for consistency, staff must use chart

Example

Abd/Pelvis Technique Chart (pediatric and adult)				Lightspeed (QX/i and Plus)				
Primary image thickness (mm)	Mode (pitch)	Table speed (mm/rot)	Retro recon thickness' available (mm)	Lateral patient width (cm)	mA (at 0.8s)	kVp (at 0.8s)	mA (at 0.5s)	kVp (at 0.5s)
3.75	HQ	7.5	2.5 5.0	up to 14	50	120	90	120
3.75	HQ	7.5	2.5 5.0	14.1 - 18	70	120	110	120
3.75	HQ	7.5	2.5 5.0	18.1 - 22	90	120	150	120
5	HQ	11.25	3.75 7.5	22.1 - 26	90	120	150	120
5	HQ	11.25	3.75 7.5	26.1 - 30	120	120	190	120
5	HQ	11.25	3.75 7.5	30.1 - 35	170	120	270	120
5	HQ	11.25	3.75 7.5	35.1 - 40	240	120	380	120
5	HQ	11.25	3.75 7.5	40.1 - 45	340	120	380*	140
5	HQ	11.25	3.75 7.5	45.1 - 50	350	140	380*	140

last modified 12/09/01   * mA limit reached - use the 0.8 sec option unless otherwise indicated

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5	HQ	11.25	3.75 7.5	30.1 - 35	170	120	270	120
5	**HQ**	**11.25**	**3.75 7.5**	**35.1 - 40**	**240**	**120**	**380**	**120**
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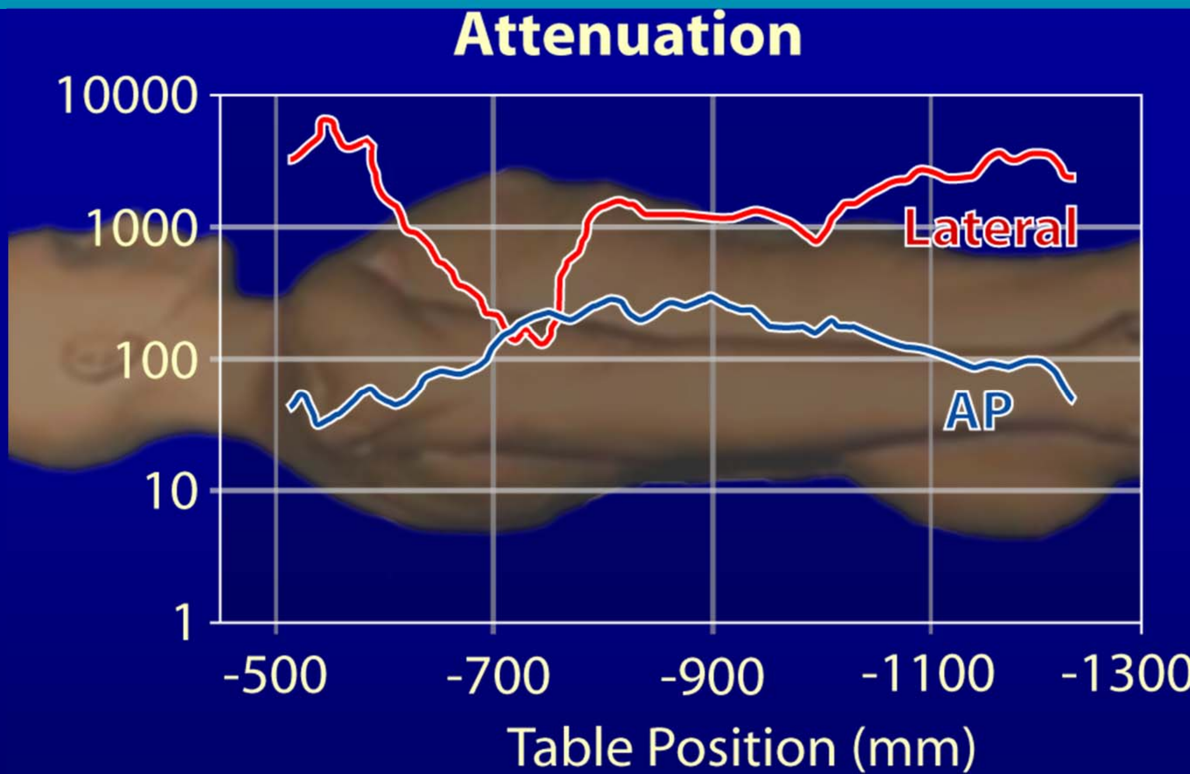
AEC: Automatic Exposure Control

- Radiographic – phototiming
- Fluroscopy - automatic brightness control



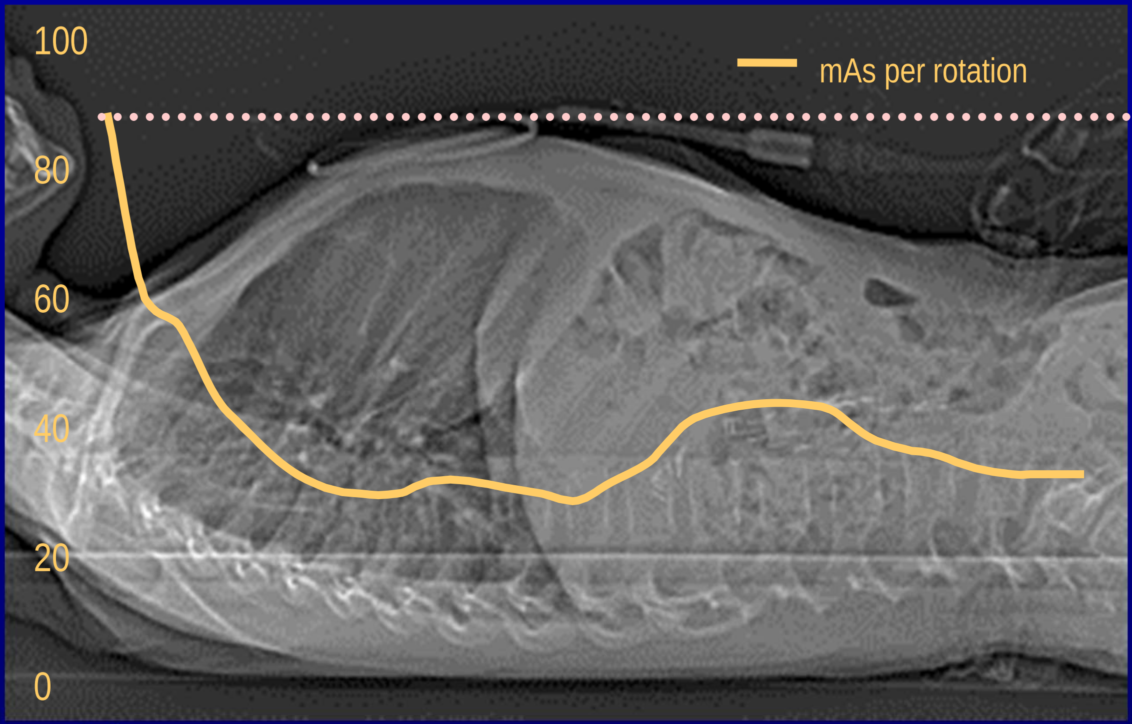
X-ray attenuation

- Varies over body region and with projection angle
- Image noise is primarily determined by noisiest projections (thick body parts)
- More photons (dose) to thinner body parts is unnecessary radiation dose

Three Levels of AEC

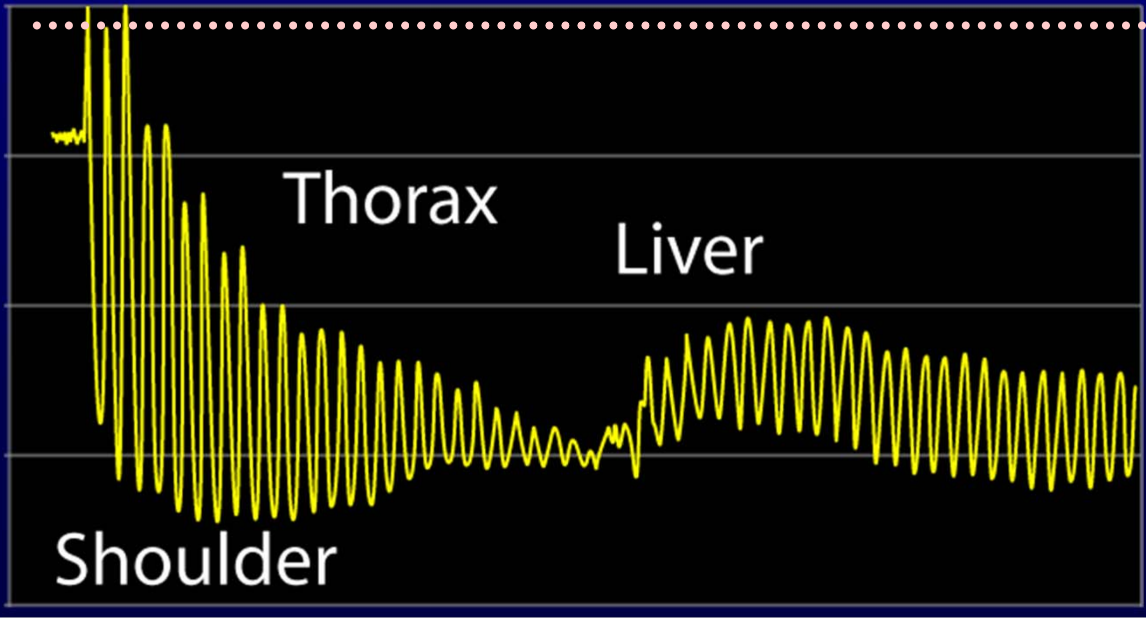
- For a single cross section, automatically adjust the mA along different directions
  - (x-y modulation)
- For a single patient, automatically adjust the mA for different body parts
  - (z modulation)
- For different patients, automatically adjust the mA based upon the patient size
  - “Right sizing” dose for each patient

Z modulation



Without modulation

Angular modulation



Without modulation

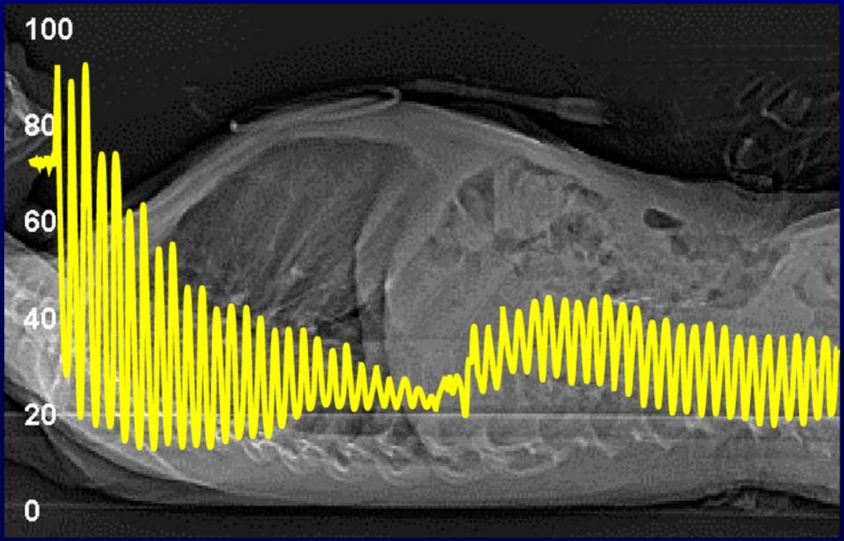
Example: 6 year old child

Scanned with adult protocol

(but using AEC dose reduction strategy)

Quality reference eff. mAs = 165

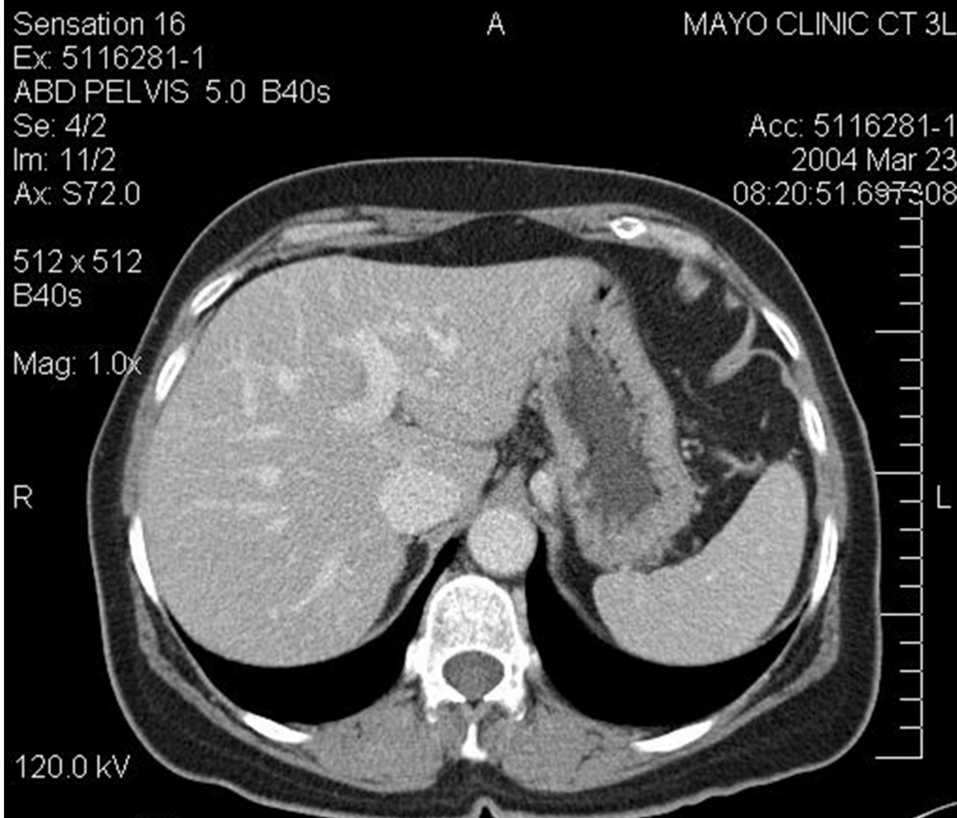
Mean eff. mAs = 38



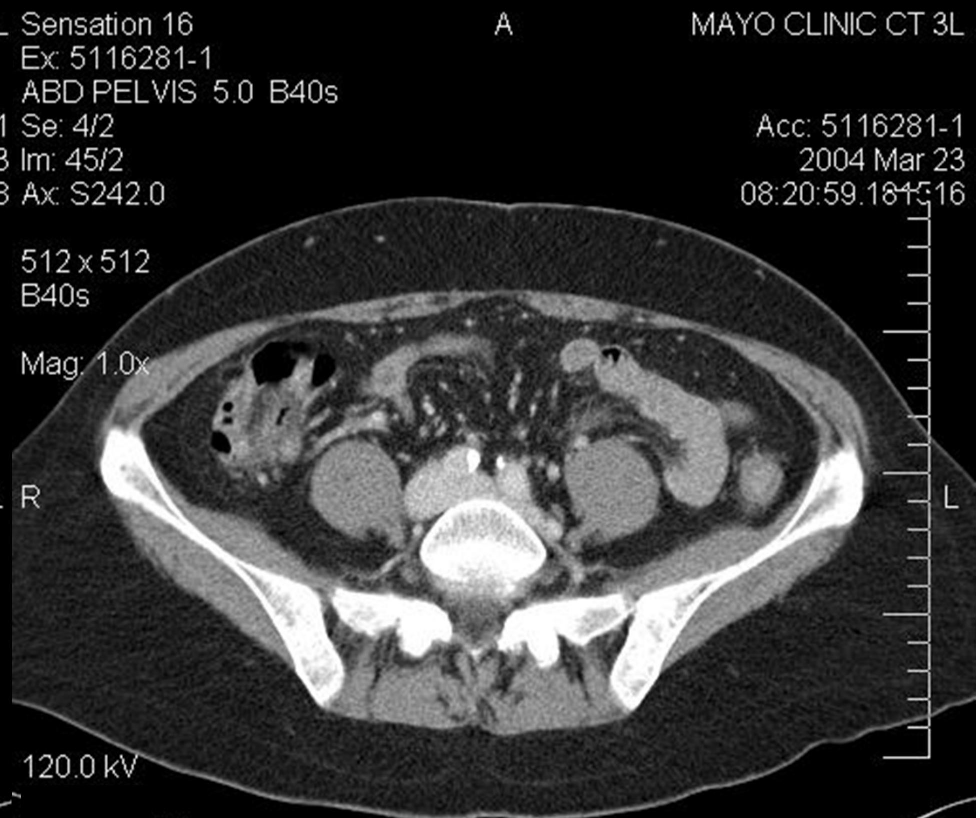
mA variation

Routine Abd/Pelvis (5 mm)
Quality reference eff. mAs = 240
61 y.o. female
30 cm lateral width -> 120 eff. mAs

?

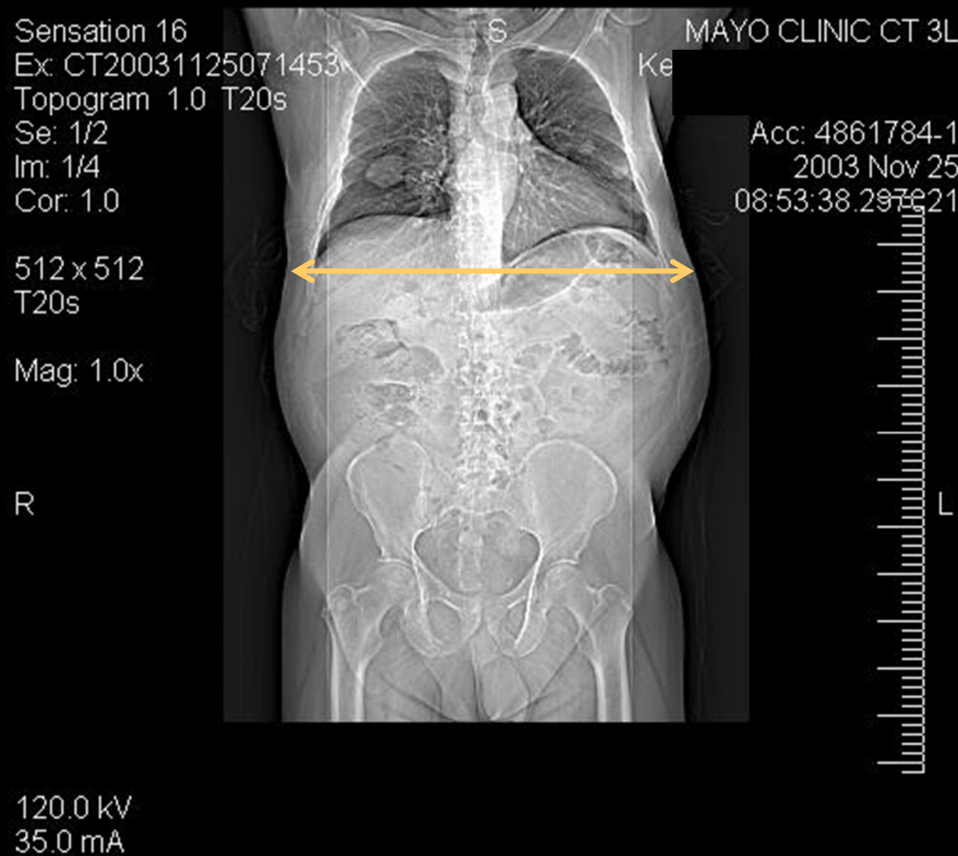


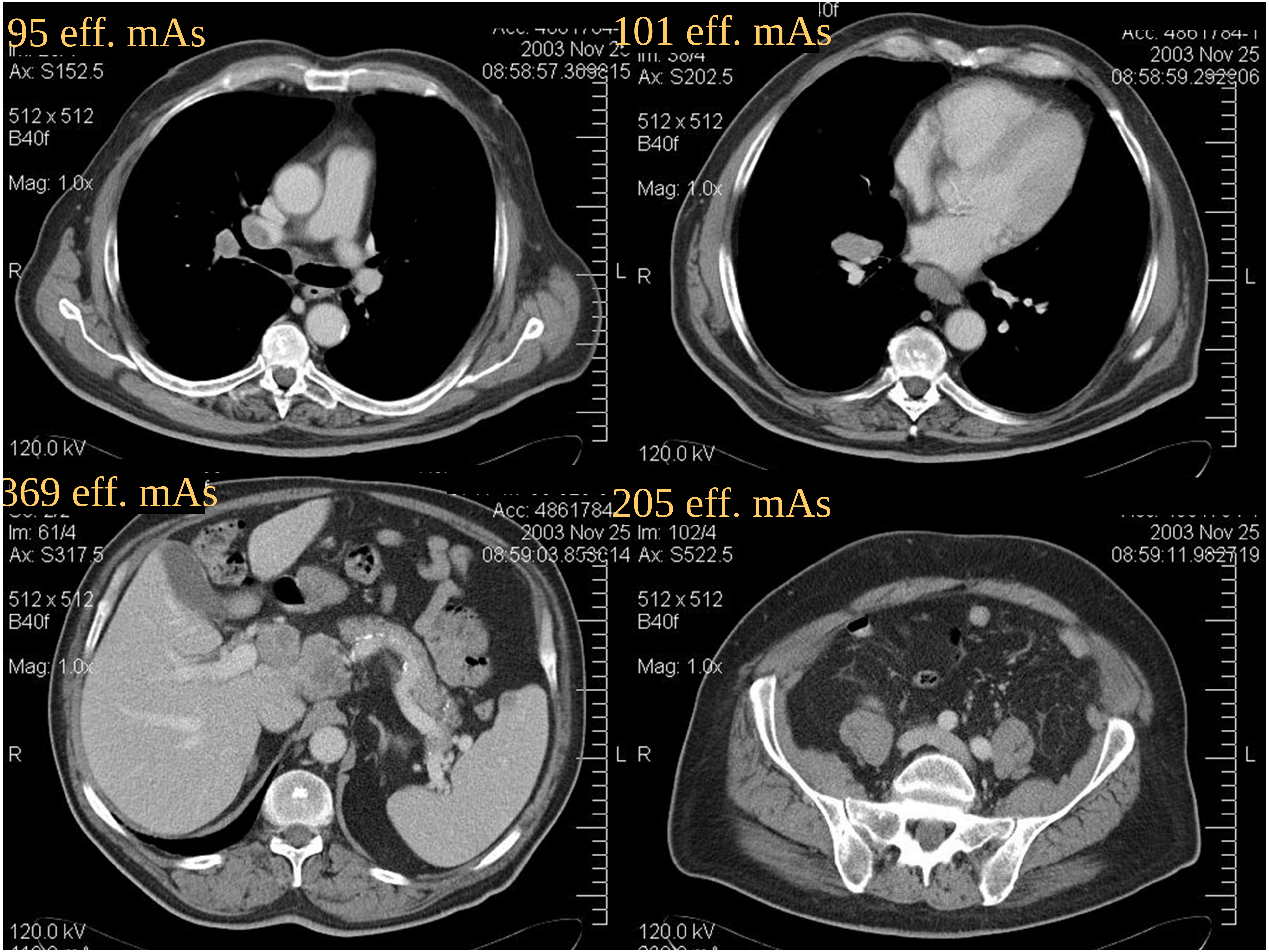
88 eff. mAs



122 eff. mAs

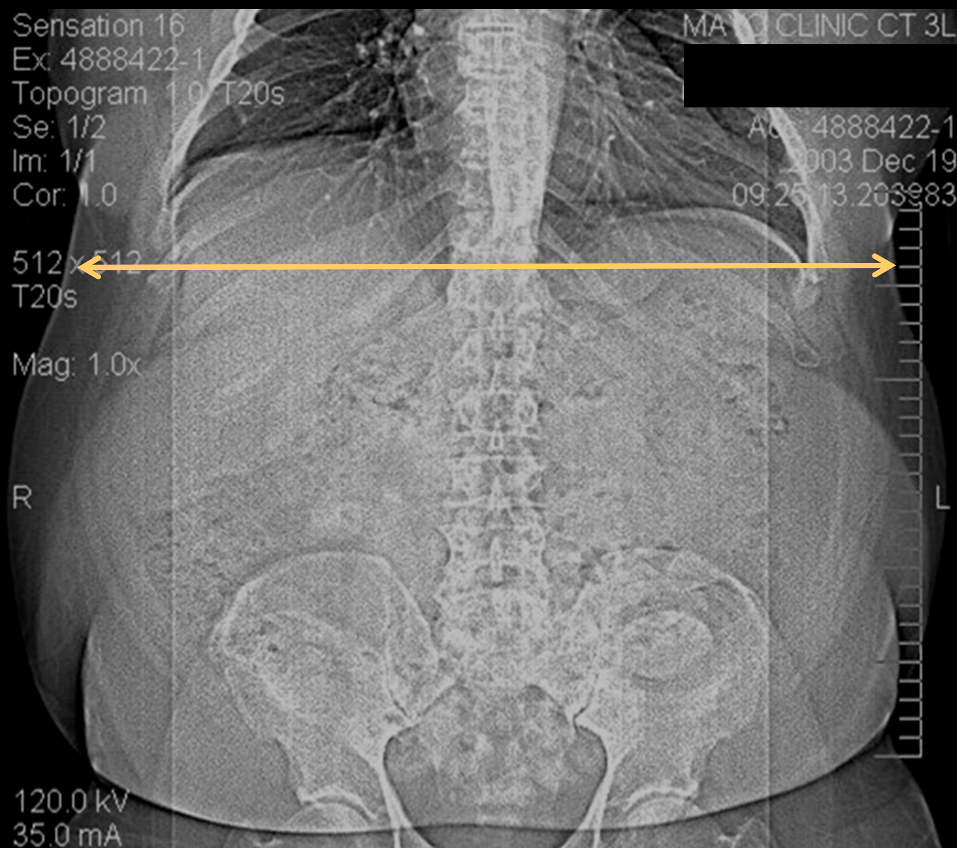
Routine Chest/Abdomen/Pelvis (5 mm)
Quality reference eff. mAs = 240
71 y.o. male
43 cm lateral width -> 340 eff. mAs



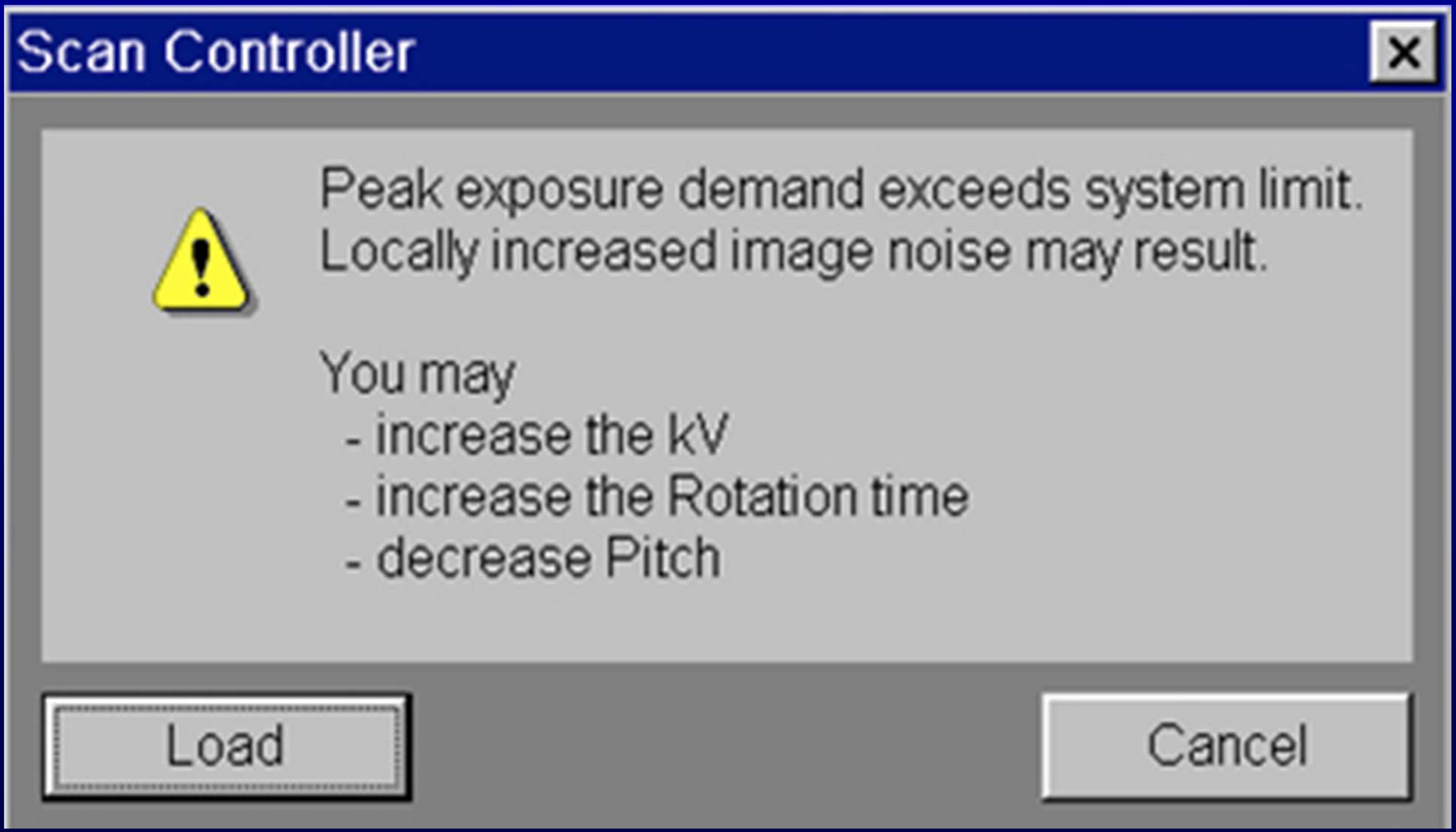

95 eff. mAs
Ax: S152.5
512 x 512
B40f
Mag: 1.0x
R
L
120.0 kV
2003 Nov 25
08:58:57.309815
101 eff. mAs
Ax: S202.5
512 x 512
B40f
Mag: 1.0x
R
L
120.0 kV
2003 Nov 25
08:58:59.292906
369 eff. mAs
Im: 61/4
Ax: S317.5
512 x 512
B40f
Mag: 1.0x
R
L
120.0 kV
Acc: 4861784
2003 Nov 25
08:59:03.853014
205 eff. mAs
Im: 102/4
Ax: S522.5
512 x 512
B40f
Mag: 1.0x
R
L
120.0 kV
2003 Nov 25
08:59:11.982719

Routine Abdomen/Pelvis (5 mm)
Quality reference eff. mAs = 240

51 y.o. male
48 cm lateral width ->350 eff. mAs @ 140 kVp



What to do when you see this (or similar)



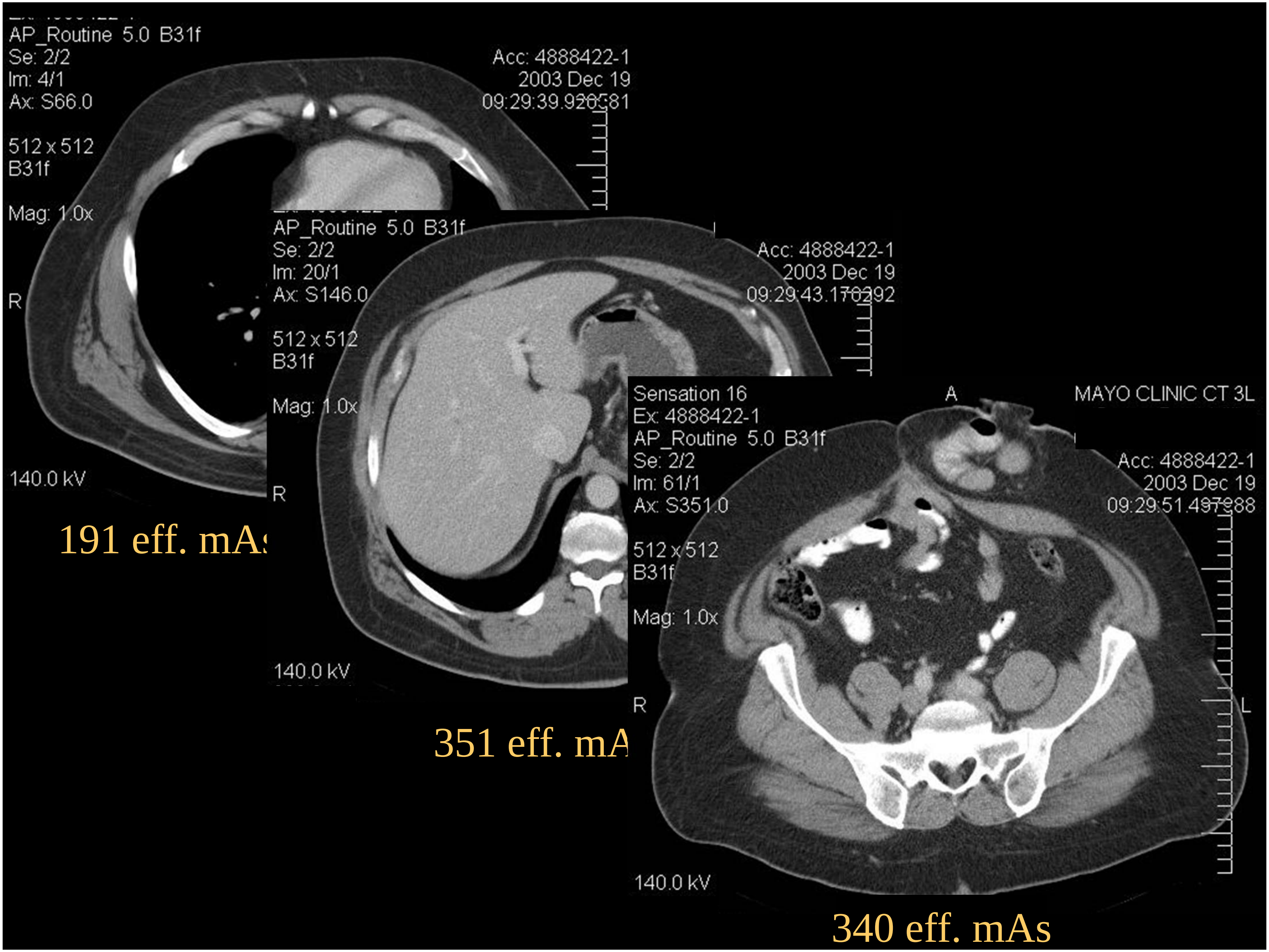
Don't proceed until you try …

- Decrease the pitch (gives same effective mAs with less mA, may be within limits)
  - Increases scan time, which may invoke other tube loading limits, so make sure CTDIvol doesn't start to drop
- Use wider collimation
  - Decreases scan time again
  - Limits thinnest images that you can reconstruct
- Increase kV
  - Decreases iodine contrast
  - MUST change threshold for bolus tracking trigger (& W/L)
  - Must set a new target mA value (e.g. quality reference mAs)

Don't proceed until you try …

- Increase rotation time
  - Increases scan time
  - Can affect contrast media timing

  -AND-
- Be sure to make sure timing and image thickness trade offs are acceptable for the exam type (e.g. angiography)
- Thicker image width and smoother reconstruction kernels may be needed
- Use extended FOV option if available
  (minimizes truncation artifacts – streaks and white regions at edge of FOV)


AP_Routine 5.0 B31f
Se: 2/2
Im: 4/1
Ax: S66.0
Acc: 4888422-1
2003 Dec 19
512 x 512
B31f
Mag: 1.0x
R
140.0 kV
191 eff. mAs
AP_Routine 5.0 B31f
Se: 2/2
Im: 20/1
Ax: S146.0
Acc: 4888422-1
2003 Dec 19
512 x 512
B31f
Mag: 1.0x
R
140.0 kV
351 eff. mA
Sensation 16
Ex: 4888422-1
AP_Routine 5.0 B31f
Se: 2/2
Im: 61/1
Ax: S351.0
A
MAYO CLINIC CT 3L
Acc: 4888422-1
2003 Dec 19
512 x 512
B31f
Mag: 1.0x
R
L
140.0 kV
340 eff. mAs

Effective mAs decreases relative to our technique charts

• Exam average	21.0%
• Upper lung	29.7%
• Breast	54.8%
• Liver	13.2%
• Pelvis	23.2%

Eff. mAs decreases relative to a single eff. mAs value (i.e. no technique charts)

• Average of all patients	18.5%
• Slim patients	44.9%
• Large patients	3.1%

Automatic exposure control

- Analogous to photo-timing
- User determines IQ (noise) requirements (hard)
  - don't need "pretty" pictures for all diagnostic tasks
  - need to choose low noise, standard, or low dose dependent on the diagnostic task
- System determines the right mAs (easy)
- Will adjust mA
  - during rotation (x,y)
  - along z-direction
  - x, y and z

SmartScan

Dose Right

CareDose

Auto mA

DOM

2004

AEC

Smart mA

CareDose4D

Z-DOM

Auto Scan

Real E.C.

ACS

Auto mA 3D

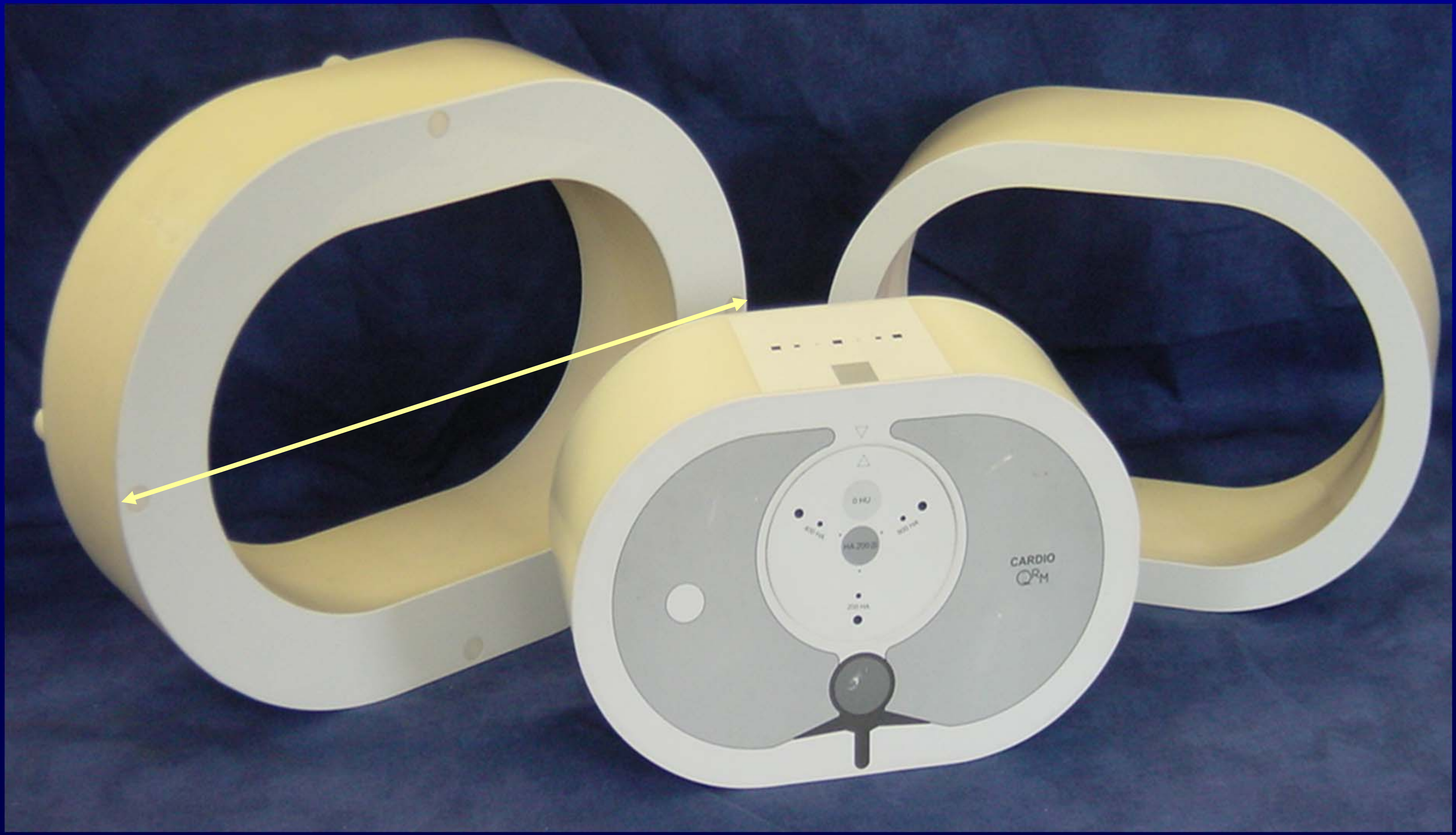
Sure Exposure

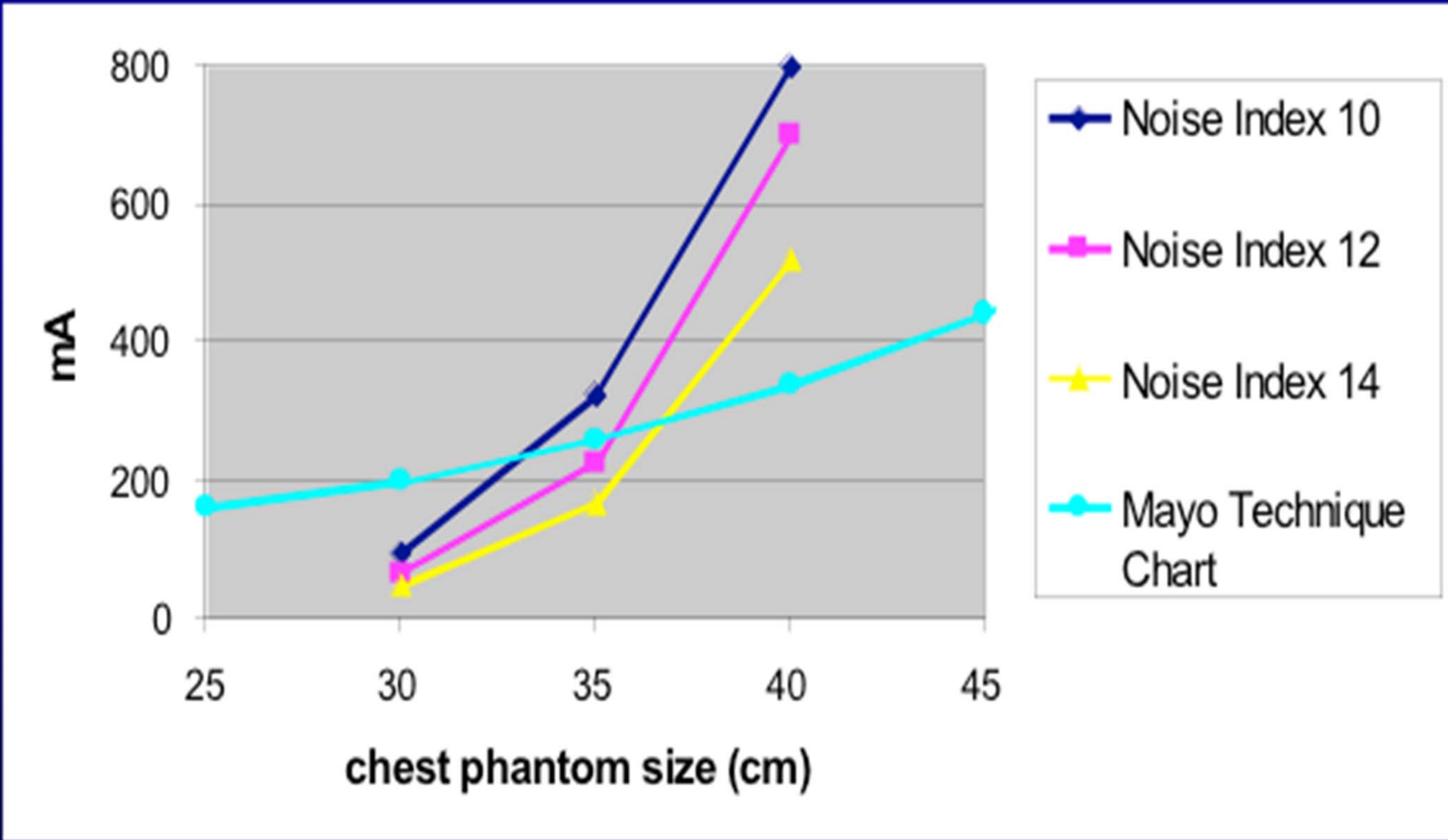
IQ (noise) Selection Paradigms

- GE: Noise Index
  - Referenced to std. deviation of pixel values in a water phantom
  - mA per rotation calculated based on Scout
  - Tries to maintain constant noise over all images
- Philips: Reference Image
  - Automatic Current Setting (ACS)
  - Save an acceptable patient exam (including SurView)
  - Raw data and noise saved, used as later reference
- Siemens: Quality Reference Effective mAs
  - Enter the effective mAs site uses in standard (approx. 80 kg) patient
  - Noise target varied on basis of patient size (empirical algorithm)
  - Topogram used to predict mA curve, on-line feedback fine tunes it
- Toshiba: Std. Deviation
  - Referenced to std. deviation of pixel values in an attenuation-equivalent water phantom, which is created from Scanogram
- All allow reference value to be stored with protocols

Thorax phantoms

Lateral dimension of 30, 35, and 40 cm





800
600
400
200
0
mA
25
30
35
40
45
chest phantom size (cm)
Noise Index 10
Noise Index 12
Noise Index 14
Mayo Technique Chart

Empirically, matched noise is

- Not well-accepted clinically
- Not achievable over range of patient sizes
- Wilting et al. A rational approach to dose reduction in CT: individualized scan protocols. Eur Radiol 2001
  - Presented constant noise images to radiologists
  - Pediatric to obese patients
  - Pediatric images were found unacceptable, even though they contained the same level of image noise

Equal noise is not acceptable because …

- Children don’t have the fat planes between tissues and organs that adults do (fat planes enhance contrast and tissue differentiation)
- 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

Clinical Impact

- AEC systems that prescribe a fixed noise level systematically
  - increase dose more than clinically required for obese patients (potentially causing tube heating problems or longer scan times)
  - increase noise more than is clinically acceptable for pediatric patients (potentially yielding non-diagnostic exams)

Recommendations

- Use of a noise target technique chart
- Use of min and max mA values to prevent excessive decrease or increase of tube current

Noise Index Technique Chart for body CT exams w/ 5 mm image thickness

Lateral Patient Width (cm)	Noise Index (at 0.5 s)	Minimum mA	Maximum mA
22.1 – 30	9	150	280
30.1 – 40	11.5	220	500
40.1 – 45	14.5	400	720
45.1 – 50+	17 (0.7 s)	450	770

Beyond right-sizing the scanner output

- Children generally benefit from
  - High pitch (short scans)
  - Shortest rotation times (stop motion)
  - Lower tube potentials (increases contrast/decreases dose)
  - Thin detector collimations (need higher resolution)
- Obese patients generally benefit from
  - Low pitch (allows adequate dose)
  - Longer rotation times (allows higher mAs)
  - Higher tube potentials (to penetrate thicker body parts)
  - Thicker detector collimations (avoid electronic noise/artifacts)

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140kV 80kV

Non-uniform “wavy” streaks due to detector-level averaging of very low signal levels (“adaptive filtering”)

Thank you

Mayo CT Clinic Innovation Center and Dept. of Radiology

D. Hough, J.G. Fletcher, J. Kofler, L. Yu, S. Leng, M. Bruesewitz, T. Vrieve

http://mayoresearch.mayo.edu/CTCIC