

# CT IMAGE QUALITY AND DOSE CONSIDERATIONS

KERRY GREENE-DONNELLY

# Biography

Kerry Greene-Donnelly has over 18 years of experience in Medical Imaging. Kerry has experience and is certified through the ARRT in Radiography, Mammography, Computed Tomography and Quality Management. Kerry has an AAS in Radiologic Technology, a BPS in Health Service Management and a MBA. Currently Kerry is an Assistant Professor at Upstate Medical University in Syracuse NY. Kerry has taught for 12 years in the Medical Imaging Sciences program, as well as, Radiation Therapy, Physical Therapy and Physician Assistant programs. Kerry's research interests are in CT dosimetry and image quality

# Image Quality

## ▣ Spatial Resolution

- Ability to image small objects that have high subject contrast <sup>(1)</sup>.
- CT has moderate spatial resolution 20 lp/cm <sup>(1)</sup>

## ▣ Contrast Resolution

- Ability to distinguish between and image similar tissues <sup>(1)</sup>
- CT has excellent low contrast detectability 0.25-0.5 % difference in tissue attenuation <sup>(2)</sup>

## ▣ Temporal Resolution

- Ability to freeze motion of the object being imaged <sup>(2)</sup>
- CT has moderate temporal resolution, ~300ms for full segment reconstruction down to 75ms with 4 segment reconstruction. <sup>(2)</sup>

# Spatial Resolution

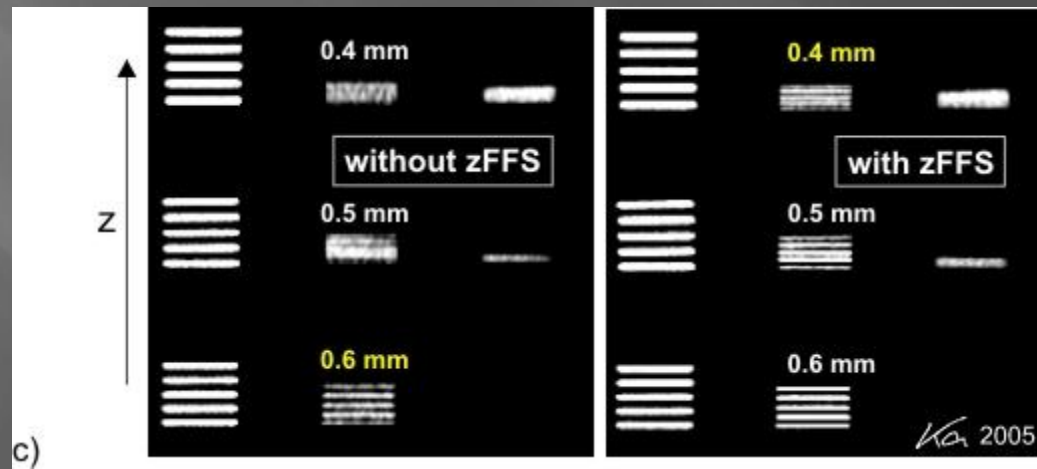
- ▣ In plane
  - x/y axis
- ▣ Through plane
  - Z axis

# Spatial Resolution- in plane

- ▣ Focal Spot Size
- ▣ Detector Size
- ▣ Scanner Geometry
- ▣ Sampling Frequency
- ▣ Reconstruction Algorithm
- ▣ Field of View (FOV)

# FSS

- ▣ Inversely related to detail.
- ▣ Increased detail requires decreased FSS
- ▣ FSS is not a selection made by the technologist it is mA dependant and automatically selected.
- ▣ *Flying Focal spots (Siemens Somatom) allow for slight change in focus, increase in data points and sampling,. Increasing detail in the z axis or through plane.* (3)



# Detector Size/Spacing

- ▣ Inversely related to detail.
- ▣ Increased detail requires decreased size or space between detector elements.
- ▣ Detector size or spacing is not a selection made by the technologist it is dependant on the make and model of CT scanner.

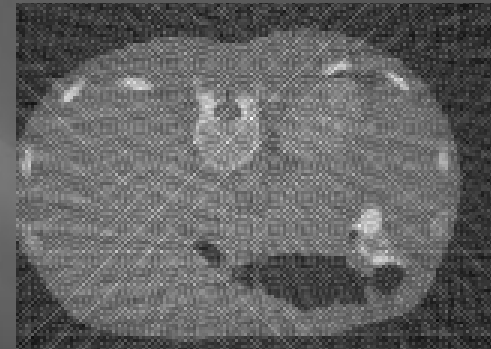
# Scanner Geometry

- ▣ Directly related to detail.
- ▣ Increased detail requires increased scan geometry.
- ▣ Describes the arc or amount of tube movement. Several types. <sup>(2)</sup>
  - One 360            most common, even dose distribution
  - Two 180           average 2 data sets, increased quality
  - One 180           ½ scan, fast, low dose, used in peds
  - One 400           over scan, increased data and quality



# Sampling Frequency

- ▣ Directly related to spatial resolution
- ▣ Increased sampling increases detail in an image
- ▣ Number of projections is also known as the “sampling frequency”
- ▣ This is accomplished by increasing the sampling rate or the speed at which the detectors are read.



128 vs. 1024 projections



# Reconstruction Algorithm

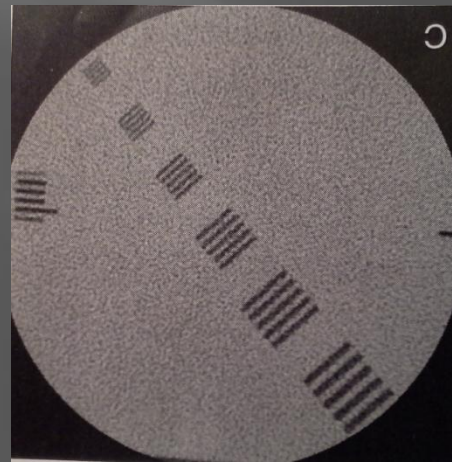
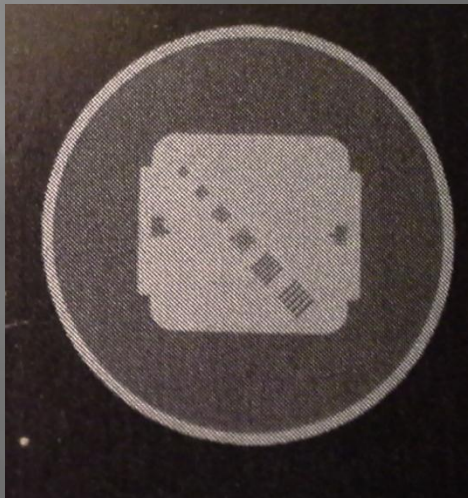
- ▣ Directly related to spatial resolution
- ▣ As the spatial frequency of a filter increases the detail increases.
- ▣ High frequency kernels may be know as “sharp, edge, bone or FC 50+.



# Pixel/FOV/Matrix

- Pixel- inversely related to detail, smaller is better
- Matrix- directly related to detail, bigger is better
- Technologist do not control pixel or matrix directly
- FOV- inversely related to detail, smaller is better
- Technologist controls FOV used for scanning /viewing
- $\text{Pixel} = \text{FOV} / \text{matrix}$

500 mm FOV



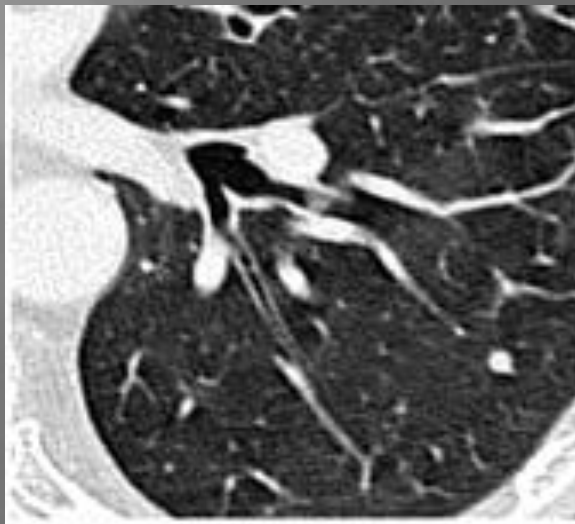
100 mm FOV

# Spatial Resolution- Through plane

- ▣ Slice Thickness
- ▣ Pitch

# Slice Thickness

- ▣ Inversely related to spatial resolution
- ▣ Increased slice thickness, scan or viewing, decreases detail in an image.
- ▣ Thick slices have an increased SSP and more partial volume averaging.

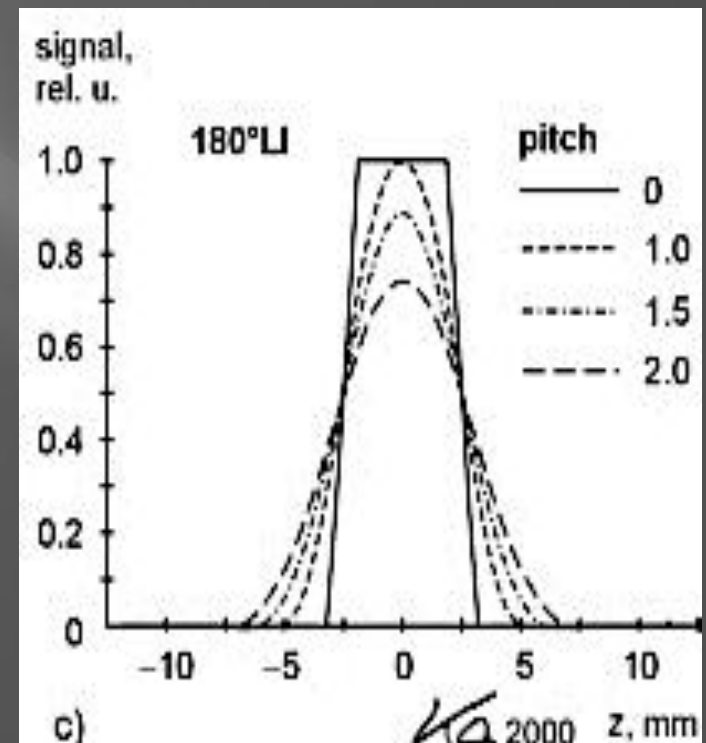


5.0 mm



# Pitch

- ▣ Inversely related to spatial resolution
- ▣ Increases in pitch will result in a decrease in image detail and increase in partial volume averaging,
- ▣ It is important in MSCT to use a pitch that will provide non overlapping spirals, i.e. 4 slice with a pitch of 1.5, we will have interlacing spirals not over lacing.



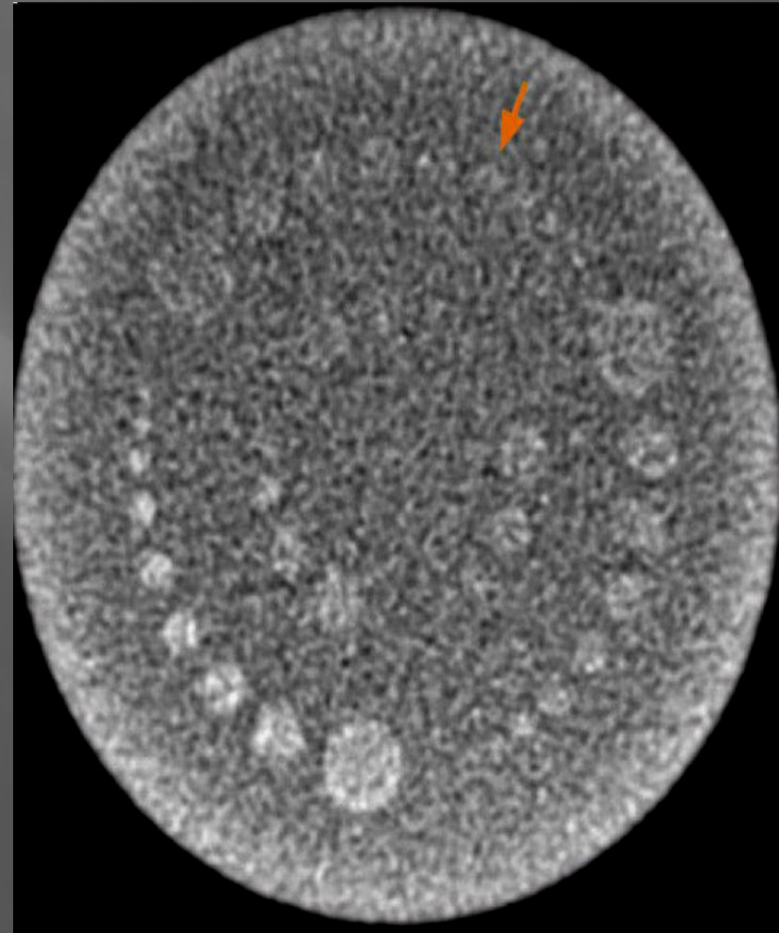
# Contrast Resolution

- ▣ Object Size
- ▣ Object attenuation difference
- ▣ Noise
  - kVp
  - mA(s)
  - Pitch
  - Slice thickness

# Object Size/Attenuation

- ▣ Object Size is directly related to contrast resolution, larger objects are easily visualized.
- ▣ Object attenuation is directly related to contrast resolution, high attenuation objects are easily seen.
- ▣ Small, low attenuating objects are the most difficult to image.

Orange arrow



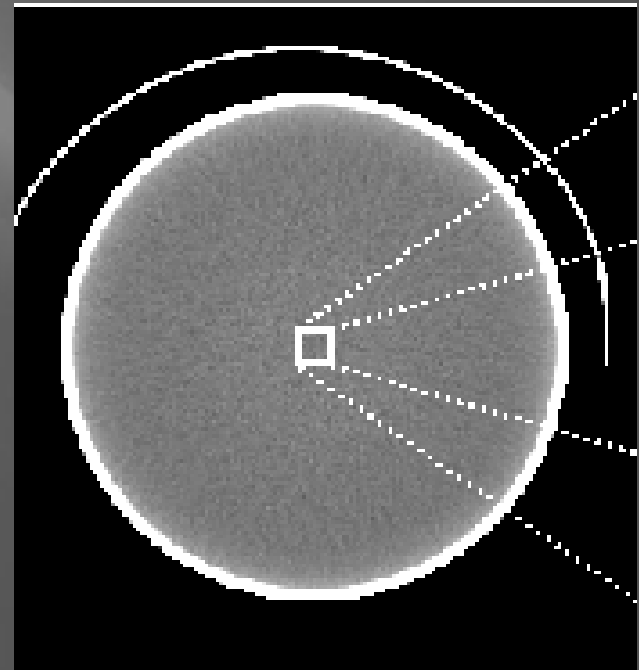
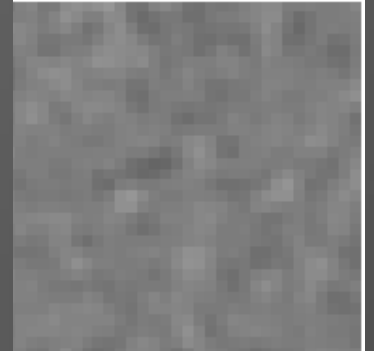


# Noise

- ▣ Variation in pixel values of a homogenous material over a specific area. Often described as a mottle or grainy appearance.
- ▣ Noise is caused by low photon count in an image. Anything that decreases the exposure to the patient, and therefore the detectors will increase noise.
- ▣ Noise is measured with a 20 cm water phantom, taking an ROI and viewing the standard deviation within the area.
- ▣ SD alone cannot fully account for the noise in an image, one can manipulate factors so that the SD is equal between images; however, the perception of noise or quality is very different- this concept is called noise power spectrum. <sup>(2)</sup>

# Noise

- ▣ *mA*
- ▣ *S*
- ▣ *kVp*
- ▣ *Filtration*
- ▣ *Pixel size*
- ▣ *Slice thickness*
- ▣ *Detector efficiency*
- ▣ *Interpolation scheme*



# mA(s)

- ▣ Indirectly related to noise, and directly related to contrast resolution.
- ▣ Increases in mAs, decrease noise and increase the ability to see slight differences in attenuation.
- ▣ To half the noise in an image the mAs must increase 4 fold. i.e. 50 mAs must increase to 200mAs to decrease noise to  $\frac{1}{2}$  the original.
- ▣ mAs is under the control of the technologist.

# kVp

- ▣ Indirectly related to noise, and directly related to contrast resolution.
- ▣ Increases in mAs, decrease noise and increase the ability to see slight differences in attenuation.
- ▣ One must remember that kVp has significant impact on PE absorption and attenuation in the subject.
- ▣ kVp is under the direct control of the technologist, but due to its complex relationship with contrast resolution it should not be a first step to decreasing noise in an examination.

# Pixel/Slice Thickness

- ▣ Indirect relationship with noise.
- ▣ As the slice or pixel size decreases noise will increase and contrast resolution will decrease.
- ▣ Scan slice thickness is often very thin, 1mm. While viewing is thicker, 4mm. Averaging 4 1mm slices into one thick 4mm will increase signal by 4X, but noise will increase  $\sqrt{4} = 2X$ .
- ▣ Thicker slices or larger pixels will have better efficiency with respect to signal to noise.



**1.25 mm**



**5.0 mm**

# Temporal Resolution

- ▣ Rotational speed
- ▣ Specialized reconstruction algorithms
- ▣ Gating studies

# Temporal Resolution

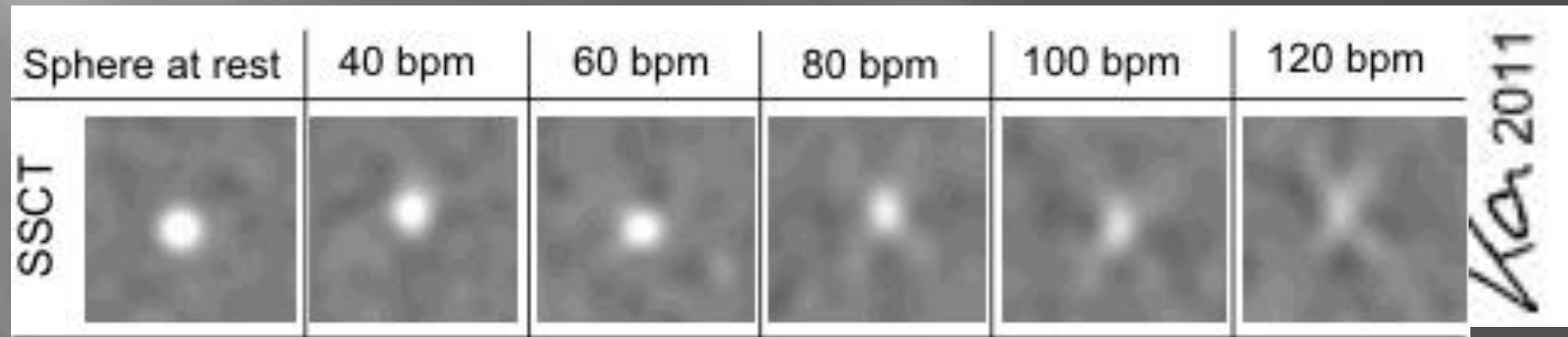
- ▣ Decreasing the affects of subject motion on image quality is best resolved with increased temporal resolution or faster scanning.
- ▣ Decreased rotation times, from 1s to  $\frac{1}{2}$  sec is common. The fastest rotation times available are  $\sim 300\text{ms}$ .
- ▣ Cardiac imaging requires excellent temporal resolution to visualize small cardiac vessels.
- ▣ Specialized equipment and techniques address the time issue in cardiac imaging.



# Segment reconstruction and Gating

- ▣ Cardiac studies are generally performed with a pitch of 0.2. Resulting in 5 images of the same anatomy.
- ▣ Using segments from several rotations to build an image decrease the overall time. For example, 300ms full rotation, using 4 segments for reconstruction decrease image time to 75ms.
- ▣ Gating tags each image to a point in the heart motion. The computer can then select only images from a specific point in the cardiac motion for reconstruction.

- ▣ The image below shows a set rotation time, with a changing heart rate, as the heart rate increase so does the blur. Even at very low heart rates, 40 bpm, motion is evident.



# Image Quality and Dose

- ▣ Image quality and dose are dependent factors
- ▣ Generally to increase image quality, dose increases.
- ▣ Consideration must always be taken when balancing patient dose with a required level of quality.
- ▣ Consultation with a Radiologist and Medical Physicist , will best assist the Technologist in producing acceptable image quality at the lowest dose possible (ALARA).

# CT Dose

CTDI is measured using a acrylic phantom and an ionization chamber, a pencil chamber.

CTDI has several types

## CTDI 100

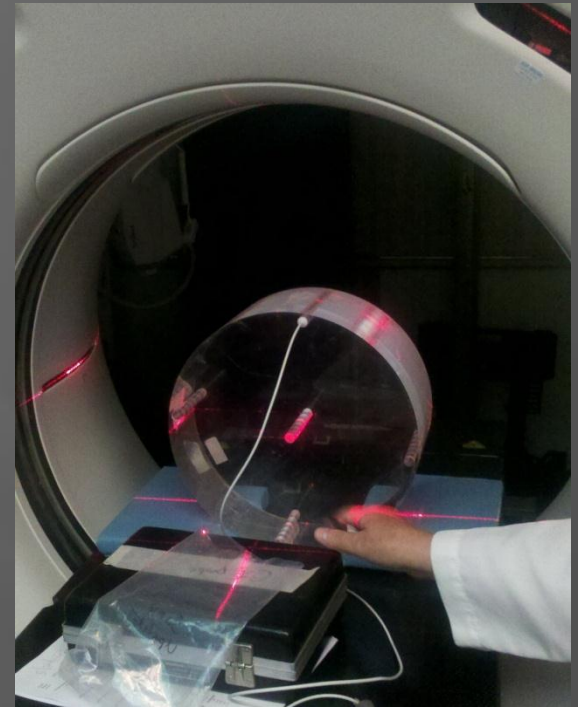
Accounts for a slice and scatter over 100mm

## CTDI<sub>w</sub>

Accounts for increased exposure to the skin surface and decreased exposure to the center

## CTDI<sub>vol</sub>

Accounts for pitch in spiral imaging, increasing pitch decreases the exposure to the patient



# Scanner provided values

- ▣ Most scanners will provide an estimated CTDI vol, prior to the start of a scan.
- ▣ An estimated CTDI vol will be given at the termination of the exam.
- ▣ It is important to remember that these are estimates and NOT patient dose.
- ▣ Patient dose maybe estimated using the AAPM report 204 and scanner generated CTDI
- ▣ An additional value is DLP, this is the CTDI vol \* the scan length.
- ▣ CTDI is useful in comparing scanner to scanner or protocol to protocol. It is most often used in accreditation and QC of a scanner.

# Scanner provided values

- ▣ CTDI reports scanner output, the question is what amount of tissue is that going into.
- ▣ For the same CTDI vol, a small patient will have a higher dose. –more radiation, less tissue.
- ▣ CTDI vol tends to overestimate dose to a large patient and underestimate for small patient.
- ▣ CTDI vol is a helpful metric, it is not the whole picture.

# ACR CTDI Guidelines

- ▣ Adult
    - Head 75 mGy
    - Abdomen 25 mGy
  - ▣ Pediatric
    - Abdomen 20 mGy
- (4)

# Dose Factors

## ▣ Filtration

- Decreases dose by filtering low energy rays 2.5mm Al minimum, most units have 6-9 mm AL, proper filtration also decreases beam hardening artifacts
- Technologist only control the beam shaping filter by selecting the correct head or body protocol.



# kVp

- ▣ Increasing kVp without a corresponding decrease in mAs, increases patient dose.
- ▣ 140kVp increases dose by 47% compared to 120 kVp .
- ▣ However, if mAs is decrease appropriately dose is reduced by 20%.
- ▣ Lower kVp should be selected for angiography due to high subject contrast. Increased noise may be tolerable in high subject contrast areas.

# mAs

- ▣ Increased mAs, mA or a decreased rotation time, increases patient dose.
- ▣ Adjusting the mAs patient size is important for dose and quality. If the patient is 3-4 cm smaller than the norm, decrease mAs by half.
- ▣ This illustrates how great a decrease in mAs is needed for children and small adults.

# Detector Configuration

- ▣ Thin slices, increase dose as more need to be taken to cover a set area and increased mAs is required to maintain noise levels.
- ▣ Thick slices decrease dose, less slices needed with less mAs.
- ▣ Radiation is most efficiently used with larger number of slices taken per rotation.
  - 16 , 1.25 mm slices are more dose efficient than 4, 1.25mm slices. (5)

# Pitch or Increment

- ▣ Pitch refers the ratio of table feed to beam width. When they are equal there is no gap or overlap in radiation.
- ▣ Increment is used in axial imaging, again it is a ration of the slice thickness to table feed. It describes if slices are contiguous, overlapping or leaving gaps.
- ▣ Overlap increases patient dose, where gaps decrease dose.

# Dose Modulation

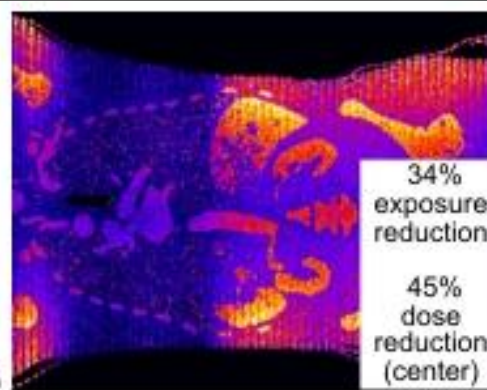
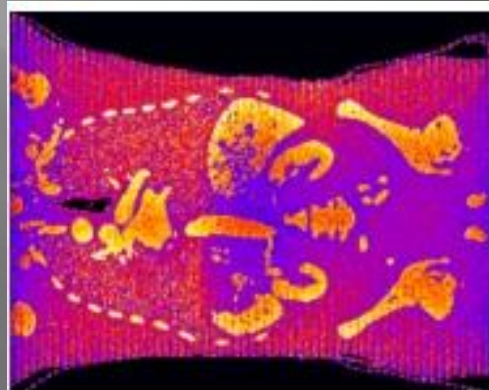
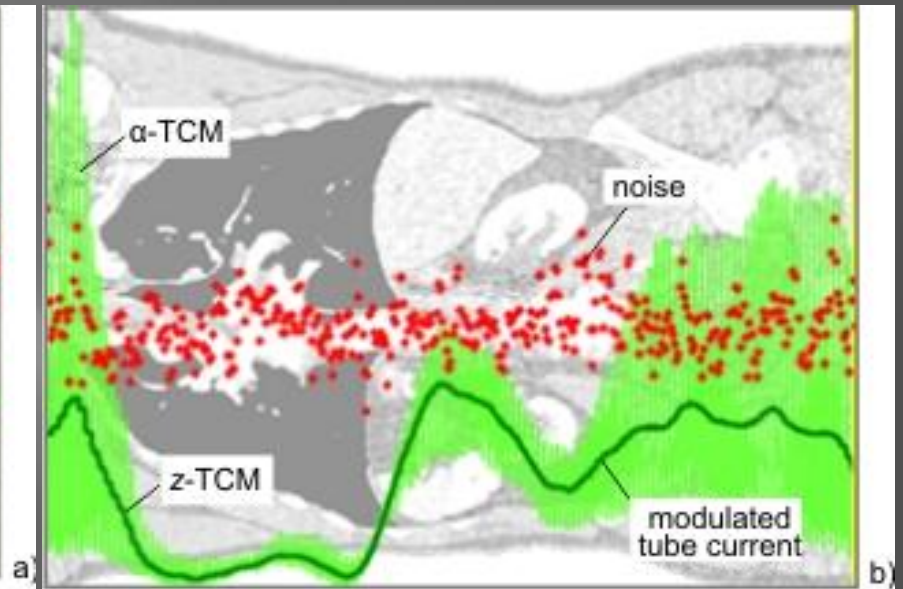
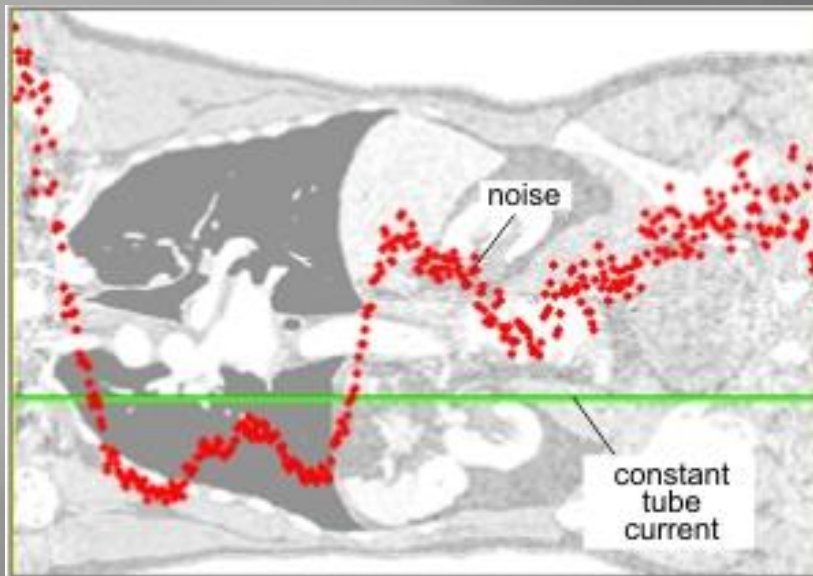
- ▣ Similar in nature to AEC in radiography, mA or dose modulation software will vary the exposure over various body parts to maintain image quality.
- ▣ As with radiography, patients must be positioned properly in the gantry, have no metal implements and shields must not be in the FOV.
- ▣ For an abdomen a ~5 cm off center in the X axis would result in ~30% increase in dose. A y axis miss center of ~4 cm would result in a ~75% increase in dose
- ▣ The mAs is set both at a minimum and maximum level. The software then varies the mAs for the anatomy and view being acquired.

# Automatic Tube Current Modulation

- ▣ May be called many things by different manufacturers. The mAs can be modulated in plane X/Y, angular modulation or through plan, z axis.
- ▣ Image noise level is selected and the mAs is modulated to maintain quality while saving on dose.
- ▣ Angular Modulation (ap vs. lat)
  - Smartscan- GE
  - DOM-dose-Phillips
  - CareDose- Siemens
- ▣ Angular-Longitudinal Modulation (ap vs. lat and changing anatomy over the z-axis)
  - Smart mA- GE
  - Z-DOM -Phillips
  - CareDose 4D- Siemens
  - SureExposure- Toshiba



# Dose vs. Noise



34%  
exposure  
reduction  
  
45%  
dose  
reduction  
(center)

1/2011

# References

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- ▣ 2. Computed Tomography 3rd, Seeram 2009, Elsevier Publishing.
- ▣ 3. Computed Tomography 3<sup>rd</sup>, Kalendar 2011, Publics Publishing.
- ▣ 4. [www.acr.org](http://www.acr.org)
- ▣ 5. AAPM Computed Tomography Radiation Dose Education Slides 9/6/12