Principles & implementation of automatic exposure control systems in CT

Maria Lewis

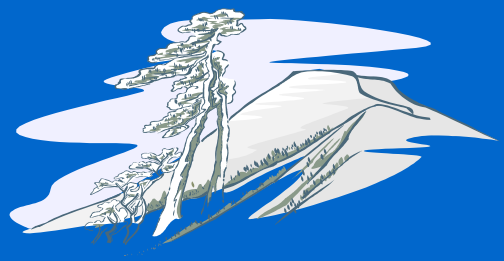
ImPACT

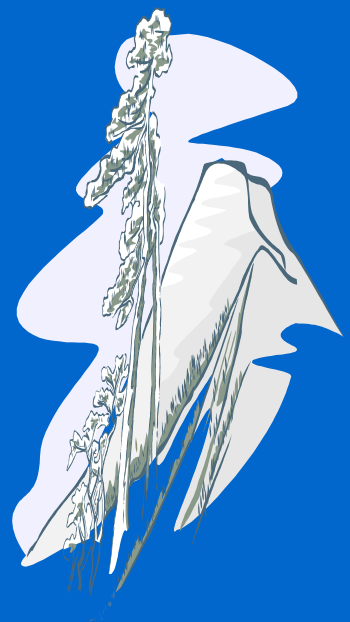
Overview

- Why AEC in CT?
- Principles of AEC in CT
- Implementation of AEC in CT

Why AEC in CT?

Cruise Control





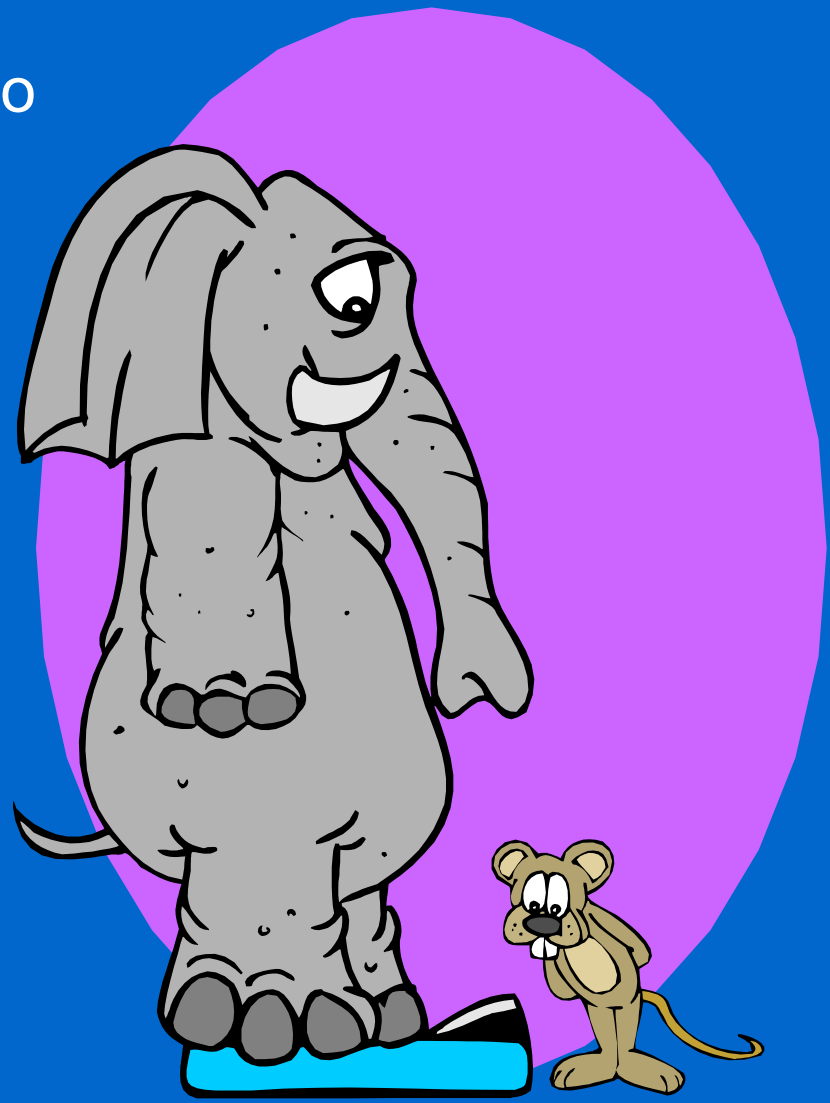
Small hill
less fuel
flow

Steep hill
more fuel
flow

Courtesy GE

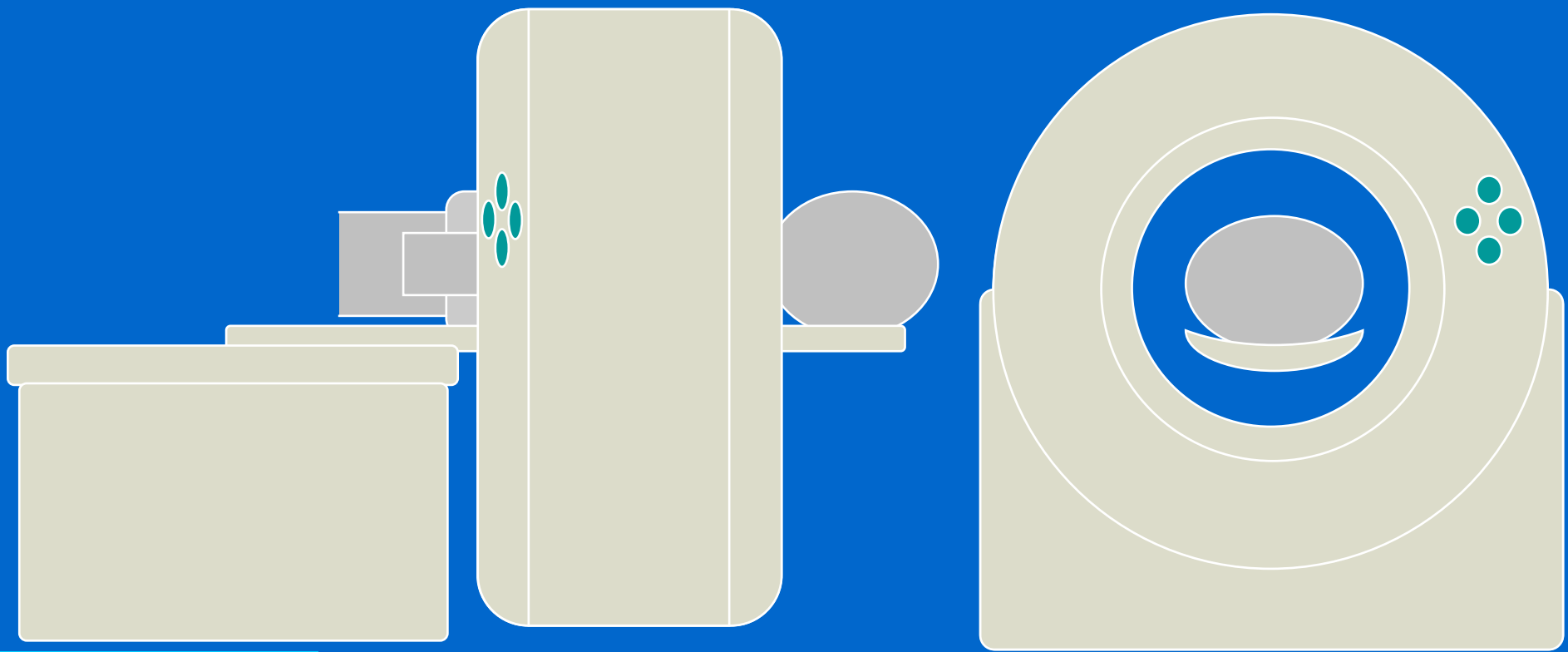
Why AEC in CT?

- Adjust tube current (mA) for variations in patient attenuation to achieve required image quality
- The driving force behind development of AEC systems in CT has been dose reduction



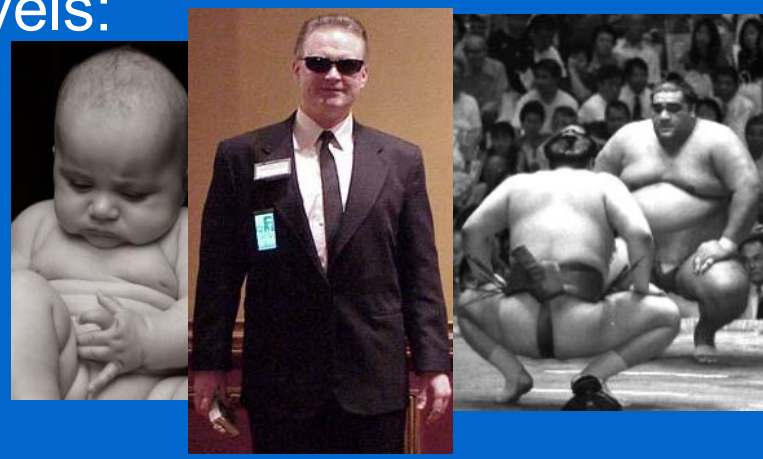
Why AEC in CT?

- CT offers ideal opportunity for tailoring mA to changes in patient attenuation

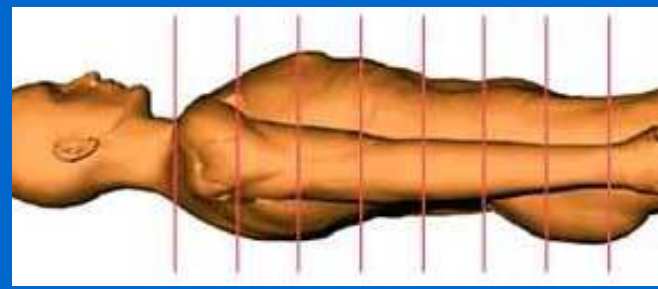


Why AEC CT?

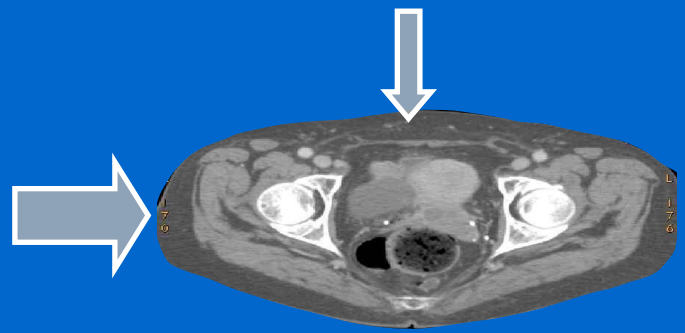
- The mA can be adjusted at three levels:
  - for overall patient size



  - for varying attenuation along z-axis

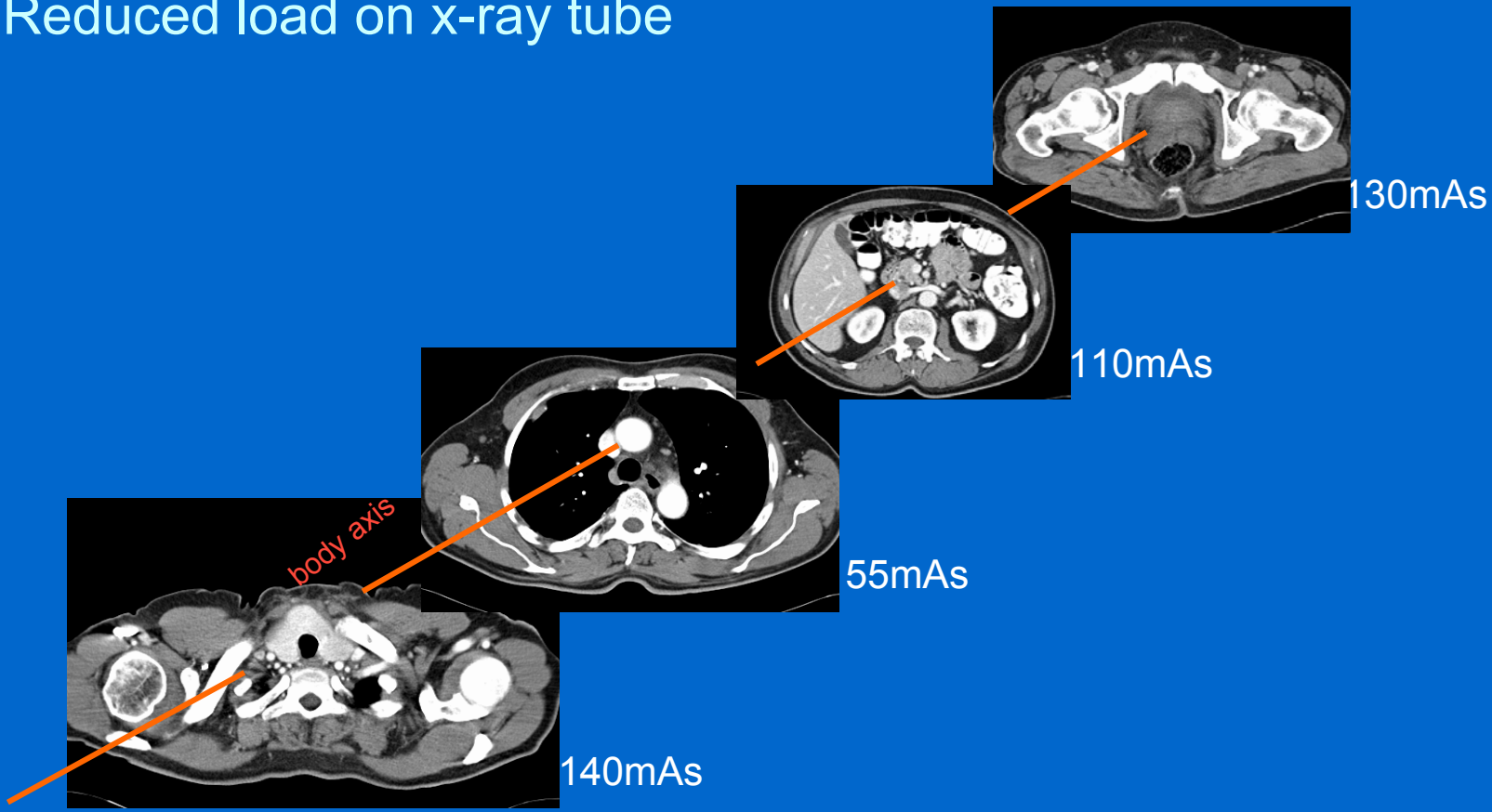


  - for varying angular attenuation



Why AEC in CT?

- Benefits of AEC:
  - More uniform image quality (noise)
  - Reduced dose to less attenuating regions
  - Reduced load on x-ray tube



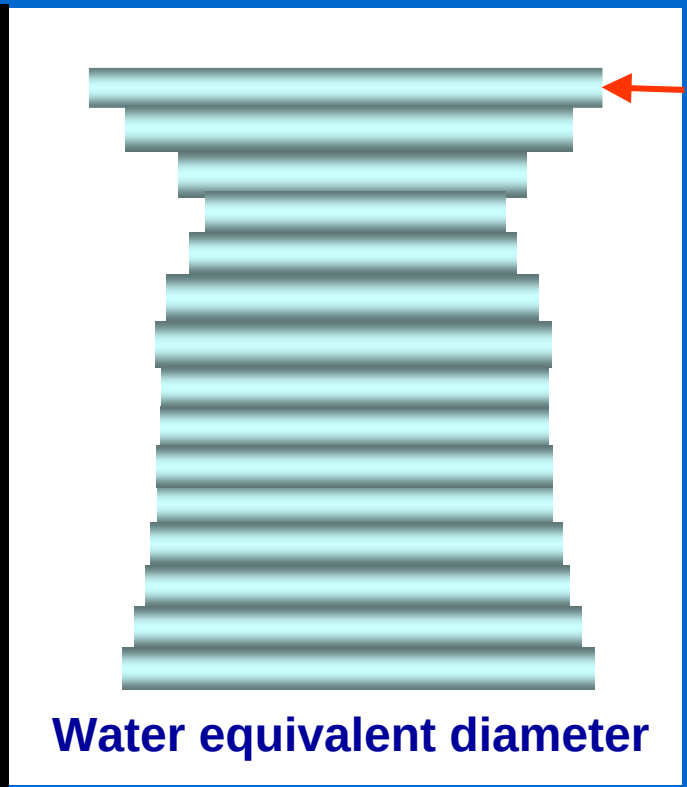
Images courtesy Erlangen University, Germany

Principles of AEC in CT

- Obtaining attenuation data and calculating required mA
  - patient size and z-axis
  - angular
- How much is the mA adjusted for changing patient size?
  - Do we want to keep image quality constant for different sizes?
- Defining image quality requirements
  - What image quality are we aiming for?

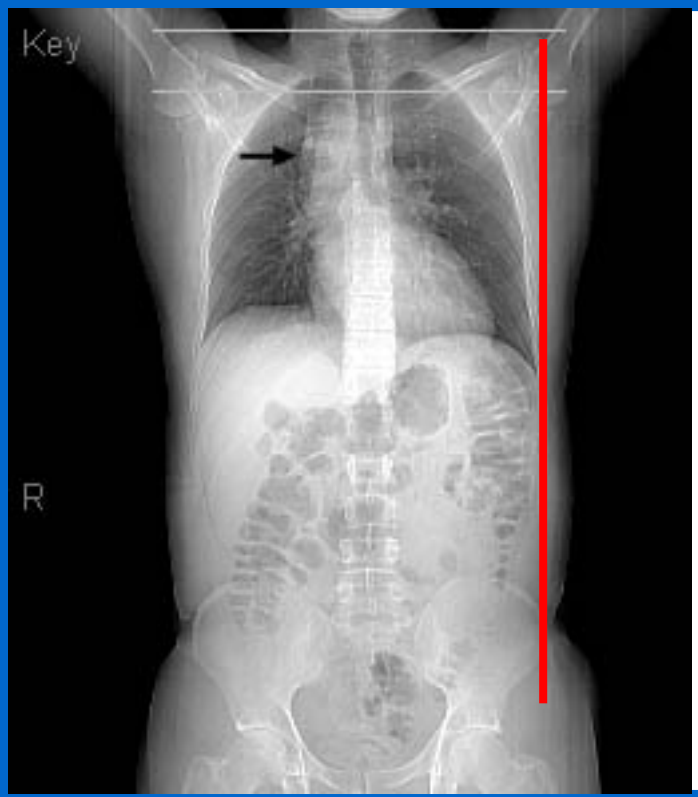
Principles of AEC: patient size & z-axis

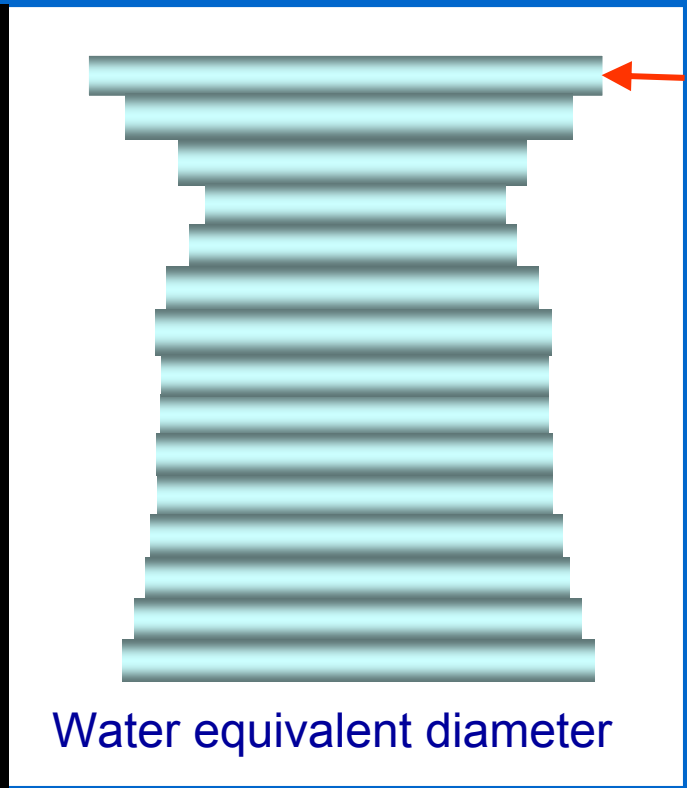
- Acquisition of attenuation data
  - SPR performed → attenuation data at each z-position
- Water equivalent diameter calculated for each level
  - max attenuation level compared to a standard size
  - allows relative mA to be calculated



Principles of AEC: patient size

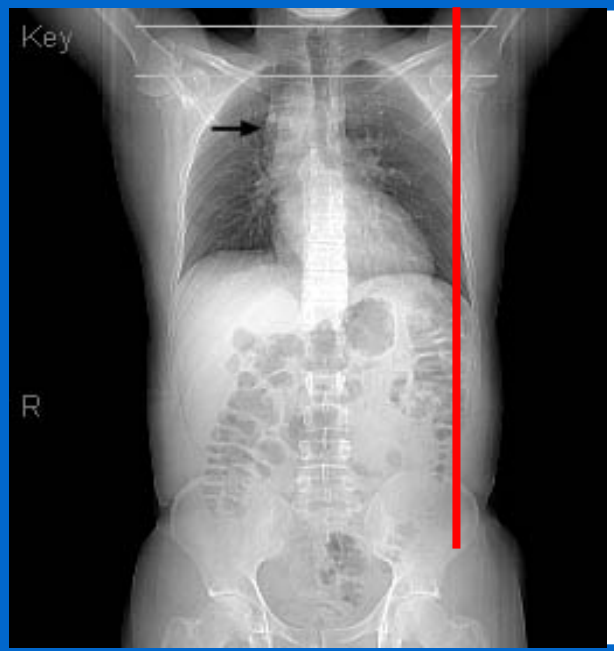
- If adjusting for overall patient size mA calculated for level of maximum attenuation is used throughout the examination

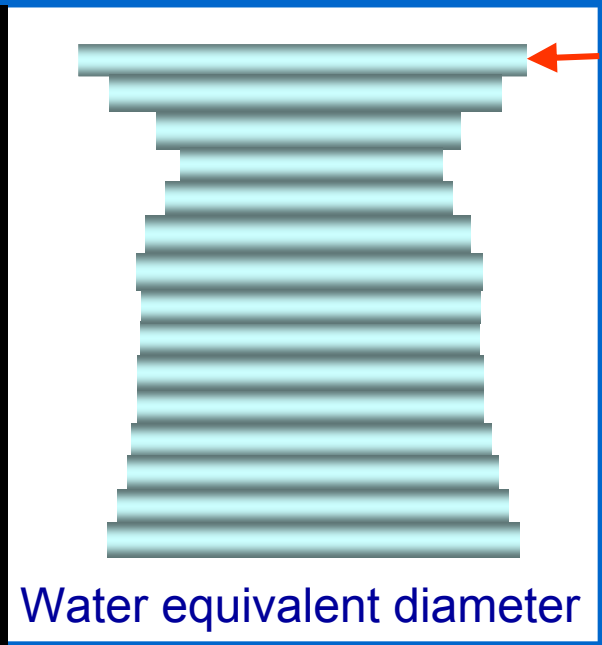




Principles of AEC: patient size

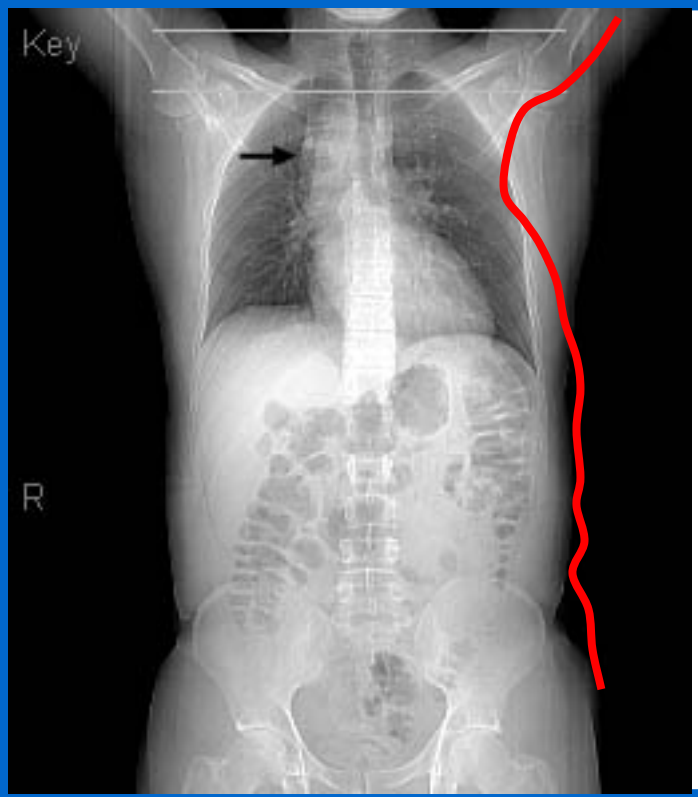
- For different patient sizes the appropriate mA will be used

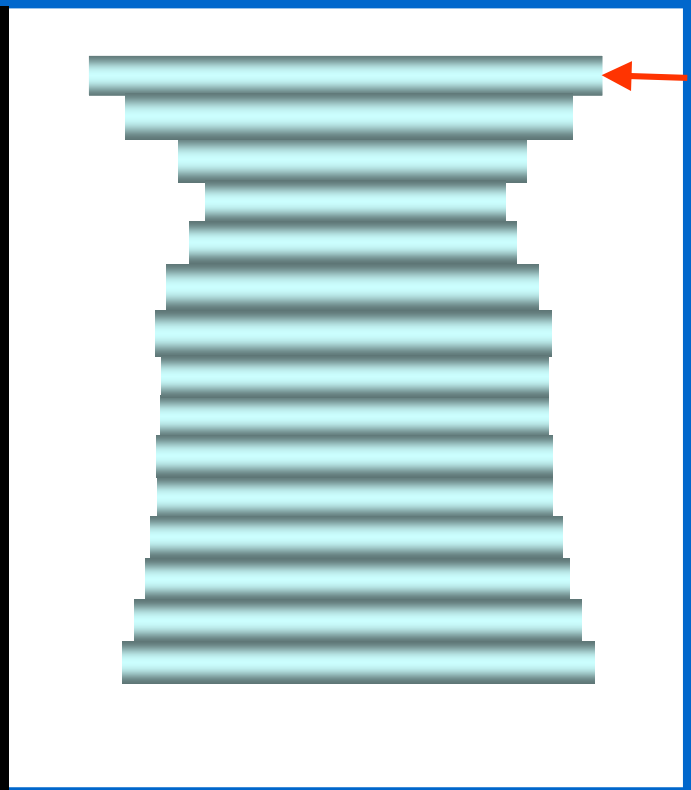




Principles of AEC: z-axis

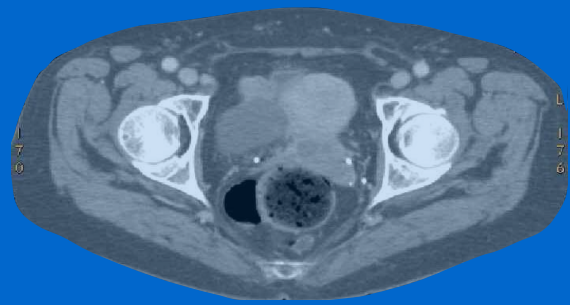
- For z-axis modulation the attenuation at each level is calculated relative to maximum
- For each rotation the appropriate mA will be used

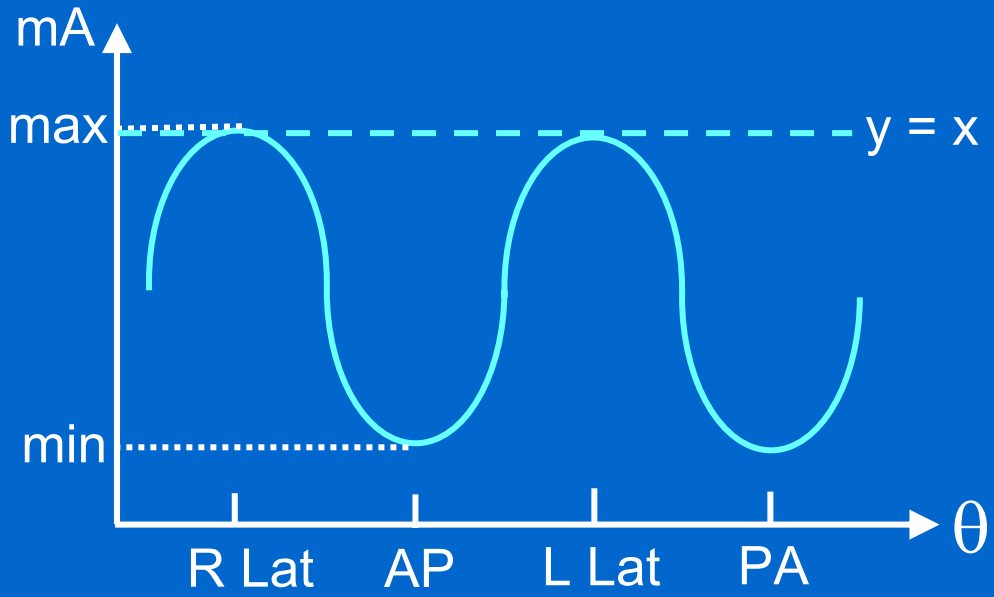


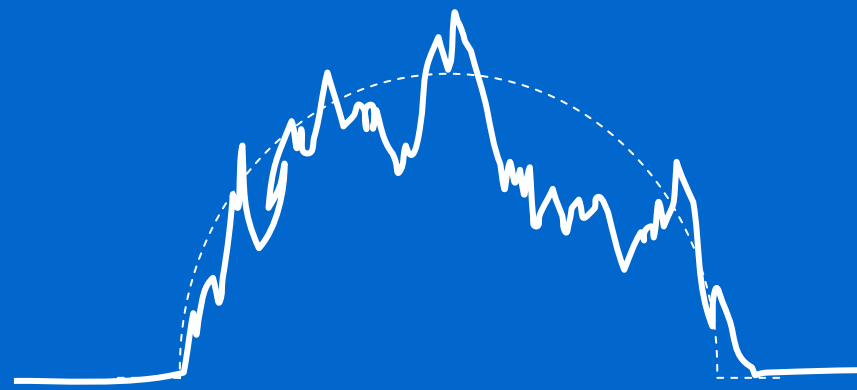


Principles of AEC: angular

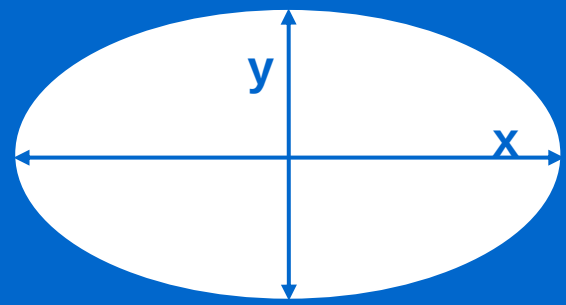
- Method 1: Prospective calculation from SPR
  - x & y dimensions of ellipse calculated from information in attenuation profile
  - tube current varied sinusoidally during rotation





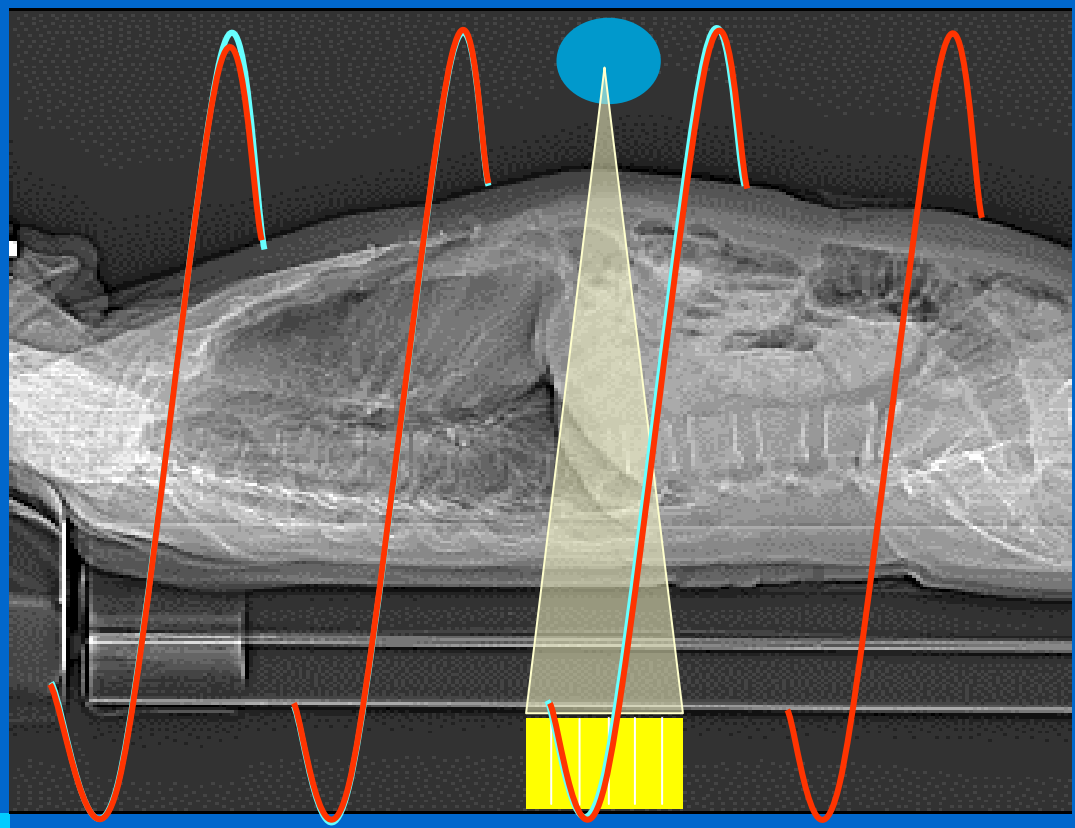


AP attenuation profile from SPR



Principles of AEC: angular

- Method 2: ‘On line’ modulation
  - uses attenuation data from previous rotation
  - adapts tube current to patient attenuation ‘on the fly’



Attenuation information

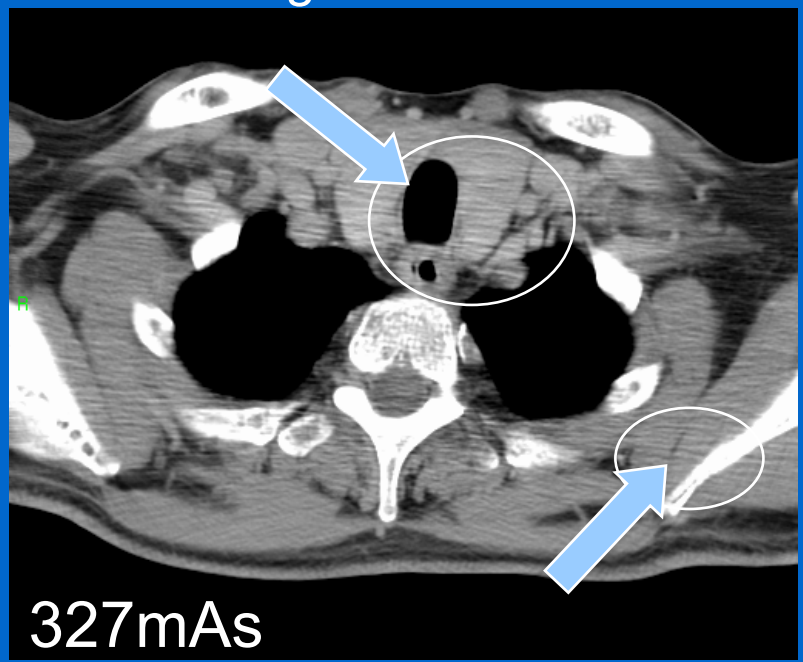
Applied mA

Diagram adapted from Siemens

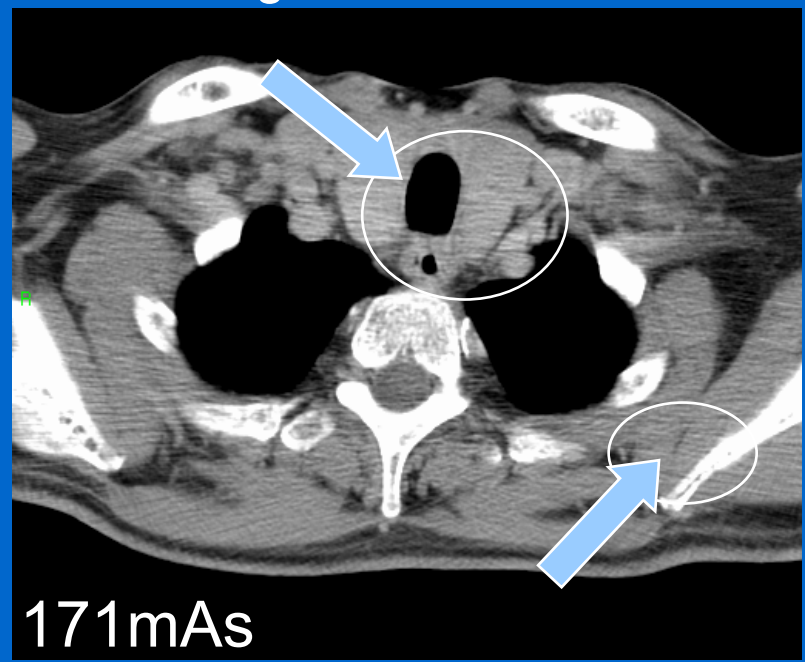
Principles of AEC: angular

- Noise in image is governed by most attenuating projections
- Reducing mA from AP direction does not change noise significantly but reduces dose

without angular mA modulation



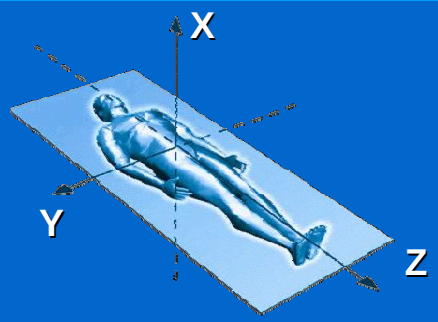
with angular mA modulation

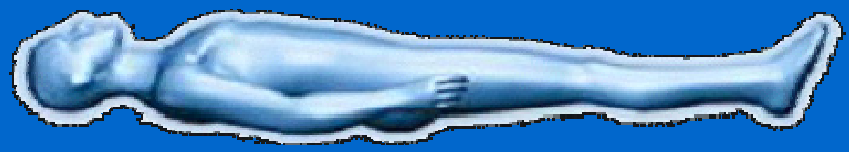


~50% dose reduction

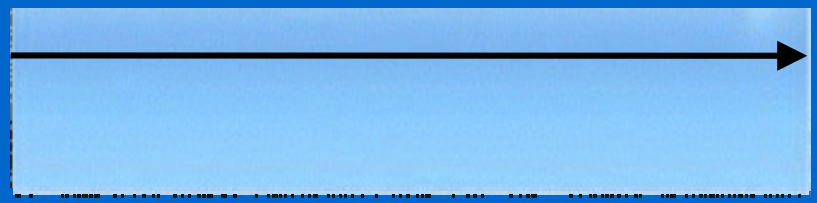
Courtesy Siemens

Principles of AEC in CT





patient size



z-axis variation

angular variation
(x-y)

x, y, z: 3D mA
modulation

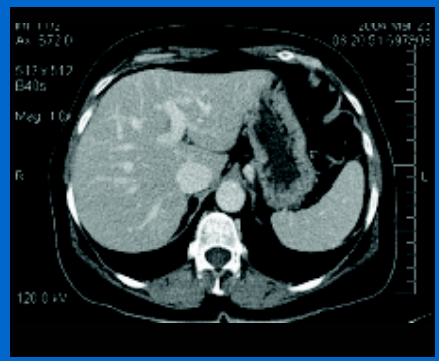
Diagram courtesy GE

How much is the mA adjusted for changing size?

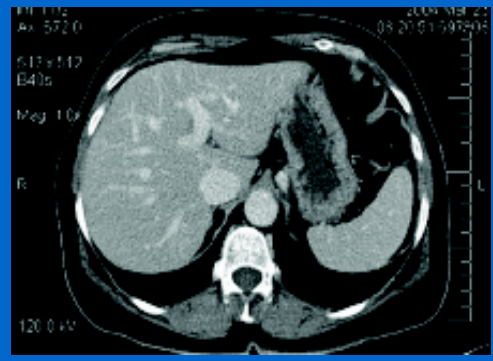
How much is the mA adjusted for changing size?

- To maintain constant image noise need constant signal to detectors
- Half value layer (HVL) of CT beam in tissue ≈ 4 cm
  - Double mA for every increase of 4 cm
  - Halve mA for every decrease of 4 cm

-4 cm
34 cm: 120 mA



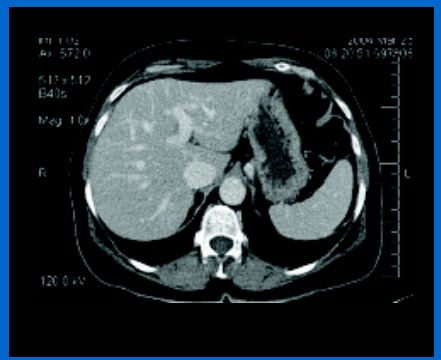
Ref size: 38 cm
Ref mA: 240

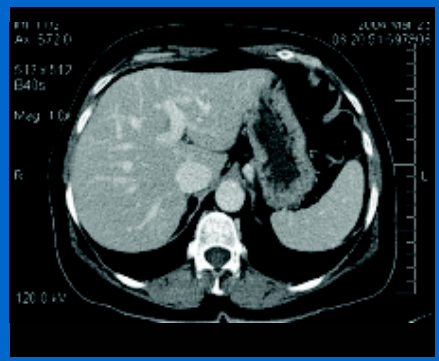


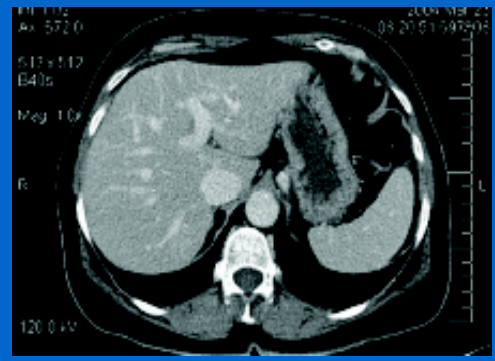
+ 4 cm
42 cm: 480 mA

How much does mA change with attenuation?

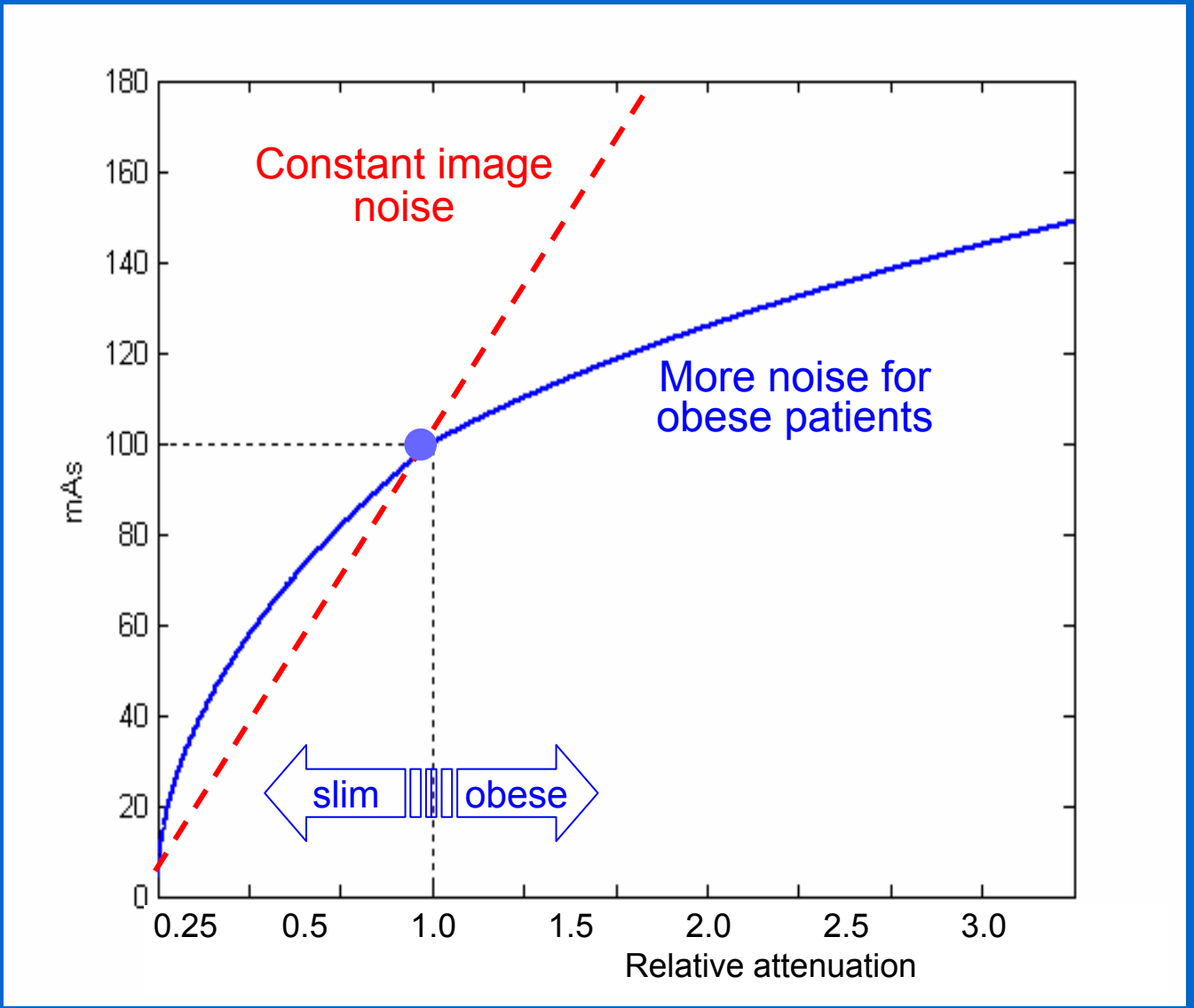
- Do we want to maintain constant noise with changing attenuation?
  - Smaller patients require lower noise
  - With larger patients can accept more noise





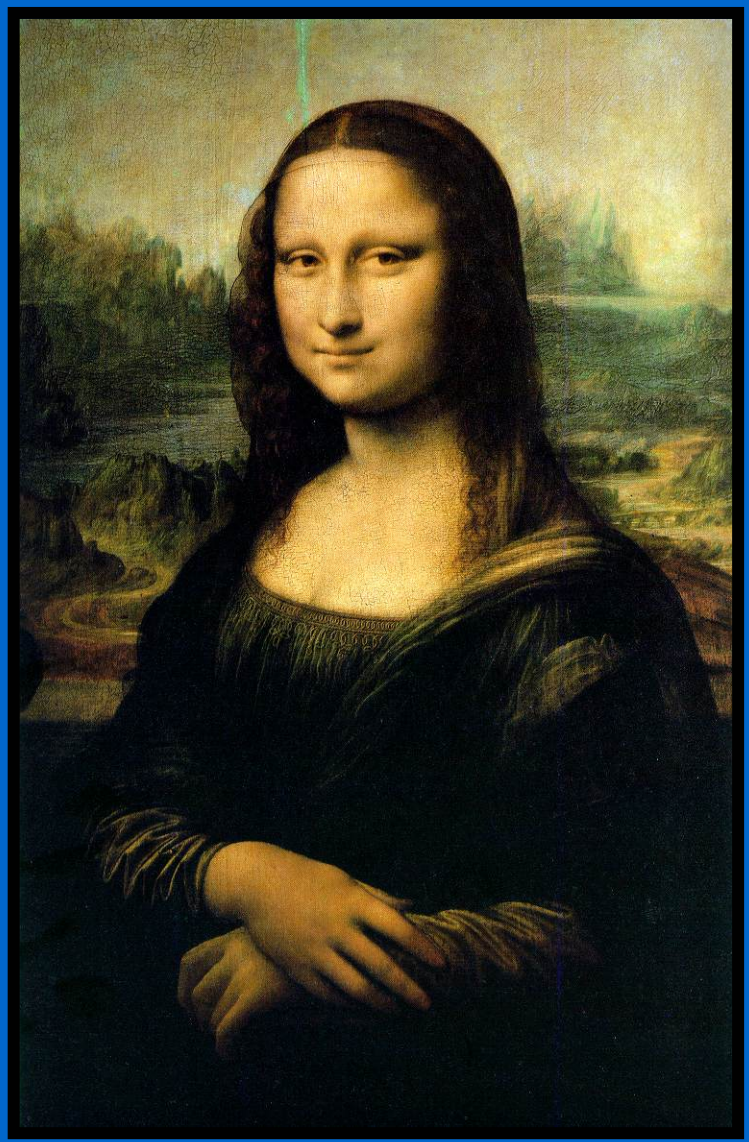


How much is the mA adjusted for changing size?



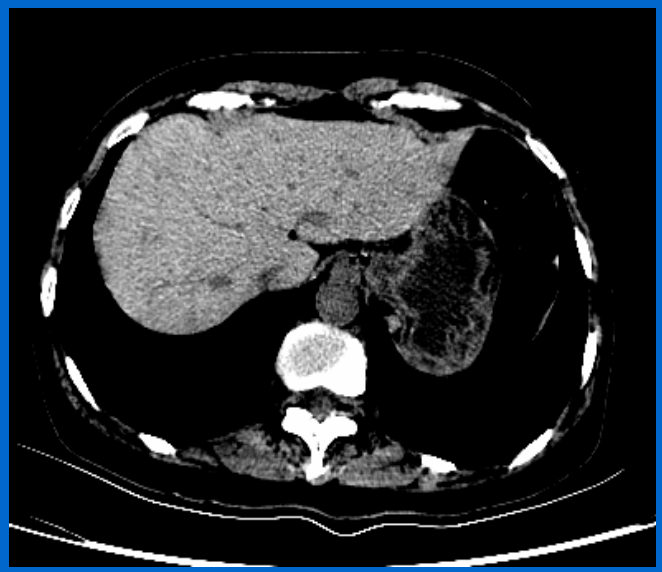
Courtesy Siemens

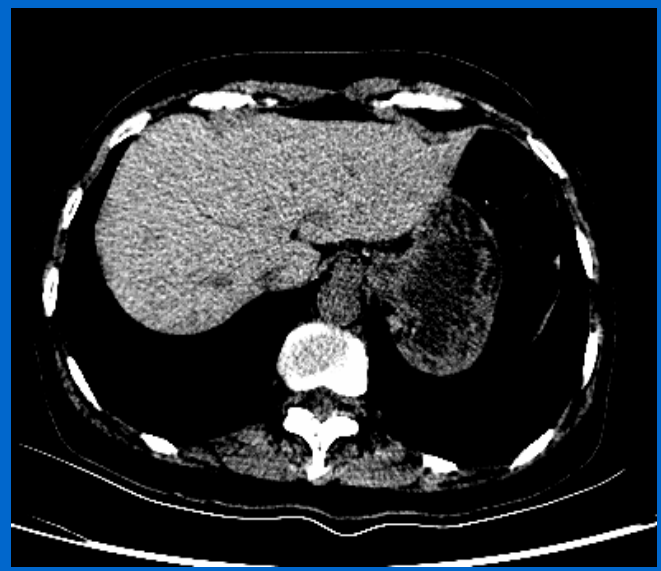
Defining image quality requirements



Defining image quality requirements

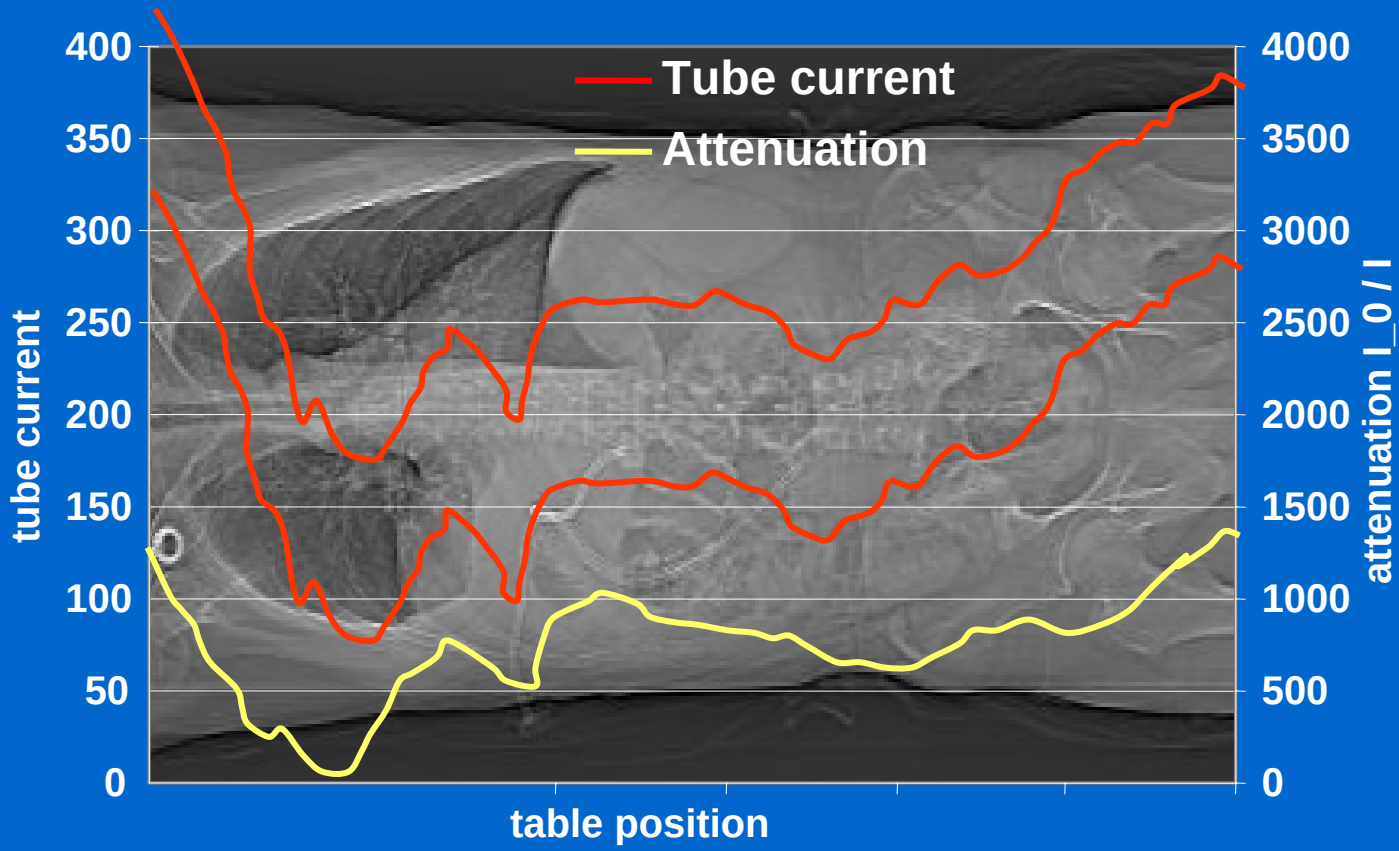
- AEC system requires a reference level from which to adjust the mA
- This must be defined by the user





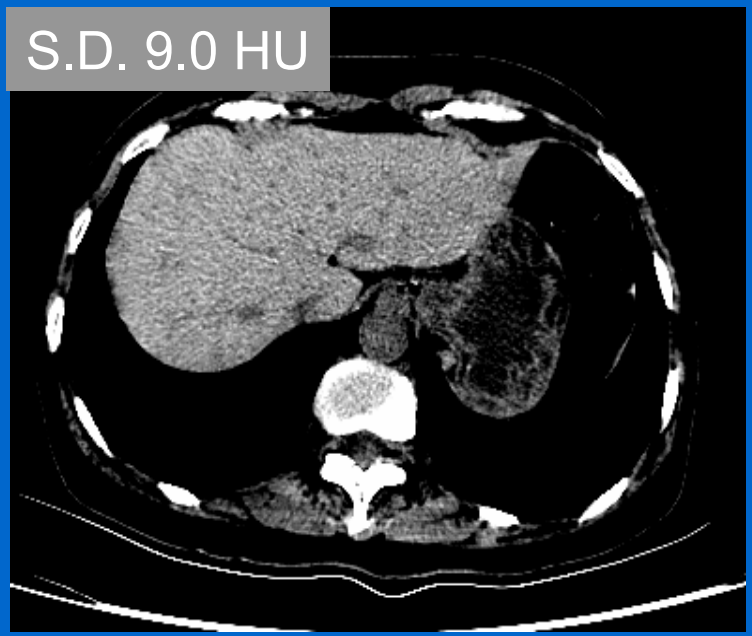
Defining image quality requirements

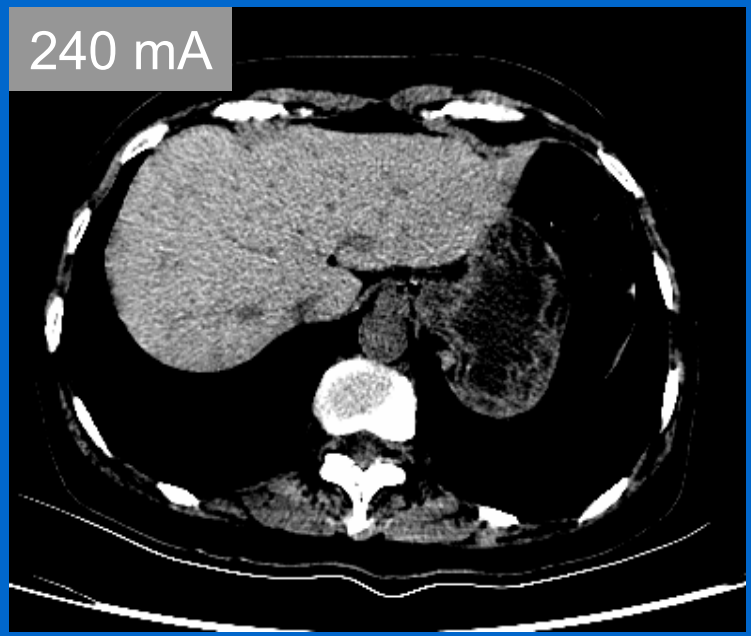
- You can have perfect adaptation of mA to patient attenuation
- Inappropriate setting of image quality can result in dose increase



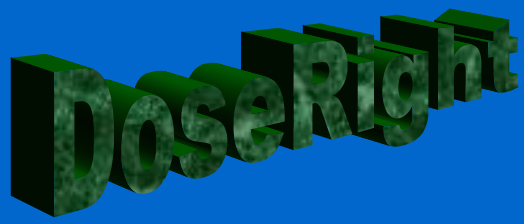
Defining image quality requirements

- Two approaches used on AEC systems to define image quality:
  - standard deviation of CT numbers (noise level)
  - reference mA: mA for standard patient required to give appropriate image quality

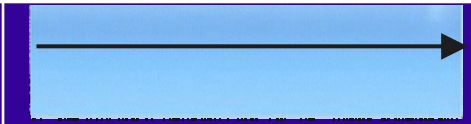




Implementations of AEC in CT

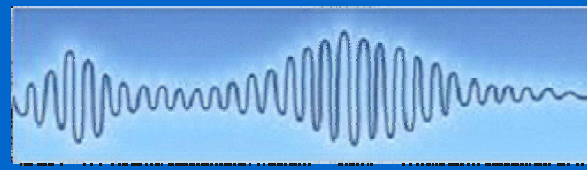


Implementations of AEC in CT

	 Patient size	 z-axis	 angular
GE	Auto mA		SmartmA
Philips	DoseRight ACS	DoseRight ZDOM	DoseRight DDOM
Siemens	CARE Dose 4D		
Toshiba	SURE Exposure		3D

GE: AutomA / SmartmA

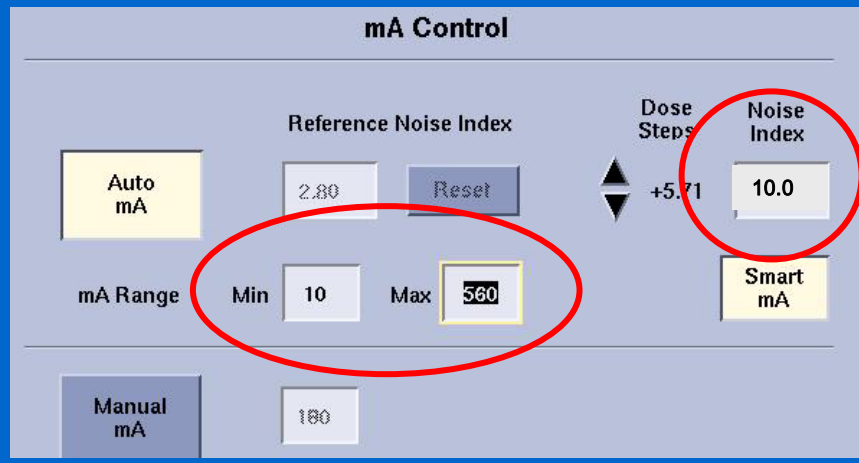
- AutomA: Patient size and z-axis
- SmartmA: Angular modulation
  - can be selected additionally*
  - uses prospective attenuation from single Scout View
- mA adjusted to maintain ~ constant noise



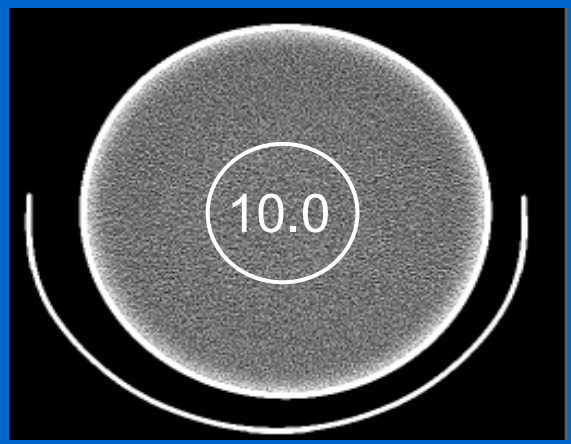
* On LS 5.X platforms

GE: defining image quality requirements

- Specify a ‘noise index’ (NI)
  - NI defined as s.d. of CT numbers in water phantom with ‘standard’ algorithm
  - Set min & max mA
- Patient s.d. ~ matches noise index for standard algorithm



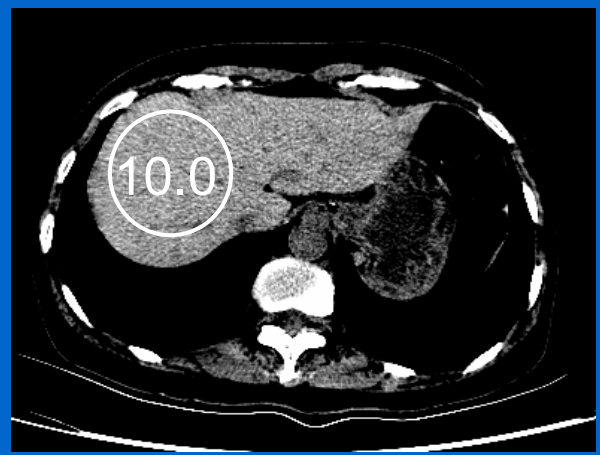
Courtesy GE



s.d. = 10.0 in water phantom for ‘standard’ algorithm

Scout view

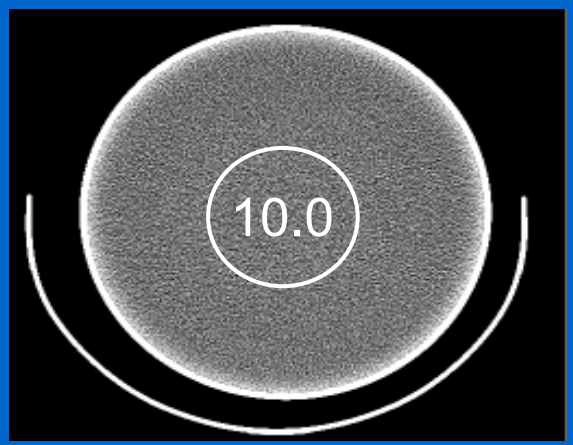
mA calculated to match s.d. for ‘standard’ alg.



s.d.≈ 10.0 in patient with ‘standard’ algorithm

GE: defining image quality requirements

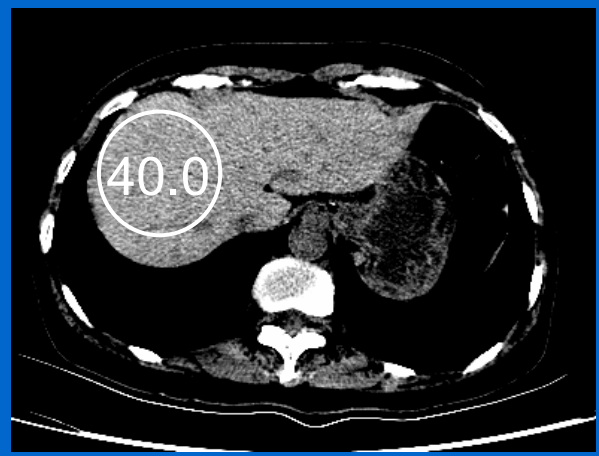
- Different algorithms: patient s.d. will not match the noise index



Noise index = 10.0

Scout view

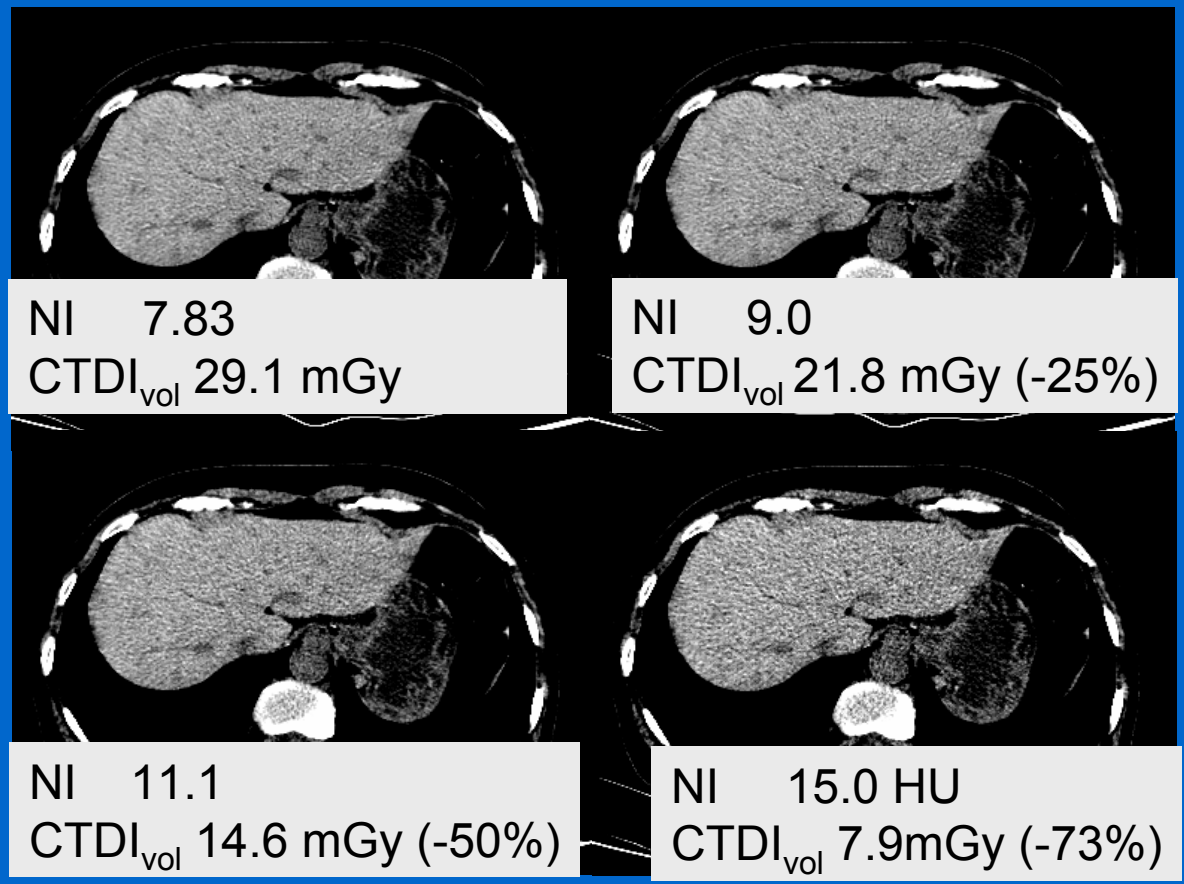
mA for patient calculated to match s.d. for 'standard' alg.



s.d.≈ 40.0 in patient with 'bone' algorithm

GE: defining image quality requirements

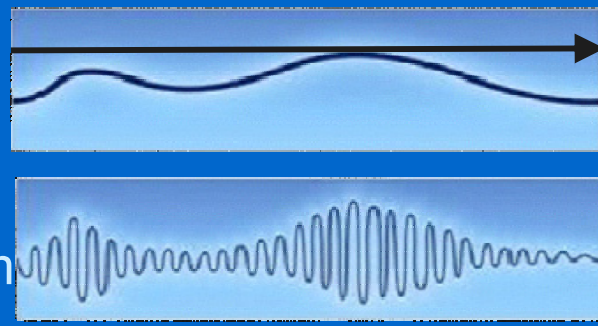
- Increasing Noise Index (NI):
  - increases noise
  - decreases dose

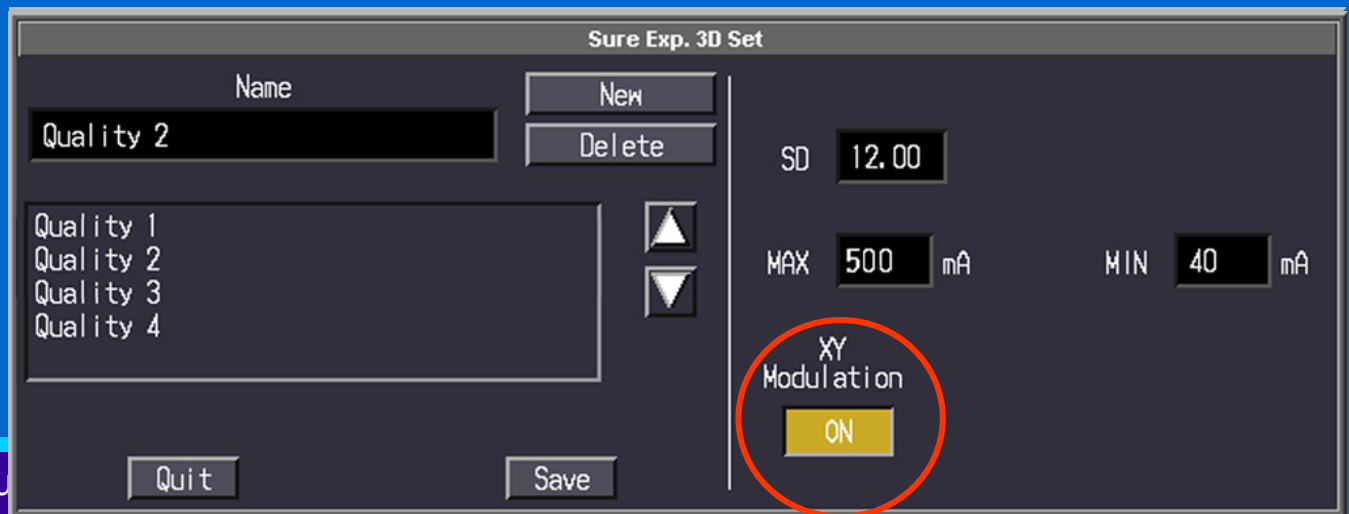


Images courtesy GE

Toshiba: SUREExposure 3D

- SUREExposure 3D
  - incorporates all three levels of modulation
  - angular (x-y) modulation: ON/OFF
    - uses prospective attenuation from Scanogram
- Two Scanograms required
  - use same kV as for scan
- mA adjusted to maintain ~constant noise





Toshiba: defining image quality requirements

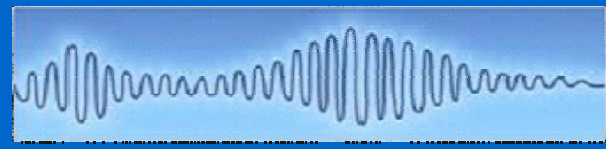
- Specify s.d. level (or ‘image quality level)
  - patient mA calculated to achieve this noise level at any scan parameter settings
- Set min & max mA

Courtesy Toshiba

Siemens: CARE Dose 4D

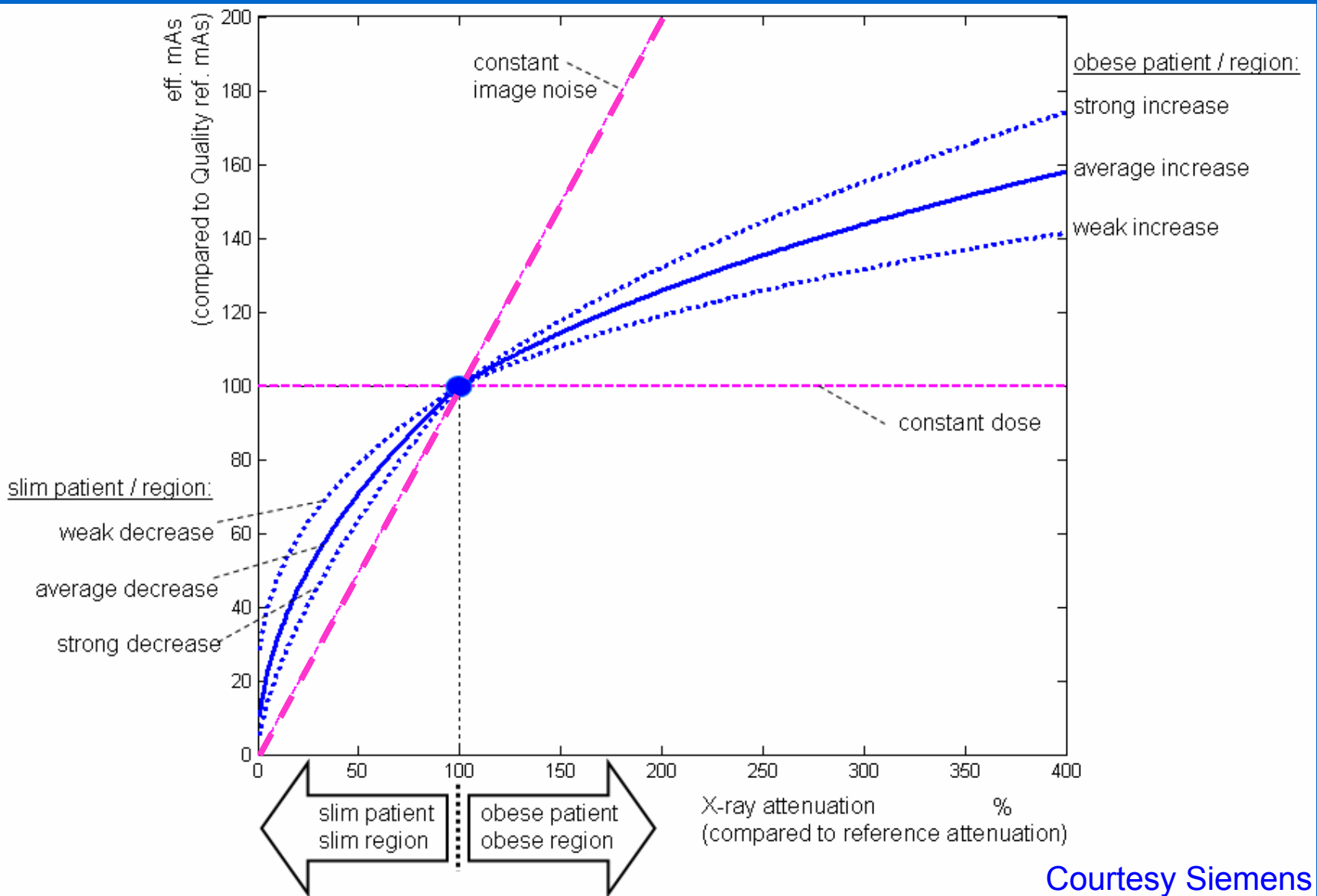
- CARE Dose 4D: all three levels of AEC applied
  - some exceptions

    e.g.adult head protocols: z-axis only
- Angular modulation uses ‘on-line’ attenuation data
- Use same kV for Topogram as for scan



Siemens: CARE Dose 4D

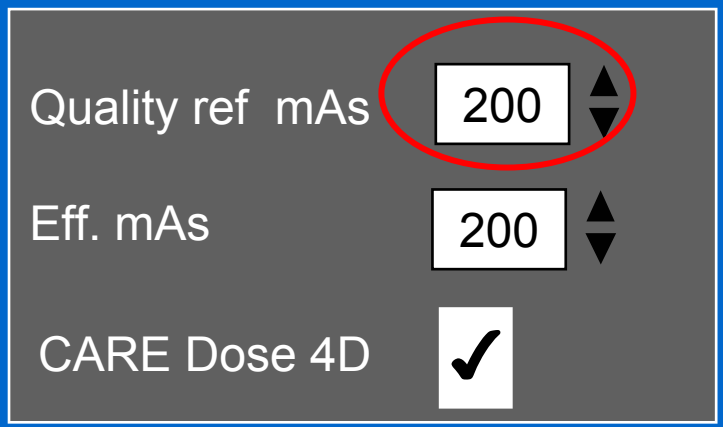
- Adapting mA for attenuation variation



Courtesy Siemens

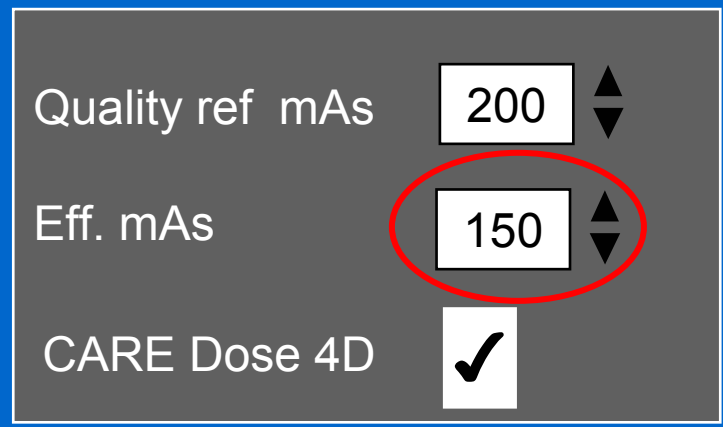
Siemens: defining image quality requirements

- Specify ‘Quality reference mAs’ in each protocol
  - effective mAs for required image quality in standard patient
- Effective mAs is determined only by ‘Quality reference mAs’ and patient size
- Independent of scan parameter settings



Prior to Topogram
Effective mAs =Quality ref mAs

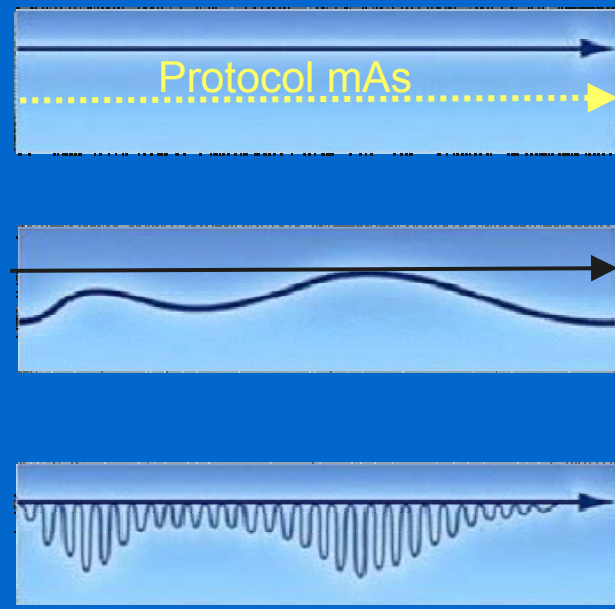
Topogram performed



Following Topogram
Effective mAs is adjusted for patient attenuation

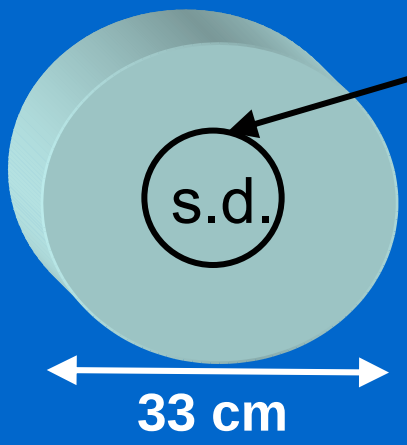
Philips: DoseRight

- ACS: Automatic Current Selector
  - patient size
- Z-DOM: Z-axis modulation
  - must be used initially with ACS
- D-DOM: Angular modulation
  - D-DOM can be used independently or with ACS
  - uses ‘on-line’ modulation
- D-DOM & Z-DOM cannot be implemented simultaneously
- Aims to keep image quality fairly constant with varying attenuation

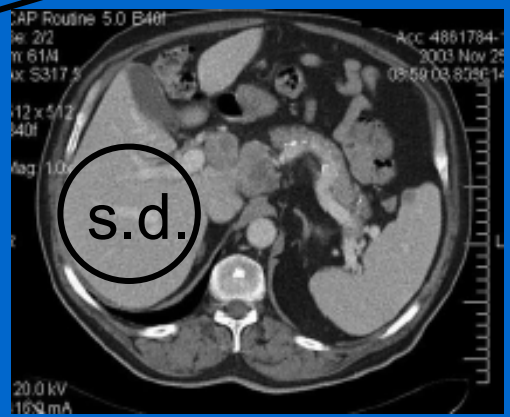


Philips: defining image quality requirements

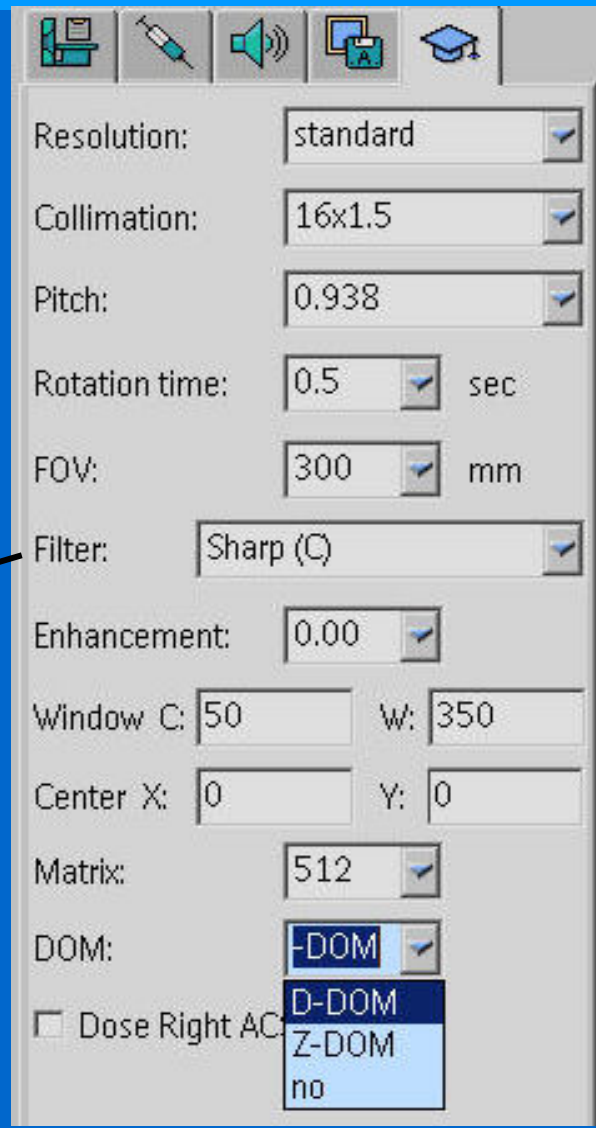
- Specify mAs/slice in protocol
  - defines image quality (s.d.) in water phantom for settings in protocol
  - following SurView mAs/slice for similar s.d. in patient is calculated



Surview



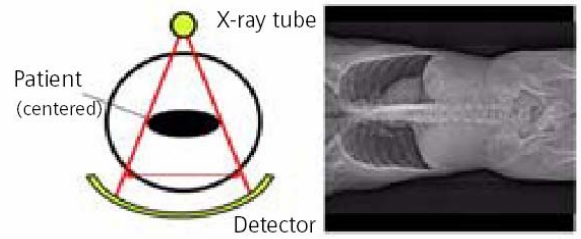
mAs required to give ≈ s.d. as in standard size



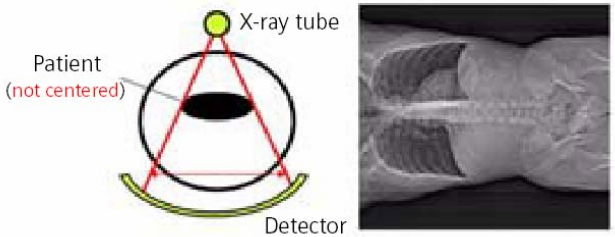
Courtesy Philips

A few practical tips….

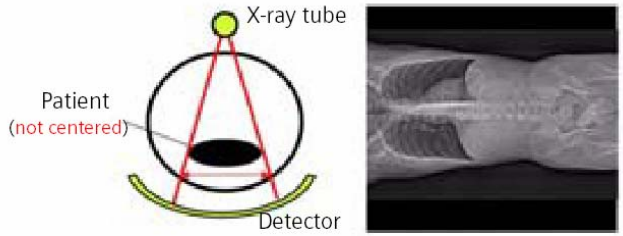
- To obtain correct attenuation data from SPR always centre the patient carefully



Patient is positioned in the isocenter – optimal dose and image quality



Patient is positioned too high – increased mAs

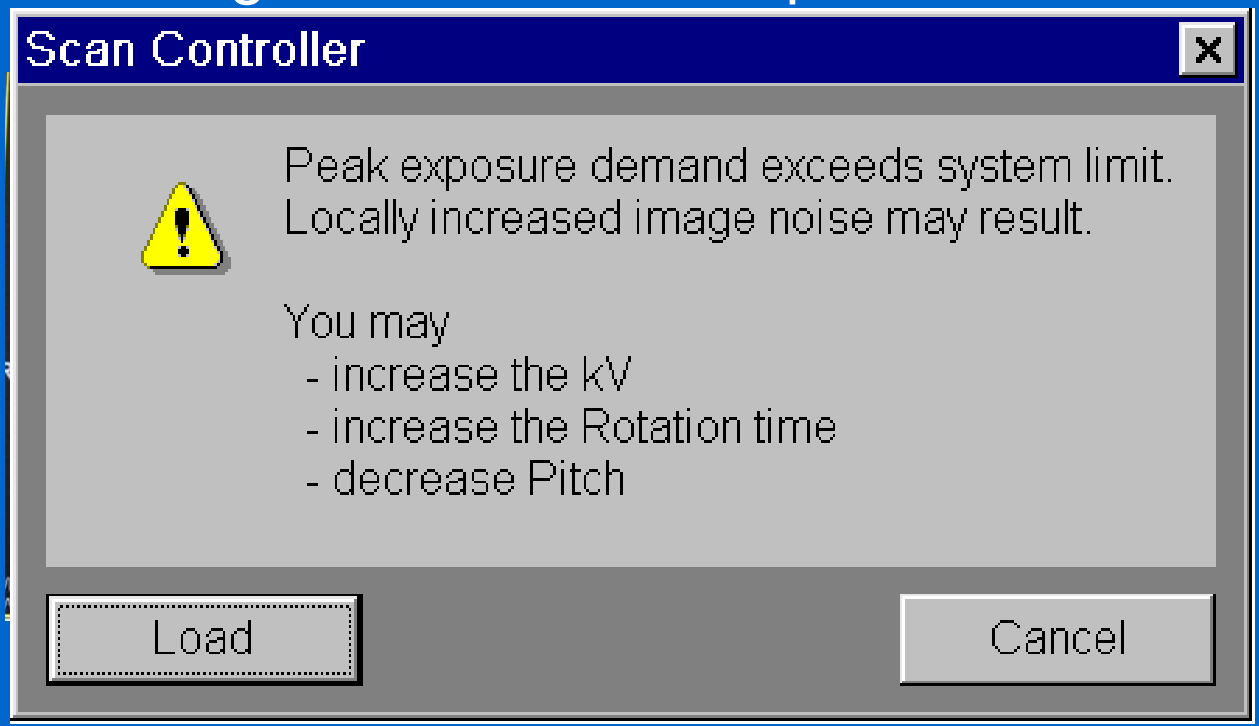


Patient is positioned too low – reduced mAs and increased noise

Courtesy Siemens

A few practical tips….

- Ensure nothing but the patient is in the beam
- Always check $CTDI_{vol}$ info
- Check system is not over-ranging – may not be able to achieve the range of mA values required



Conclusions

- Manufacturers differ in their approach to AEC
- Know your AEC system: read manual, talk to applications specialist
- AEC systems can increase as well as decrease dose
- Define image quality requirements carefully for each protocol
- Review image quality and dose continuously

Acknowledgements

- The manufacturers for providing information & material; in particular:
  - Thomas Toth & Sandie Jewell, GE
  - Iris Sabo-Napadensky & Derek Tarrant, Philips
  - Christoph Suess & Susie Guthrie, Siemens
  - Henk de Vries & Craig Hagenmaier, Toshiba
- The physicists & radiographers who gave me their time & time on their scanners; in particular:
  - Grace Keltz, St. George's Hospital
  - Claire Skinner, Royal Free Hospital
  - CT department, Royal National Orthopaedic Hospital
  - Lynn Martinez & Nina Arcuri, Royal Mardsen Hospital
  - Trupti Patel, Harefield Hospital
- Sue & Jim, my colleagues at ImPACT, for helpful comments