Tube Current Modulation Approaches: Overview, Practical Issues and Potential Pitfalls

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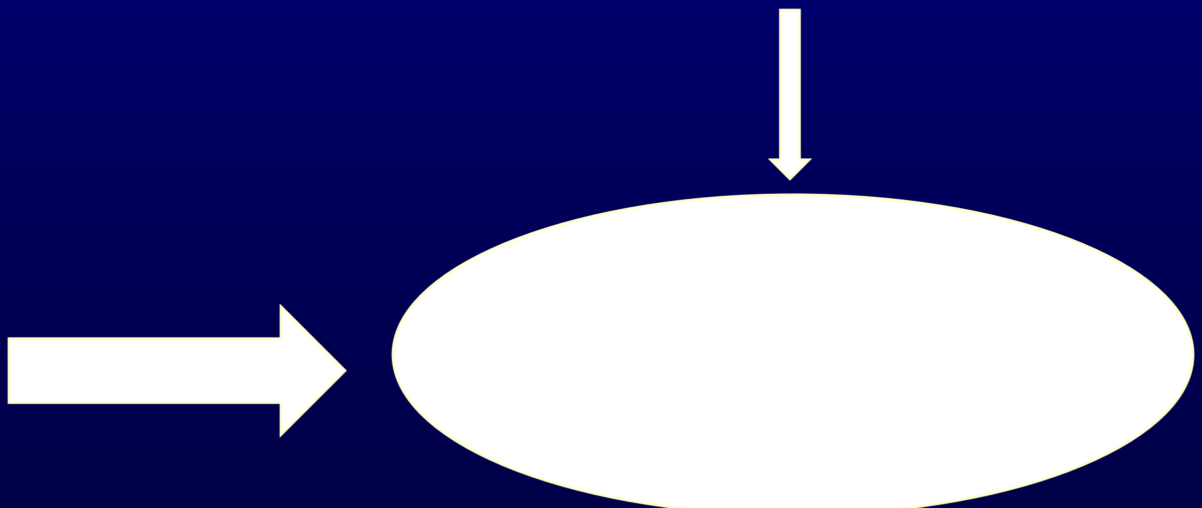
Tube Current Modulation - Overview

- Basic Idea:
  - Adapt Tube Current to Attenuation of Body Region
  - Increase Tube Current for more attenuating area
  - Decrease Tube Current for less attenuating area
- Overall Goal: Reduce dose yet maintain image quality



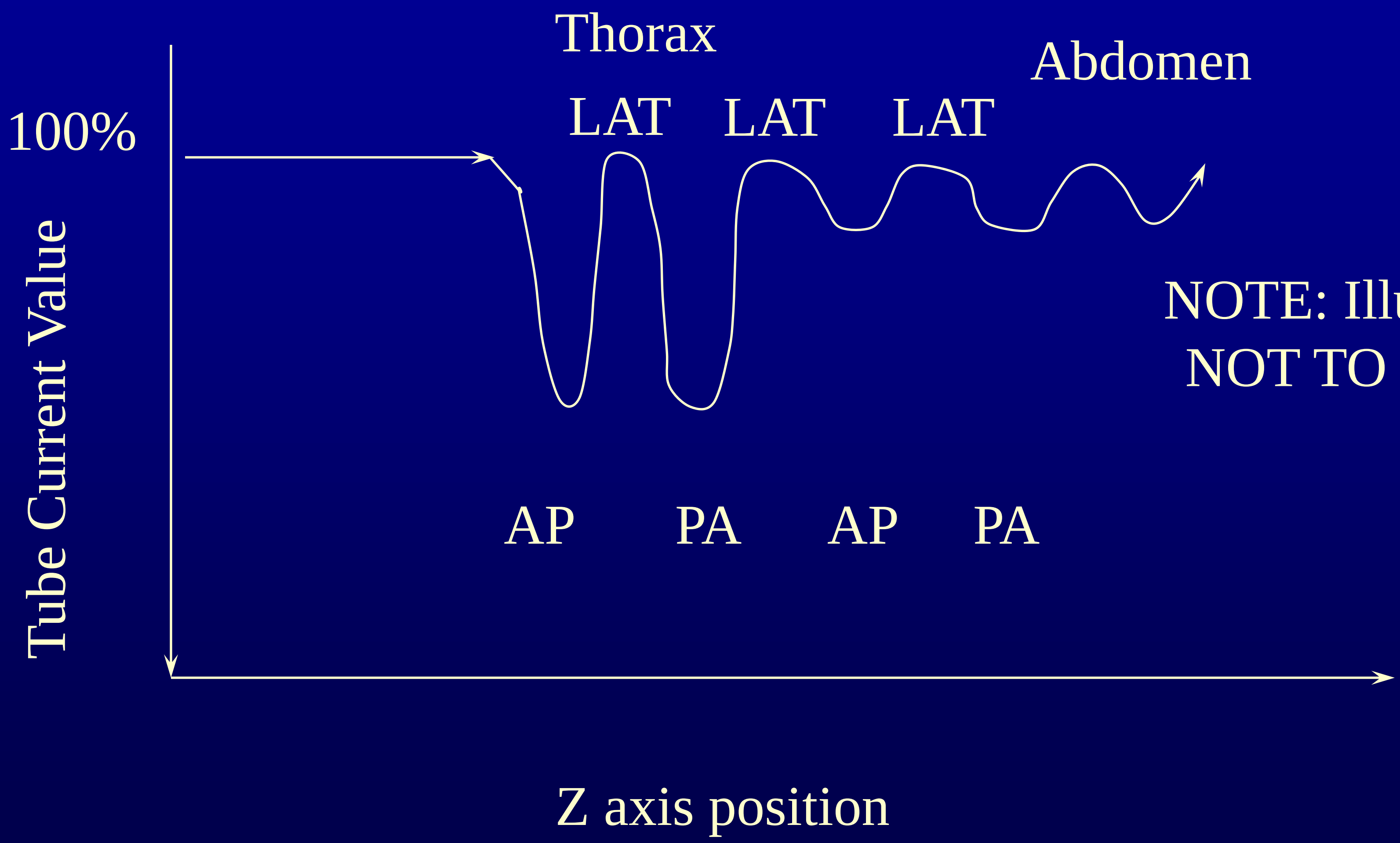
Tube Current Modulation - Implementations

- (Adapted from McCollough et al Radiographics, 2006)
- How is the tube current modulated:
  - Based on measured attenuation or a sinusoidal-type function.
  - Preprogrammed, implemented in near-real time by using a feedback mechanism, or a combination of these two
  - Only angularly around the patient, along the long axis of the patient, or both.
  - To allow use of one of several algorithms to automatically adjust the current to achieve the desired image quality..

Tube Current Modulation Methods

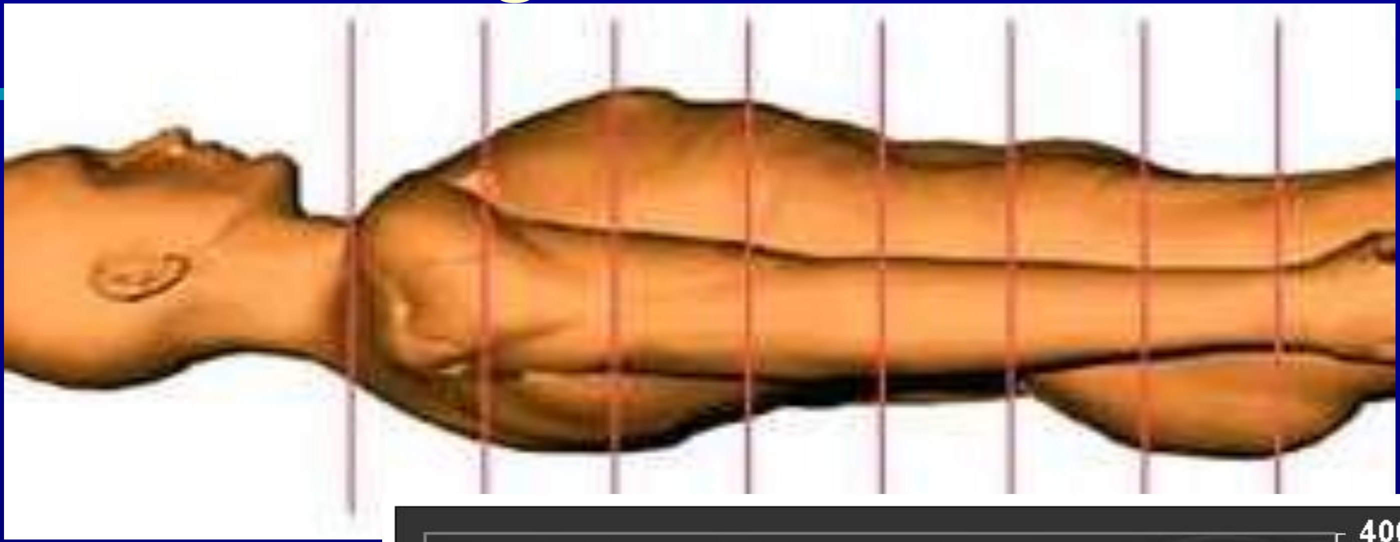
- Several Flavors
  - Angular modulation (in plane (x-y))
  - Longitudinal modulation (along patient length, z-axis)
  - Combination (x, y and z) modulation
  - Temporal (ECG-gated) modulation

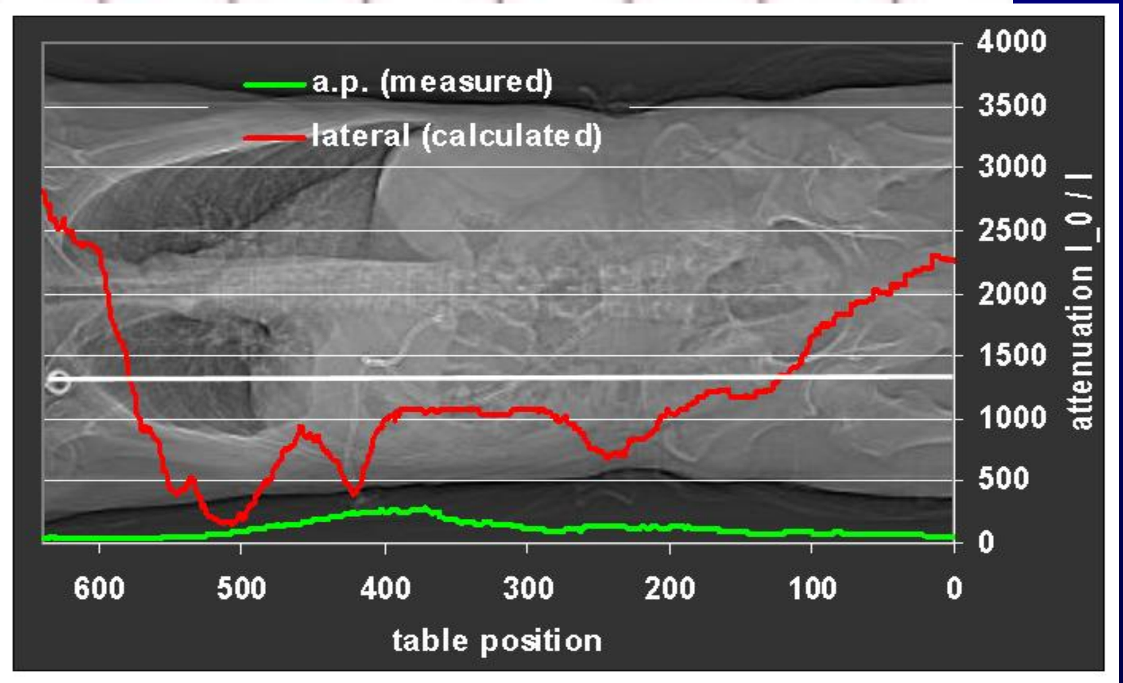
Angular Modulation



NOTE: Illustrative, NOT TO SCALE

Measuring the attenuation in z-axis

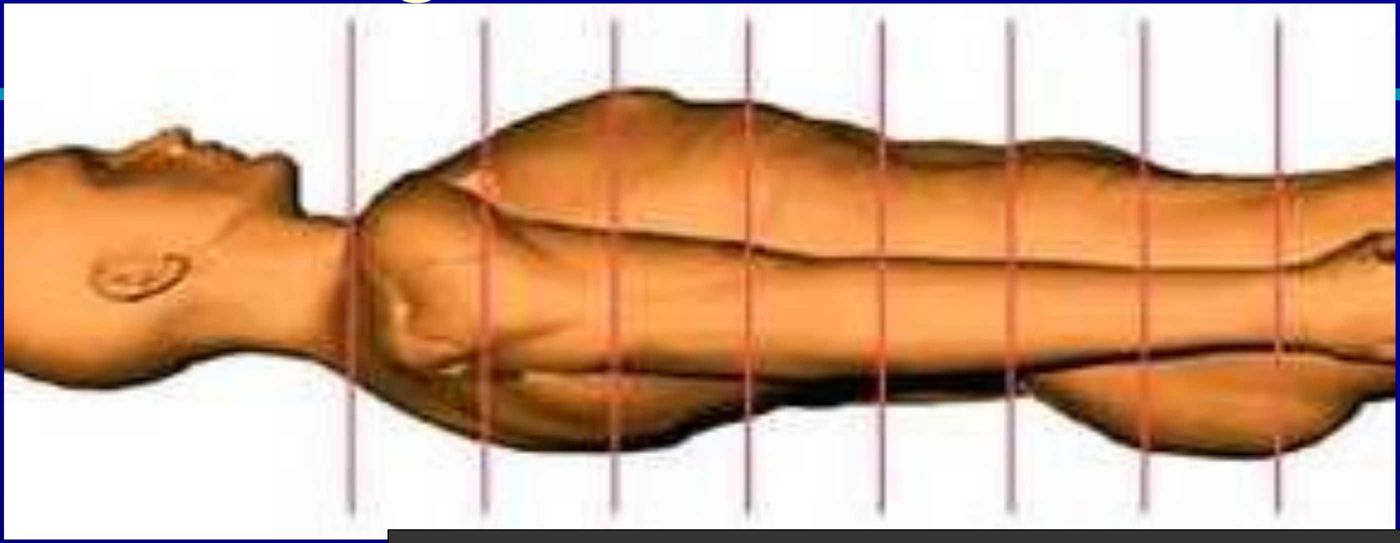


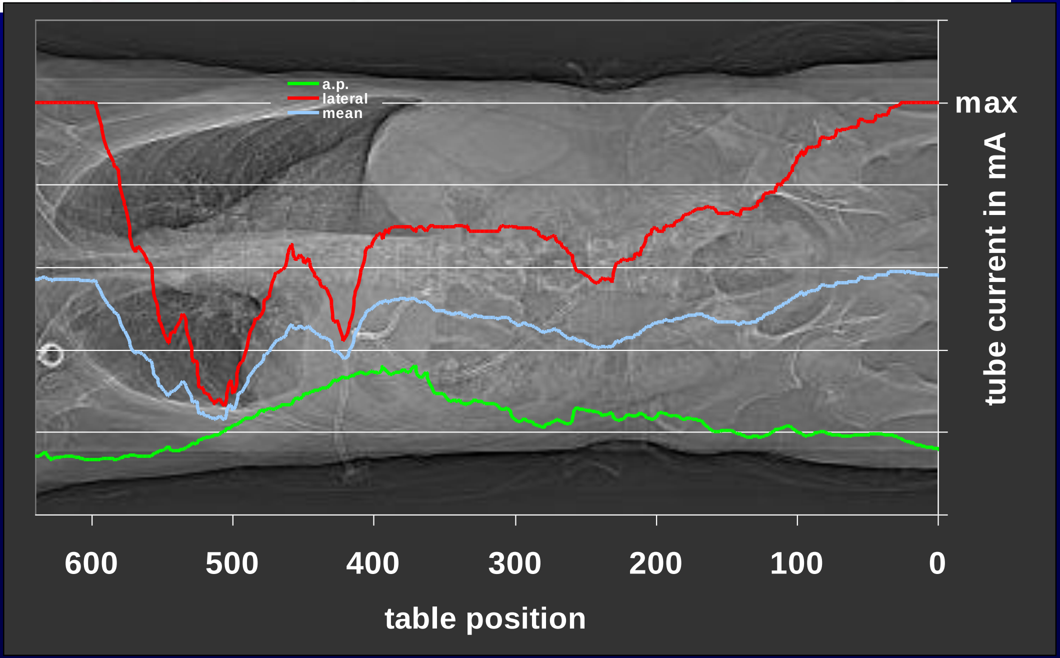


Longitudinal Modulation (Along z)

- Adapts to patient variations from one anatomic region to another along length of patient
  - Neck to chest to abdomen to pelvis
- Seeks to produce approximately equivalent image quality along length of patient
- Operator has to select desired image quality parameter:
  - Reference noise index (GE)
  - Reference image acquisition (Philips)
  - Quality reference mAs (Siemens)
  - Reference standard deviation (Toshiba)

Measuring the attenuation in z-axis

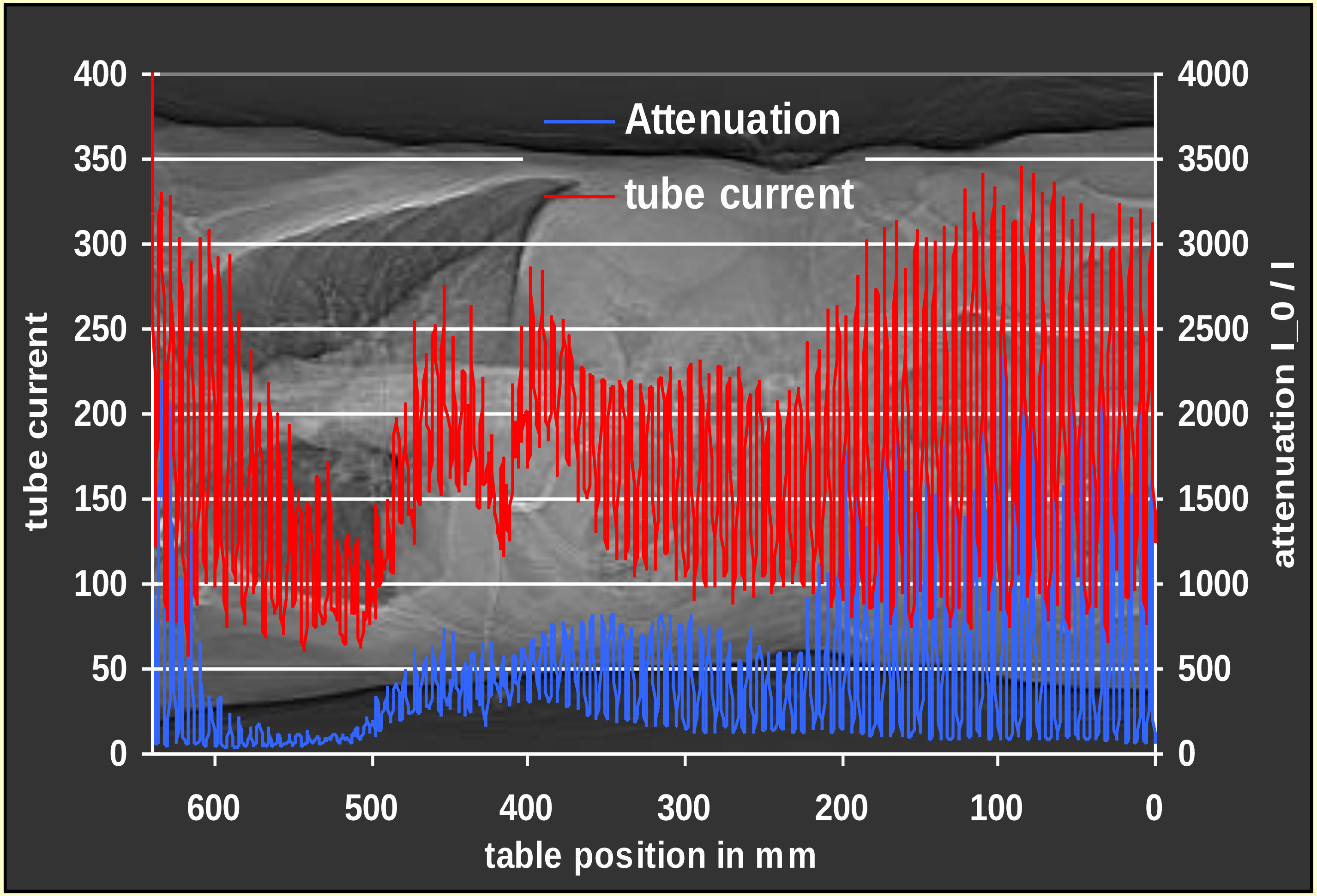


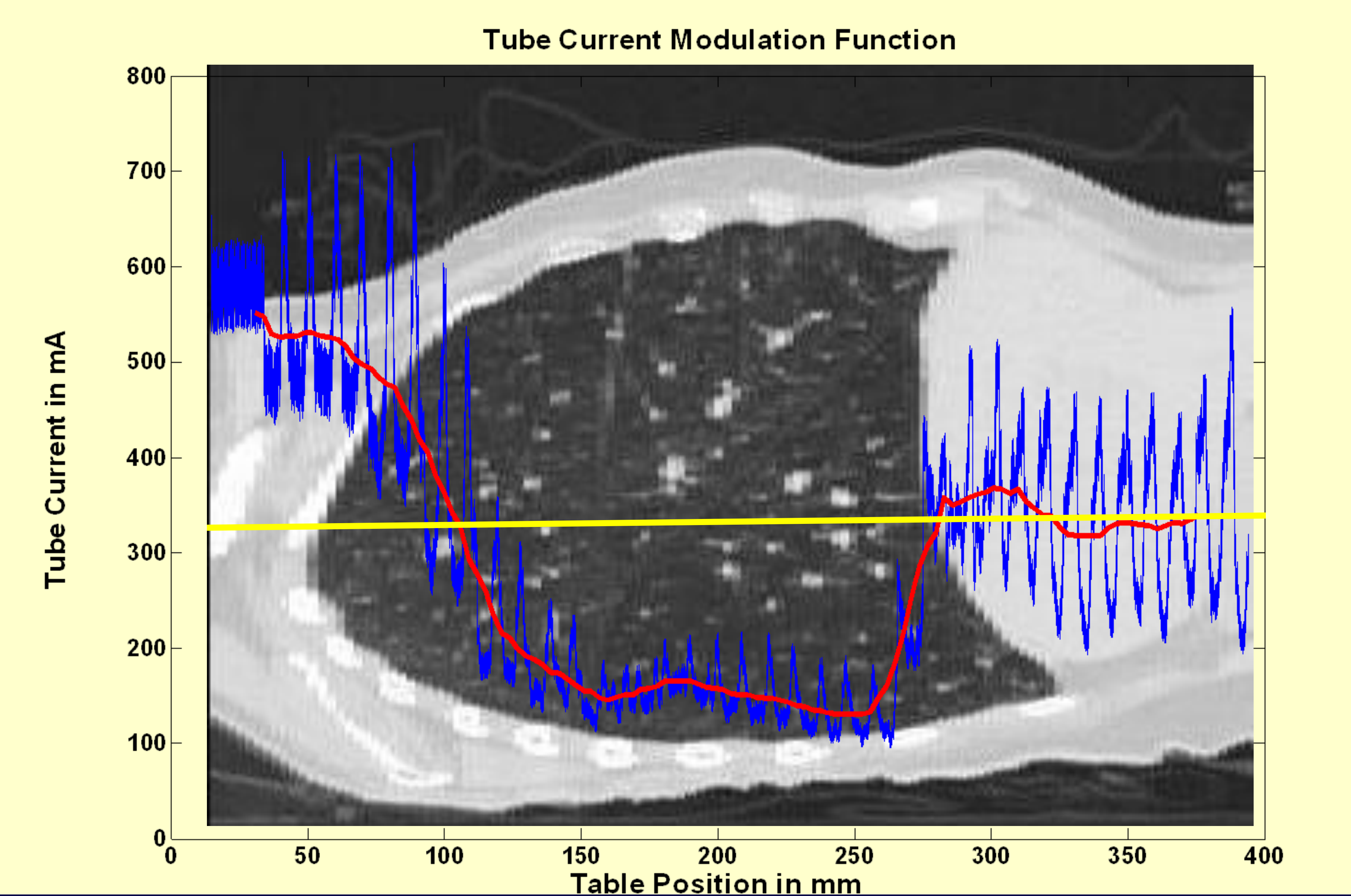


Combination (x,y and z)

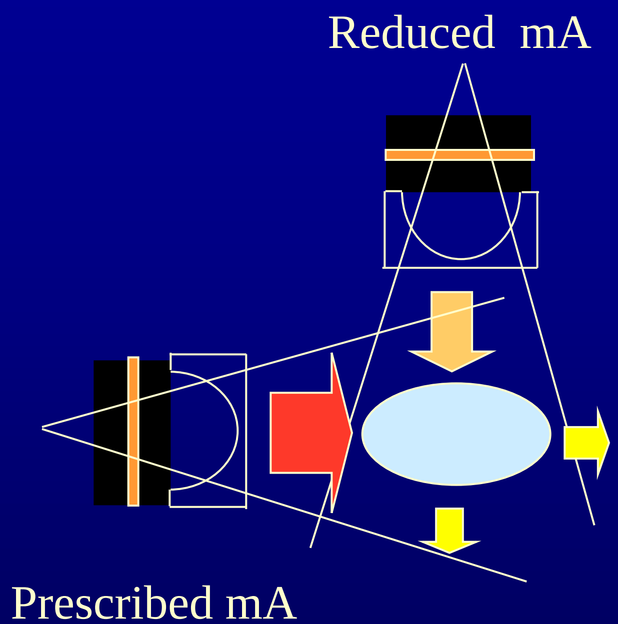
- Adapts to patient size
- Adapts to variation from one anatomic region to another along length of patient and in plane
- Low frequency changes across anatomic regions (z)
- High frequency changes across angular variations (x,y)

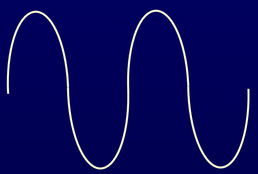
Optimal mA for a.p. and lat. Views:
On-line mA modulation




Tube Current Modulation Function
Tube Current in mA
Table Position in mm
800
700
600
500
400
300
200
100
0
0
50
100
150
200
250
300
350
400

Auto mA and Smart mA automatically adjust tube current





Incident X-ray flux decreased vs angle depending on patient asymmetry

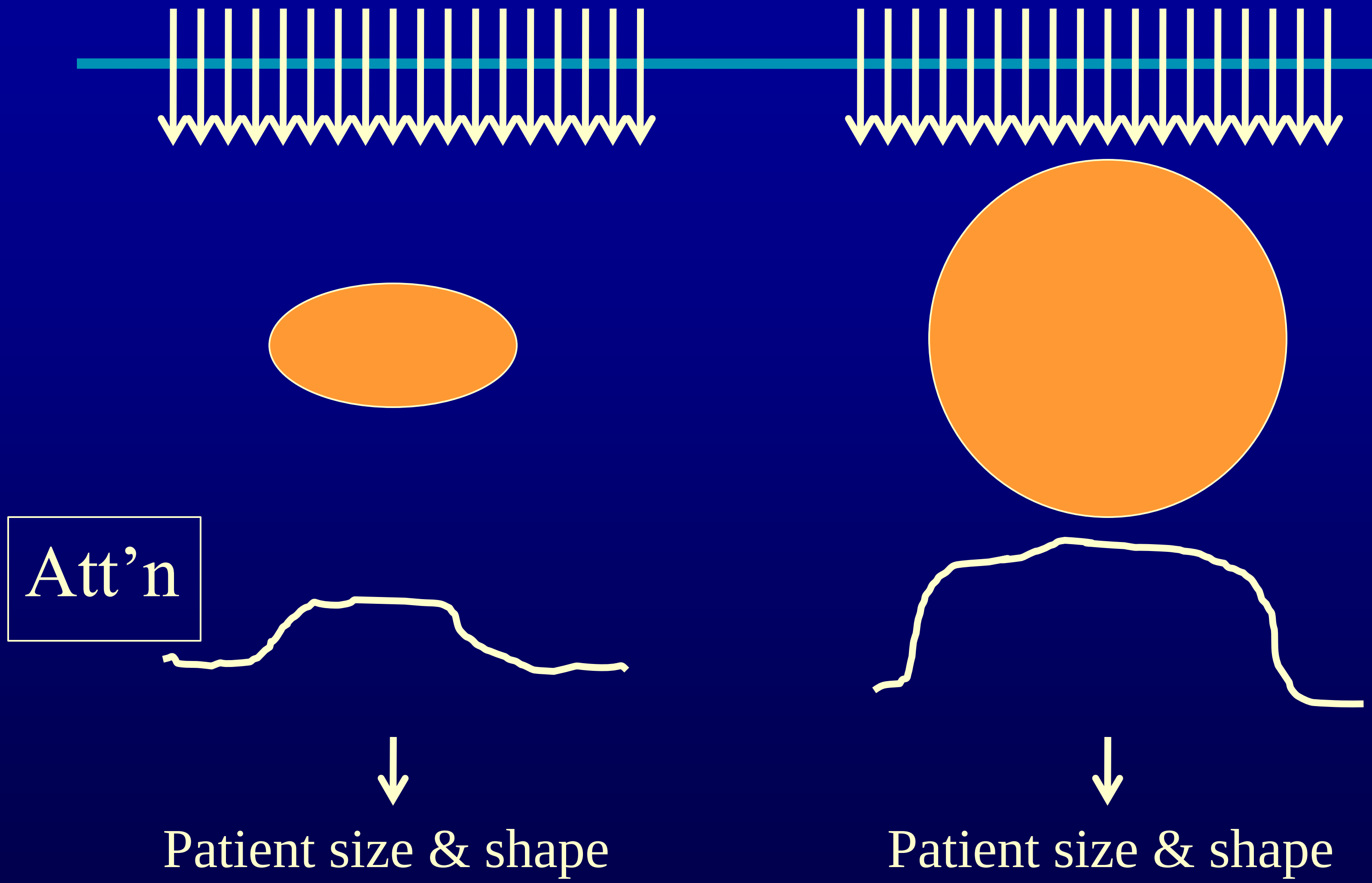
- AutomA (Z only) reduces noise variation allowing more predictable IQ. Dose reduction depends on User (Noise index = image noise)
- Smart mA (X,Y,Z) reduces dose without significantly increasing image noise

imagination at work

Implementation Issues

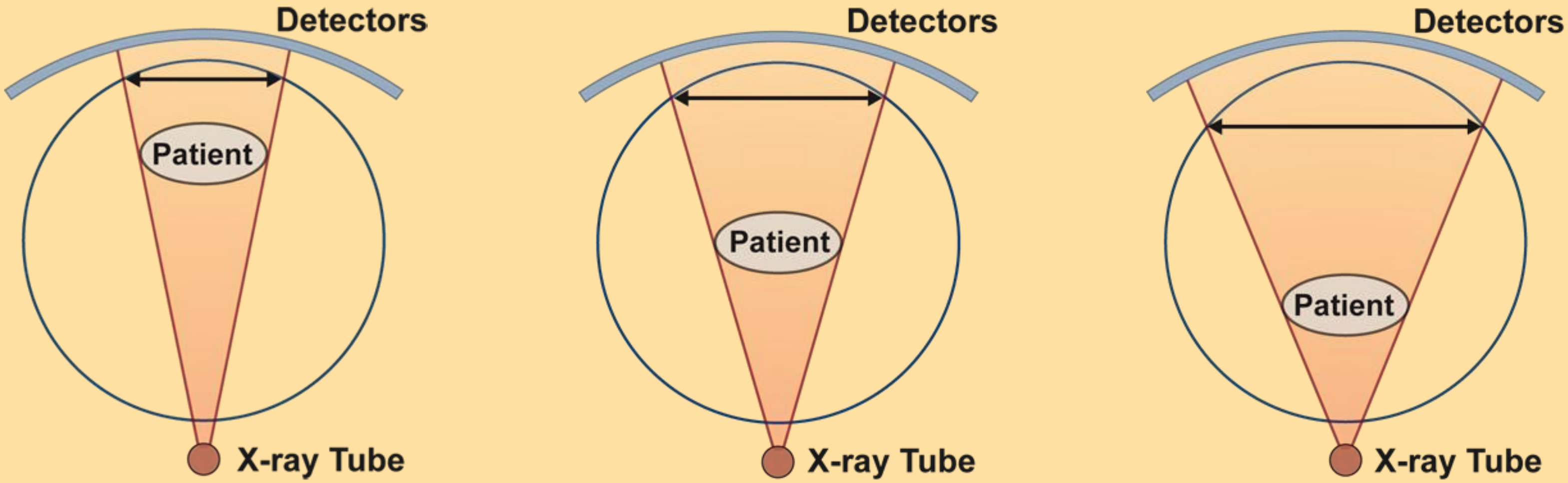
- How to measure patient attenuation?
- Primarily from Scout/Topogram/Surview/Scanogram
  - (aka CT radiograph or planning view)
- How is tube current modulated?
  - Siemens and Philips adjust tube current based on online feedback (measurements from previous 180 degree views)
  - Others do predictive calculation or sinusoidal interpolation between AP and Lateral views

Use of Scout Image for Modulation



mA Modulation Scout Scans

Jim Kofler, Ph.D.



Same patient – vertical table height can affect size-shape model!

Bottom Line

- Tube current modulation REQUIRES CAREFUL CENTERING OF THE PATIENT IN THE GANTRY

How do scouts affect the resulting helical dose when TCM is used?

- kVp mismatch between scout and helical?
- A/P vs P/A scout?
- P/A vs lateral scout?

Methods

- GE VCT
- Adult Chest Phantom
- Adult acrylic abdomen/pelvis phantom
- Ran various scout options
- Planned helical scans according to our protocol
- Used predicted $CTDI_{vol}$ values to compare dose for each scout option

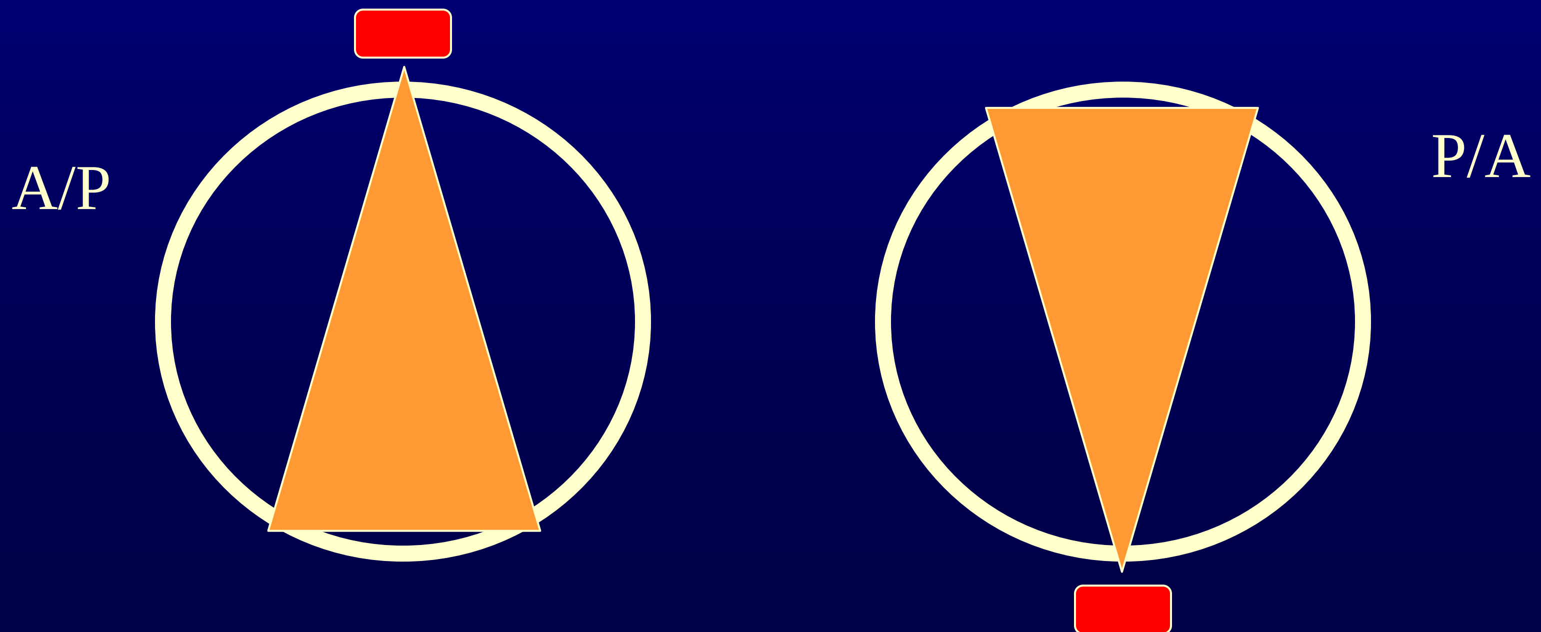
kV mismatch

- Chest Phantom
- Scouts @ 80 and 120 kV
- Helical runs at 80, 120 kV

- -7 to + 13% difference in predicted helical dose when kV for scout did not match kV for helical
- **Works well enough (don’t sweat this detail)**

A/P vs P/A Scout

- In A/P scout, tube is at top of gantry (0°)
- For P/A scout, tube is at bottom of gantry (180°)
- Usually part of scout prescription
- Which is generally preferred? Why?



A/P vs P/A vs Lateral scout?

- Chest Phantom
- Scouts performed at 120 kV
- Helical run prescribed at 120 kV

- When Lateral used instead of A/P, predicted helical dose was 15% HIGHER.

- When P/A used instead of A/P, predicted helical dose was **34-60% HIGHER**

- Confirmed by GE, attributed to “oval ratio”

- **Perform last (final) scout in A/P direction when TCM is used!**

One Scout Vs Two Scouts?

- MUST generate ONE scout view for TCM
  - Produce patient model (size & shape)
- Can have oddball result w/single scout approach
- May be more reliable if TWO scouts used instead of ONE.
- **In this case – do Lateral view FIRST and A/P view LAST**

Implementation Issues

- User Specifies Image Quality Input Parameter
  - GE: Noise Index (Does not adjust with patient size)
  - Siemens: Quality Reference mAs (Does adjust for patient size)
  - Philips: Reference image selection (matching to reference image acquisition)
  - Toshiba: Reference standard deviation
- Each one operates on slightly different principles
- Take into consideration
  - Exam Image Quality Requirements
  - Patient Size (and whether TCM adapts to patient size or not)

Implementation Issues

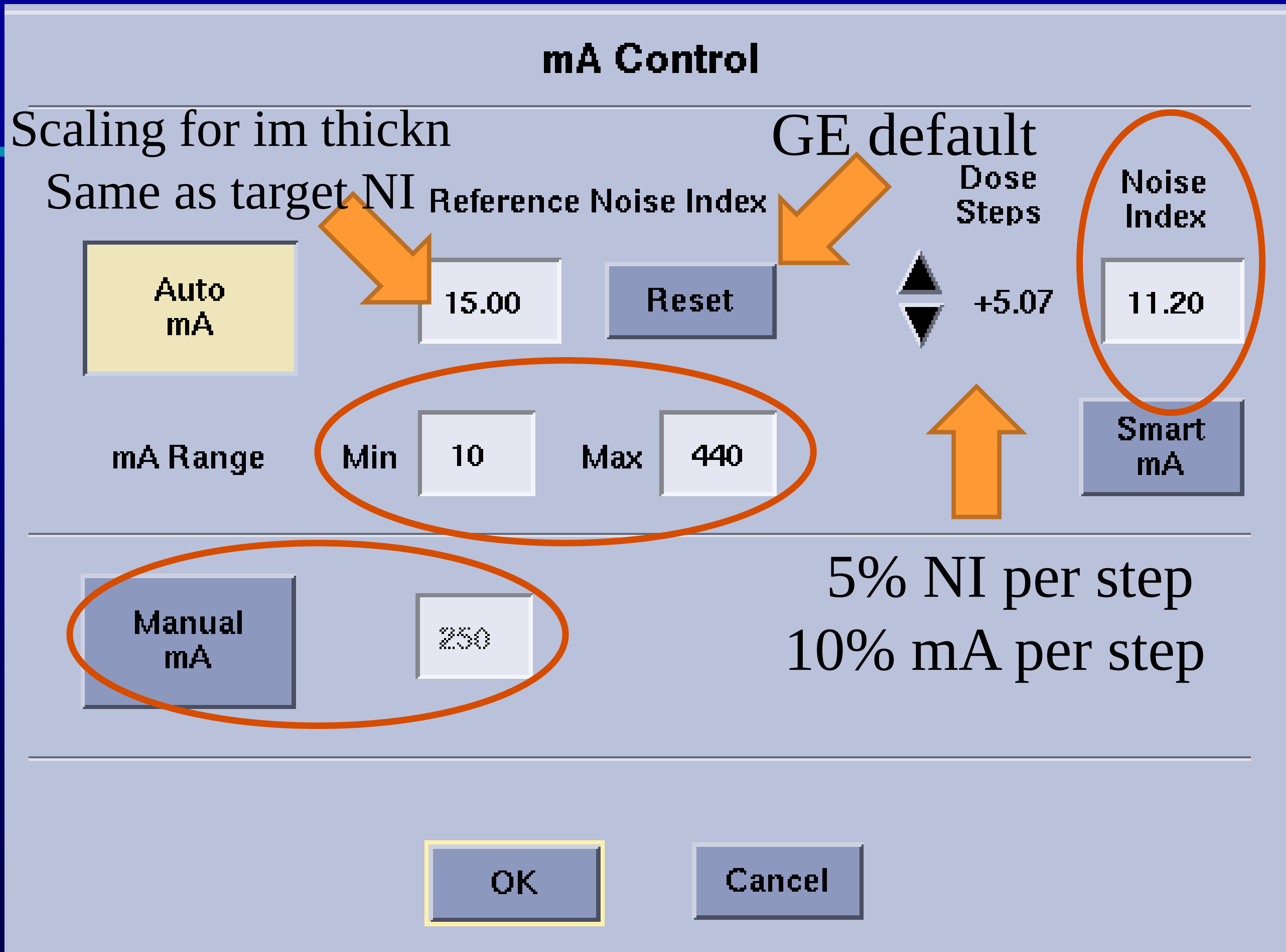
- NOT ALL Protocols need same image quality
  - Initial scan for kidney stones vs. followup study
  - Lung nodule followup vs. Diffuse Lung Disease
- Adaptation to Patient Size
  - Some schemes adapt to patient size, some do not
  - GE’s Noise Index – aims to provide a constant noise, regardless of patient size; therefore, sites often use different NI values for different sized patients
  - Siemens Quality Reference mAs – adapts to patient size, so sites use same value for different sized patients (tube current adapts to patient size)

Implementation Issues

- Be Aware of Patient Size Reference, Especially difference between Peds and Adult
- For example,
  - Siemens Adult Protocols – ref 70 kg
    - Standard man is 20-30 year old MALE, 70 kg, 5’7” tall
  - Siemens Pediatric Protocols – ref 20 kg (approx 5 year old)
  - This makes perfect sense, but be aware

Implementation Issues

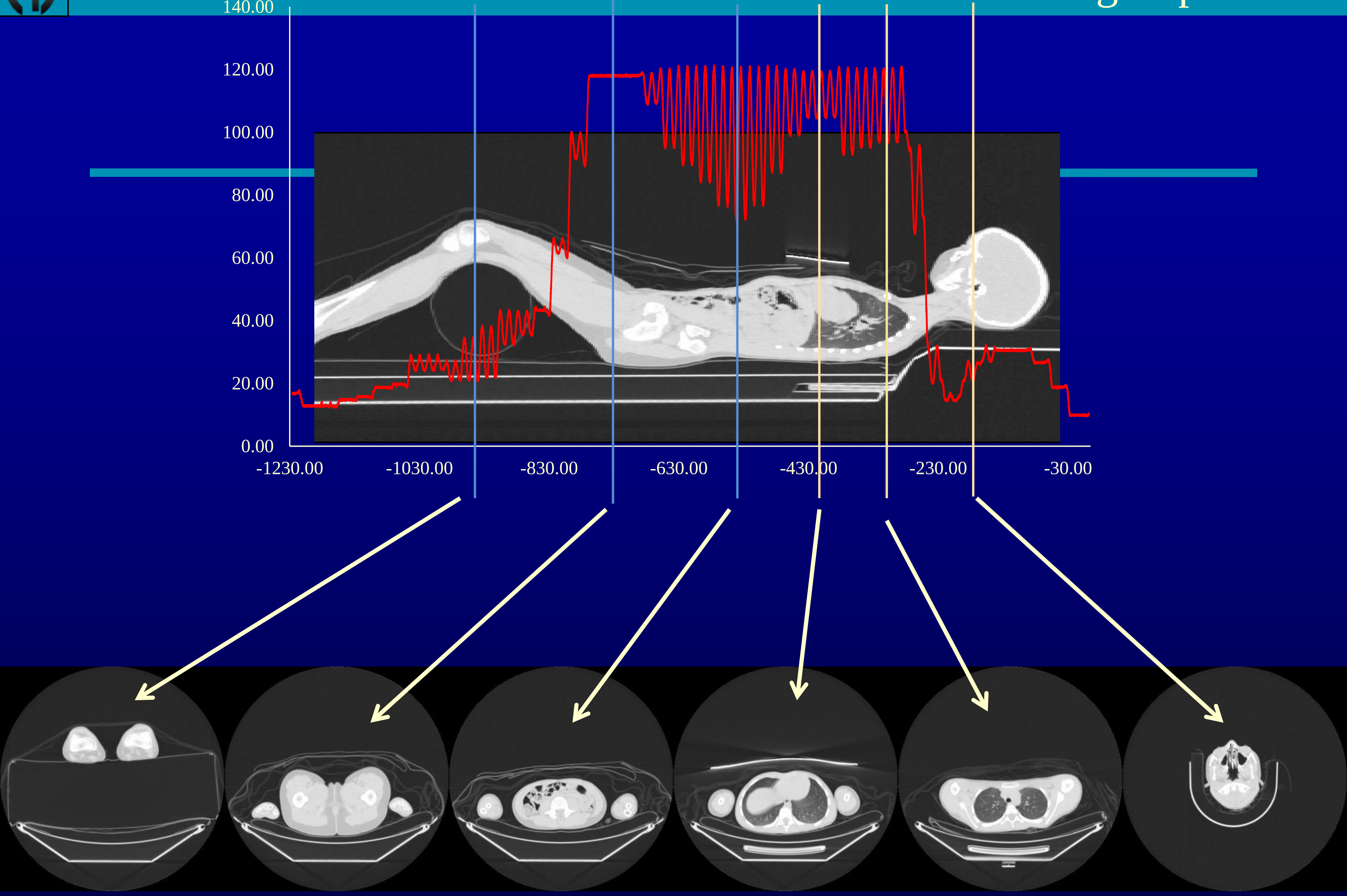
- Siemens Adult Protocols – ref 70 kg
- Siemens Pediatric Protocols – ref 20 kg
  - If you scan a pediatric patient on an adult protocol selection, but use reduced kVp and mAs appropriate for peds
    - Scanner will see small patient compared to 70 kg
    - **REDUCE** mAs even further -> poor image quality
  - If you scan an adult (or large teen) on peds protocol, but happen to use adult settings for kVp and mAs
    - Scanner will see large patient compared to 20 kg reference
    - **INCREASE** mAs even higher -> increased dose


mA Control
Scaling for im thickn
Same as target NI
GE default
Reference Noise Index
Dose Steps
Noise Index
Auto mA
15.00
Reset
+5.07
11.20
mA Range
Min
10
Max
440
Smart mA
5% NI per step
10% mA per step
Manual mA
250
OK
Cancel

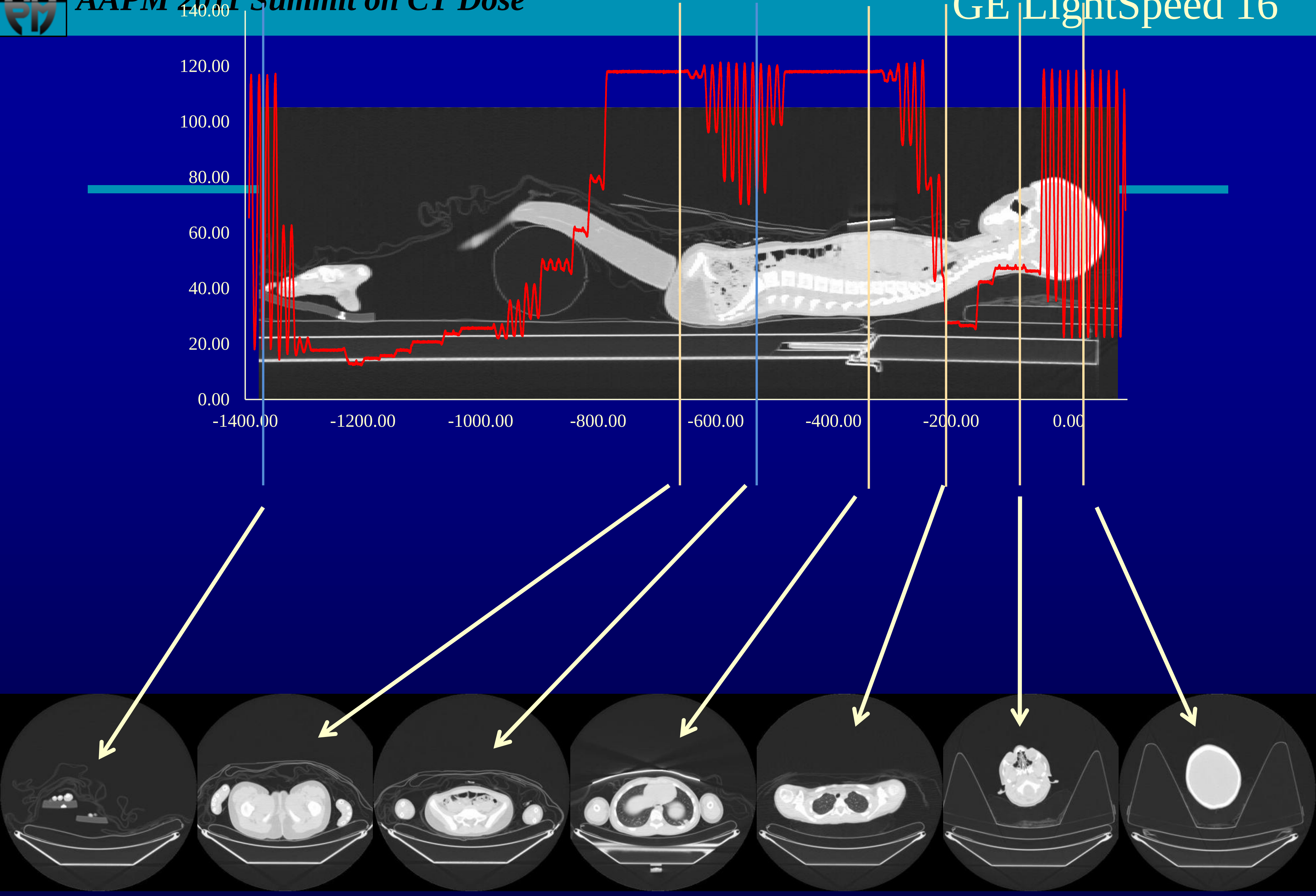
Other parameters

- Reference Noise Index
  - Scales NI for image thickness change
  - Difficult to understand
  - Backup – set equal to Noise Index value
- mA window
  - Set min mA carefully (100 mA min for adults?)
  - Set max mA carefully (500 mA max for adults?)
- Manual mA
  - **Set this value for typical patient size!!!**

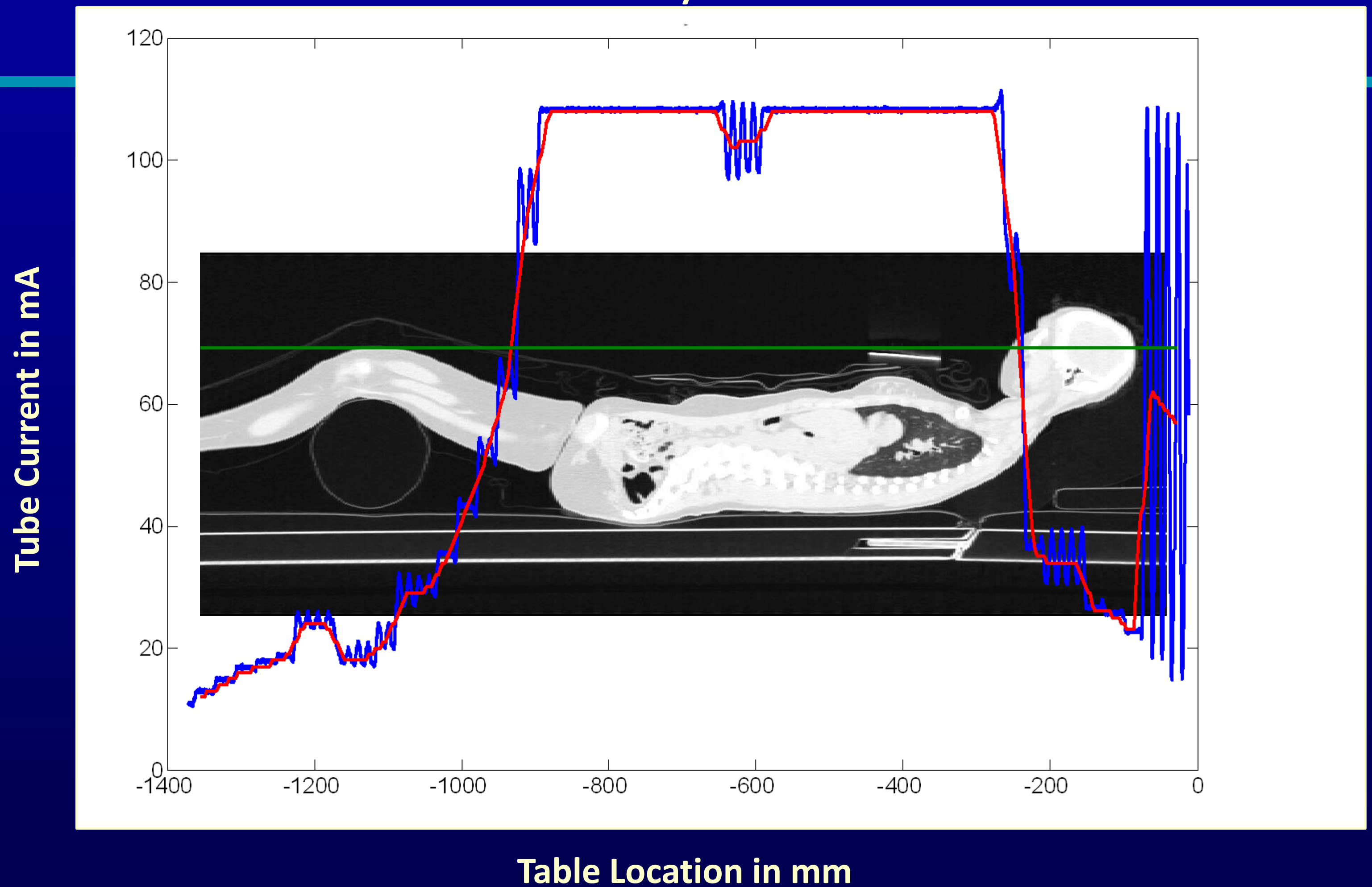
GE LightSpeed 16



GE LightSpeed 16



Whole Body CT Exam



Suggested Noise Index Values ADULTS (by GE)

Image thickness (mm)	Noise Index Range
5	10-12
3.75	12-15
2.5	15-18
1.25	18-20
0.625	20-24

<u>Primary reconstructed image thickness – not recons!**</u>**

Changing primary image thickness – change NI?

$$\text{New NI} = \text{Prev NI} \bullet \sqrt{\left[\frac{\text{Pref Im Thickn}}{\text{New Im Thickn}}\right]}$$

Example: Change from 5mm to 2.5mm, NI = 12

New NI = 12 • √ (5mm/2.5mm) = 12 (1.4) = 17

Also see: Kanal KM, et al. AJR 189: 219-225, 2007.

So what is TCM good for?

- Right sizing for patient habitus
  - Automatically sets technique for variable size patients
  - Body: Pediatrics, Adults of all sizes
  - PET/CT
- Adjusting mA for cross section size & shape
  - Head – to neck – to shoulders
  - Shoulders!
  - Chest – Abdomen – Pelvis (attenuation changes)
  - Attenuation correction scans (Hybrid scanners)

When should it be avoided?

- Head exams?
  - Brain
  - Orbits
  - Sinuses
- CT Perfusion
  - Little to no table motion
  - No chance to change cross section shape
  - LOW MANUAL TECHNIQUE

Summary

- Tube Current Modulation is typically based on attenuation calculations based on CT planning radiograph
  - Centering is important
- Can be used to adjust for patient size
- Can take into account variations in x,y and z
- Can reduce dose to smaller patients
  - May also INCREASE dose to large patients

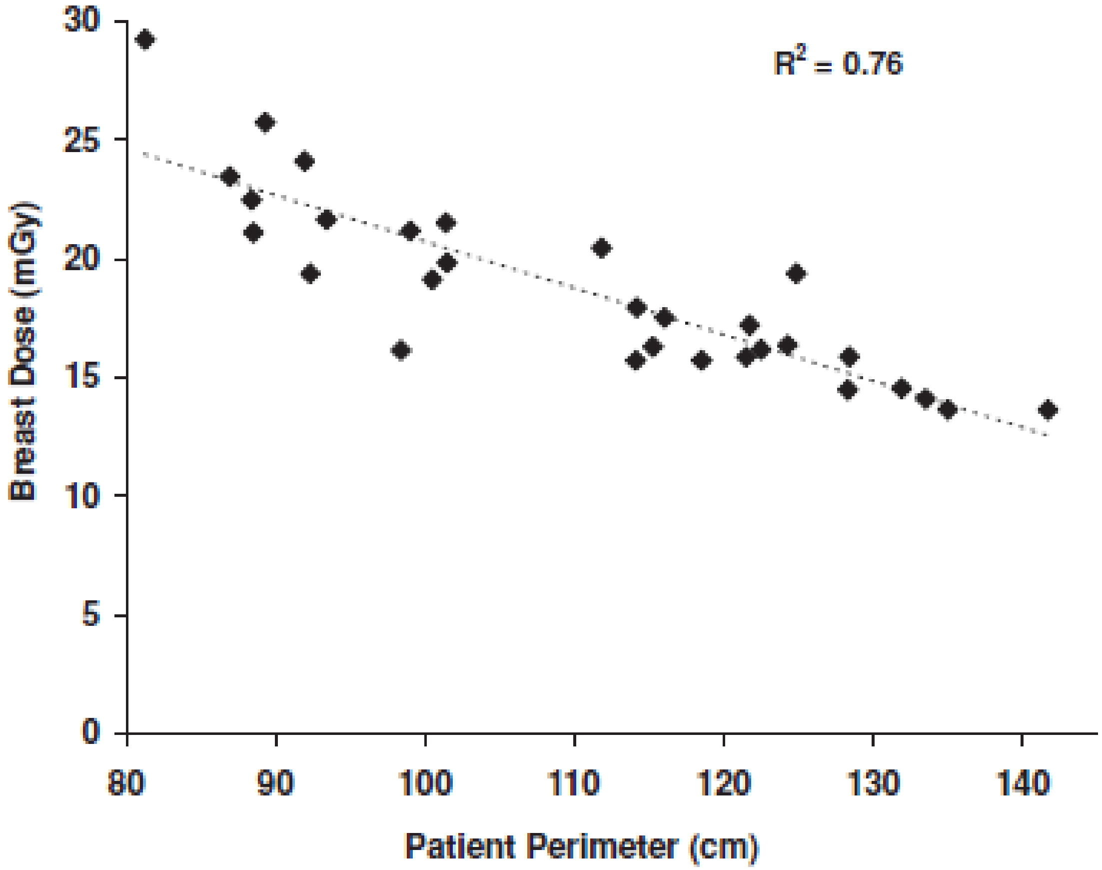


Figure 4. Breast dose versus patient perimeter for all 30 patient models in the fixed tube current simulations. Breast dose decreases linearly with an increase in patient perimeter ($R^2 = 0.76$).

From Angel et al, Phys. Med. Biol. **54 (2009) 497–511**

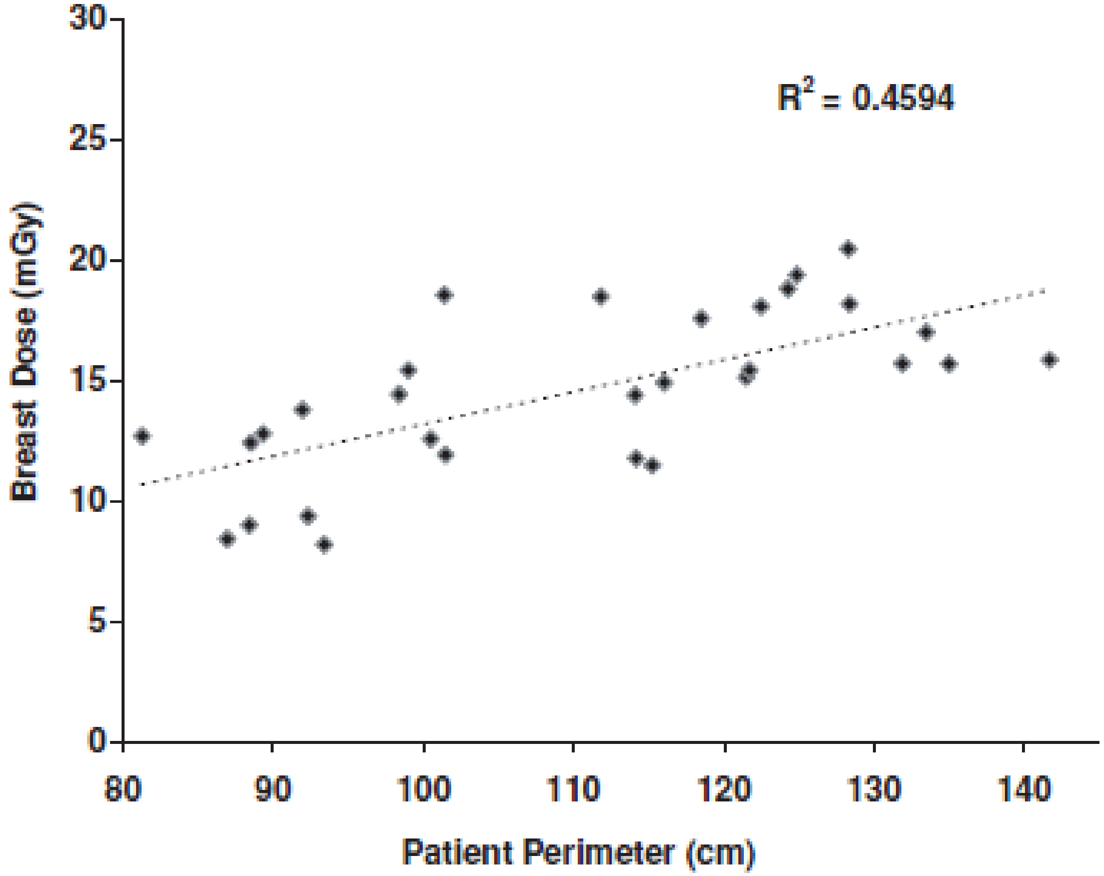


Figure 5. Breast dose versus patient perimeter for all 30 patient models in the TCM simulations. Breast dose increases linearly with an increase in patient perimeter ($R^2 = 0.46$).

From Angel et al, Phys. Med. Biol. **54 (2009) 497–511**

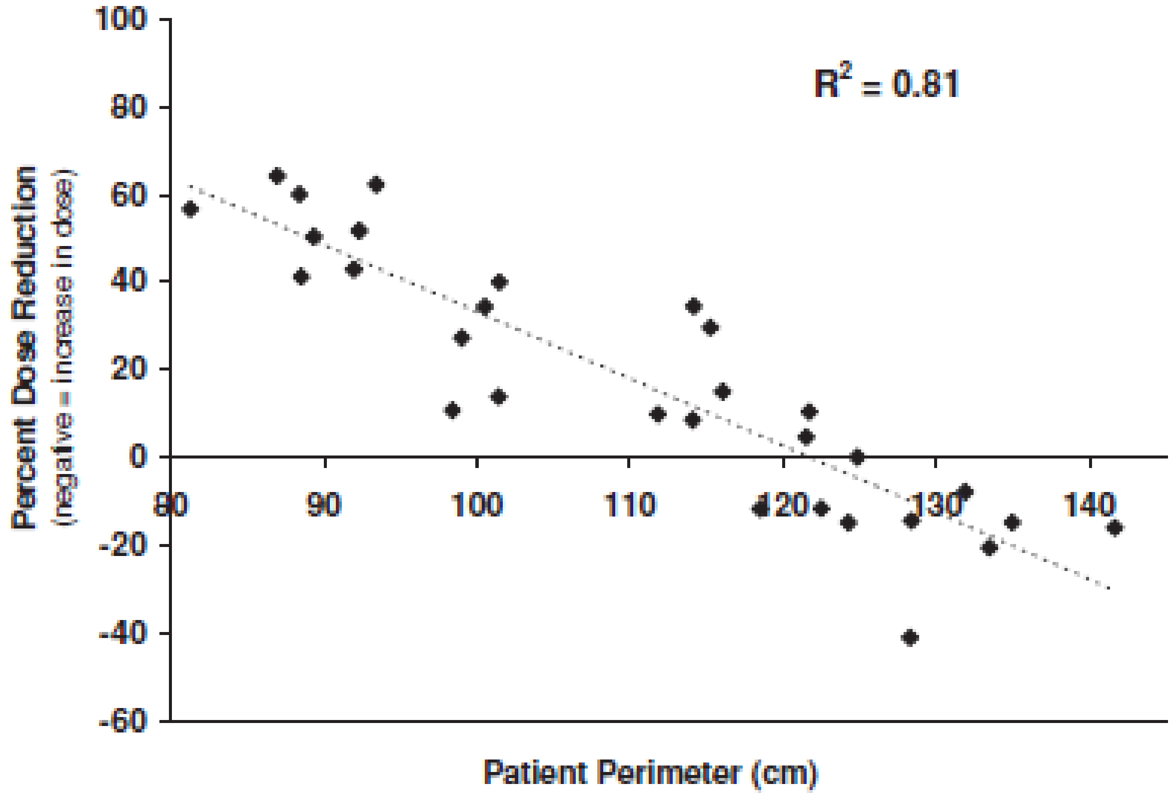


Figure 6. Percent dose reduction for the TCM simulations as compared to the fixed tube current simulations. Percent dose reduction decreases linearly with an increase in patient perimeter ($R^2 = 0.81$).

From Angel et al, Phys. Med. Biol. **54 (2009) 497–511**

Summary

- User Inputs Image Quality Parameter
- This has SIGNIFICANT effect on TCM
- Should be chosen based on:
  - Image Quality Requirements
  - Patient Size adjustments – and knowledge of how manufacturer’s TCM does or does not adjust for size
    - i.e. whether TCM adjusts for size
    - or user has to adjust input value based on patient size