CORSO DI LAUREA
TECNICHE DI RADIOLOGIA MEDICA, PER IMMAGINI E RADIOTERAPIA

CORSO INTEGRATO
«RADIODIAGNOSTICA II – RMX013»

ANNO ACCADEMICO 2023/2024

Formazione per l'eccellenza

Gemelli

UNIVERSITAS CATHOLICA SACRI CORDIS JESU MEDIOLANI

Insegnamento:
TECNICHE DI IMAGING TC E ANGIOGRAFICO
RMX055 - 25 ore MED/50 CFU 2

gen. '24

2° anno I semestre

Fondazione Policlinico Universitario Agostino Gemelli IRCCS
Università Cattolica del Sacro Cuore

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RADIATION DOSE MANAGEMENT IN CT

Gemelli

gen. '24

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Radiation Dose Management in Computed Tomography

https://elearning.iaea.org/m2/course/index.php?categoryid=147

https://rpop.iaea.org/RPOP/RPoP/Content/AdditionalResources/Training/E-learning/index.htm

IAEA | Learning Management System
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IAEA

Welcome to Radiation Dose Management in CT!

This e-learning program is designed to provide continuing education to medical imaging professionals regarding safety and quality in computed tomography (CT).

Throughout this e-learning course the participants are expected to:

1. Learn the appropriate use of CT;
2. Understand the various CT techniques and scan parameters;
3. Understand CT dose metrics and tracking methods;
4. Address the needs of creating various CT protocols, including those for chest, abdomen, and head, as well as those for paediatric patients; and
5. Understand how to optimize exposure during pregnancy.

The estimated time for the entire course is 5 hours maximum. After completing the course, participants can take the final exam to receive a certificate of attendance. This e-learning course is provided in English.

CERTIFICATE OF COMPLETION

This is to certify that

MARINO GENTILE

has completed the course

Radiation Dose Management in Computed Tomography

April 17, 2017

This certificate has been issued based on the completion of the IAEA online training course.

RADIATION DOSE MANAGEMENT IN CT

MENU

TUBE CURRENT (mA)

- Represents number of electrons flowing through the X-ray tube per unit time
- Measured in milliamperes (mA)
- The photons emitted (photon fluence) from the focal spot per unit time is proportional to mA
- Tube current time product (mAs)
  - Tube current x gantry rotation time in seconds
  - Effective mAs or mAs/slice = mAs/pitch
- Most commonly adjusted scan parameter to increase or decrease radiation dose.
  - 50% mA reduction results in 50% dose reduction #
  - 50% mA increase results in 50% dose increment #

TUBE CURRENT (mA)

- Can be fixed over entire scan range (fixed mA)
- Can be automatically adjusted over the scan range (automatic exposure control or AEC)
- Different CT scanners have different mA limits
  - Some can operate at much higher mAs than others

GE	Philips	Siemens	Toshiba
mA	mAs/slice	Effective mAs	mA

TUBE POTENTIAL (kV)

- Represents potential difference between cathode and anode, which drives electrons across X-ray tube
- Unit is kilovoltage (kV)
- Affects both the quality & quantity of the generated X ray spectra
- There is non-linear relationship between kV and dose
- Dose changes by the square of kV change#
- Most scanners require users to specify a fixed kV for CT protocols
  - Generally, smaller patients (particularly children) should be scanned at low kV (70-100 kV)
  - Generally, CT angiography or contrast enhanced CT can be scanned at low kV (80-100 kV)
- Some CT have automatic kV selection where CT scanner picks up the right kV.
  - Care kV (Siemens)
  - kV Assist (GE)

If all other scan parameters are held constant

TABLE MOVEMENT

Table Increment (mm)

- Term used for table travel in Axial scanning mode
- Represents distance travelled by the table in one 360°rotation of tube

GE	Philips	Siemens	Toshiba
Interval	Increment	Feed	Couch Movement

Table Feed (mm/rotation)

- Term used for table travel in Helical scanning mode.
- Represents distance travelled by the table in one 360° rotation of tube

GE	Philips	Siemens	Toshiba
Speed	Table Speed	Table Feed	Couch Speed

PITCH

Beam Pitch

- Table feed (mm) divided by the width of collimated beam (mm)
  - Beam Pitch: Table feed / X-ray beam collimation

Slice Pitch

- Table feed divided by selected detector width
  - Slice Pitch: Distance in mm/ detector collimation in mm
  - (Detector collimation = width of each effective data channels * number of detector rows)

GE	Philips	Siemens	Toshiba
Pitch	Pitch	Pitch	CT Pitch factor

PITCH: CONSIDERATIONS

- Pitch is now a small factor in dose for modern MDCT

  - Scanners are dose efficient

  - Some CT change mA to compensate for pitch change
    - Higher pitch: higher mA - similar dose – faster scanning #
    - Lower pitch: lower mA - similar dose – slower scanning #
    - Example: Siemens and Philips

  - Other CT partially change mA to compensate for pitch change
    - Higher pitch: lower dose – faster scanning #
    - Lower pitch: Higher dose – slower scanning #
    - Example: GE and Toshiba

DETECTOR ARRAYS

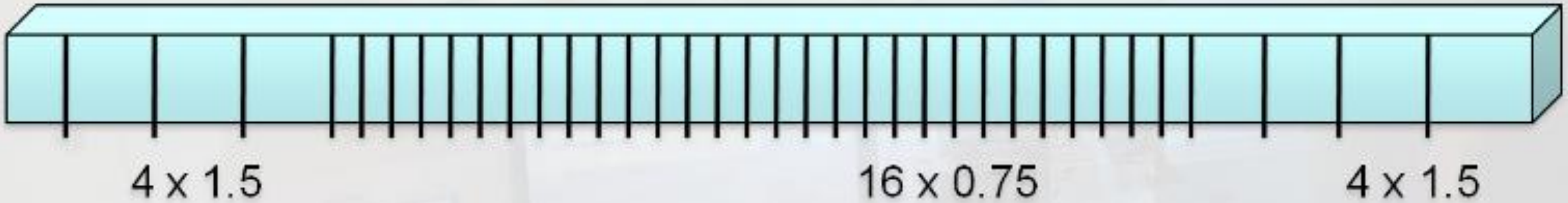
- Detector arrays can be fixed or variable in configuration.

Fixed detector array: Each detector row has same width
Ex: GE 64 slice CT
64 detector rows each 0.625mm thick

Variable detector array: Central rows are thinner than outer.
Ex: Siemens 16 slice CT
16x0.75mm (central) with 4x1.5mm on outer sides

DETECTOR CONFIGURATION

Represents number of data channels along patient length (or z-axis) multiplied by the effective detector row thickness of individual data channel.



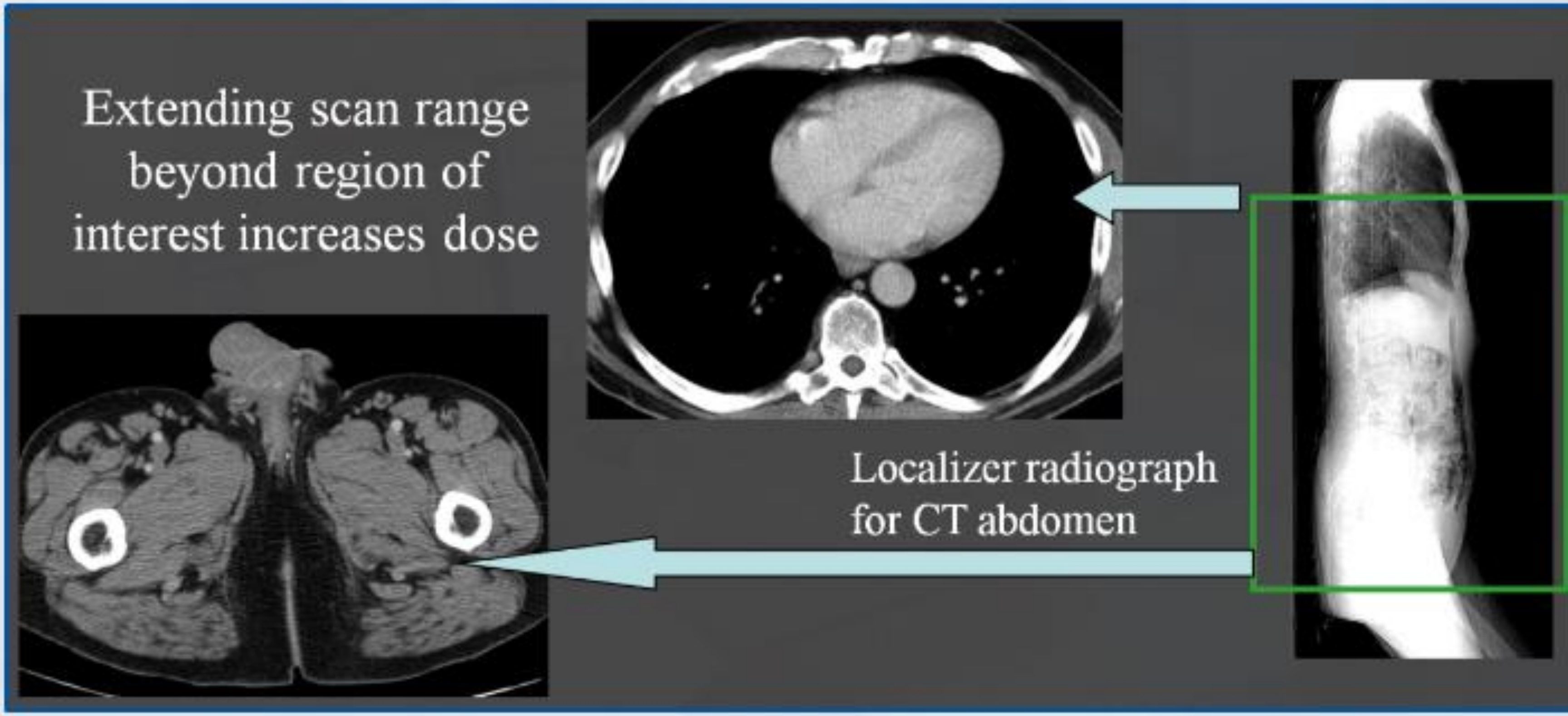
GE	Philips	Siemens	Toshiba
Detector configuration	Collimation N X T (mm)	Detector Configuration	Detector Configuration

GANTRY ROTATION TIME

- Time needed for X-ray tube and detector array to complete one 360° rotation
- Different scanners have different minimum rotation times: 0.25 seconds is the lowest at the time of publishing this presentation
- Faster gantry rotation: Faster scanning
  - Children
  - Moving patients (uncooperative)
  - Moving organs (heart)

SCAN LENGTH

- Dose increases with increase in scan length
- Scanning must be restricted to what is essential



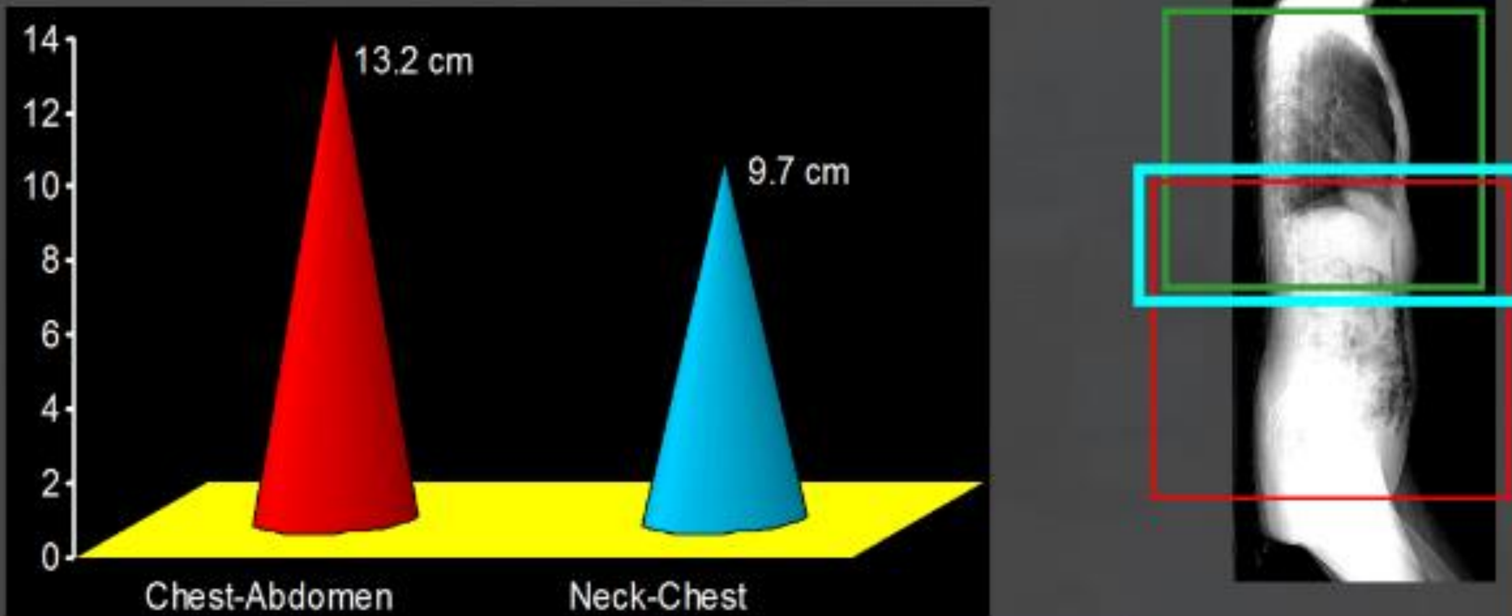
SCAN LENGTH

- 95% of CT abdomen have extra images acquired beyond the area of interest.
- Study showed that 1280 extra images were acquired in 106 patients equivalent to that in 12 -16 CT exams!
- Limit scan to intended anatomic area to cut dose by 10%
  - Abdomen-pelvis:
    - Just above diaphragm – Inferior pubic symphysis
  - Chest:
    - Routine: Apex to adrenals
    - Pulmonary embolism: Apex to lung bases

Kalra MK, et al. Radiology 2004
Campbell J, et al. AJR 2005

LENGTH OF OVERLAP SCANNING

Minimize overlap when scanning two contiguous body regions.



	Chest-Abdomen	Neck-Chest
Overlap scanning	100% (100/100)	100% (49/49)
Overlap scan range	7-18.5 cm	6-15.5 cm
Mean overlap scan	13.2 cm	9.7 cm
Total overlap scan	1,317 cm	476.5 cm

SLICE THICKNESS

- Choice of slice thickness depends on the clinical indication and body region being scanned.
  - Thin slice: higher noise > higher contrast > less partial volume artifact
    - Suitable for high contrast and subtle abnormalities
  - Thicker slice: less noise > more artifacts
    - Suitable for low contrast and large patients

IMAGE THICKNESS AND LUNGS: NOISE AND DETAILS

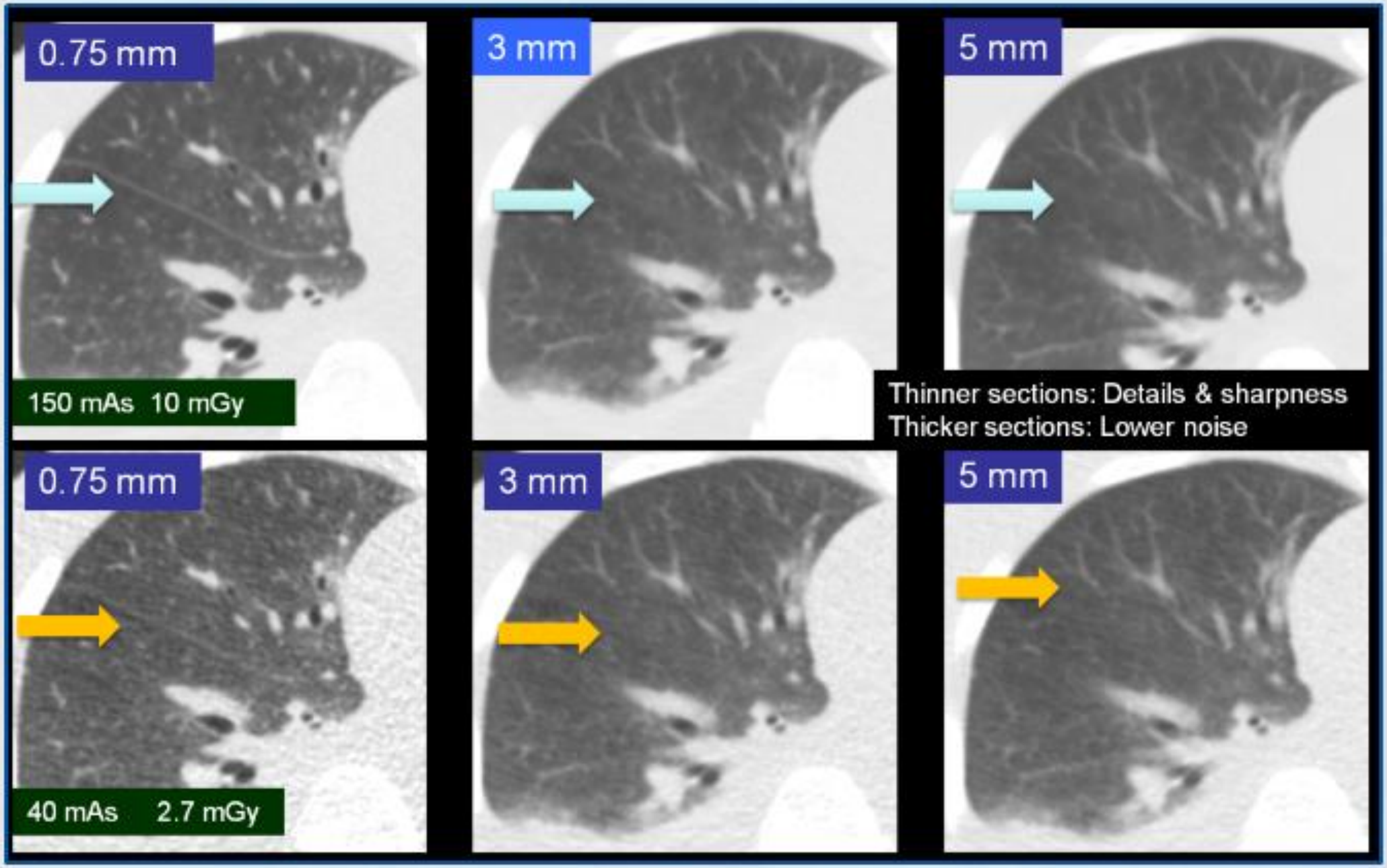
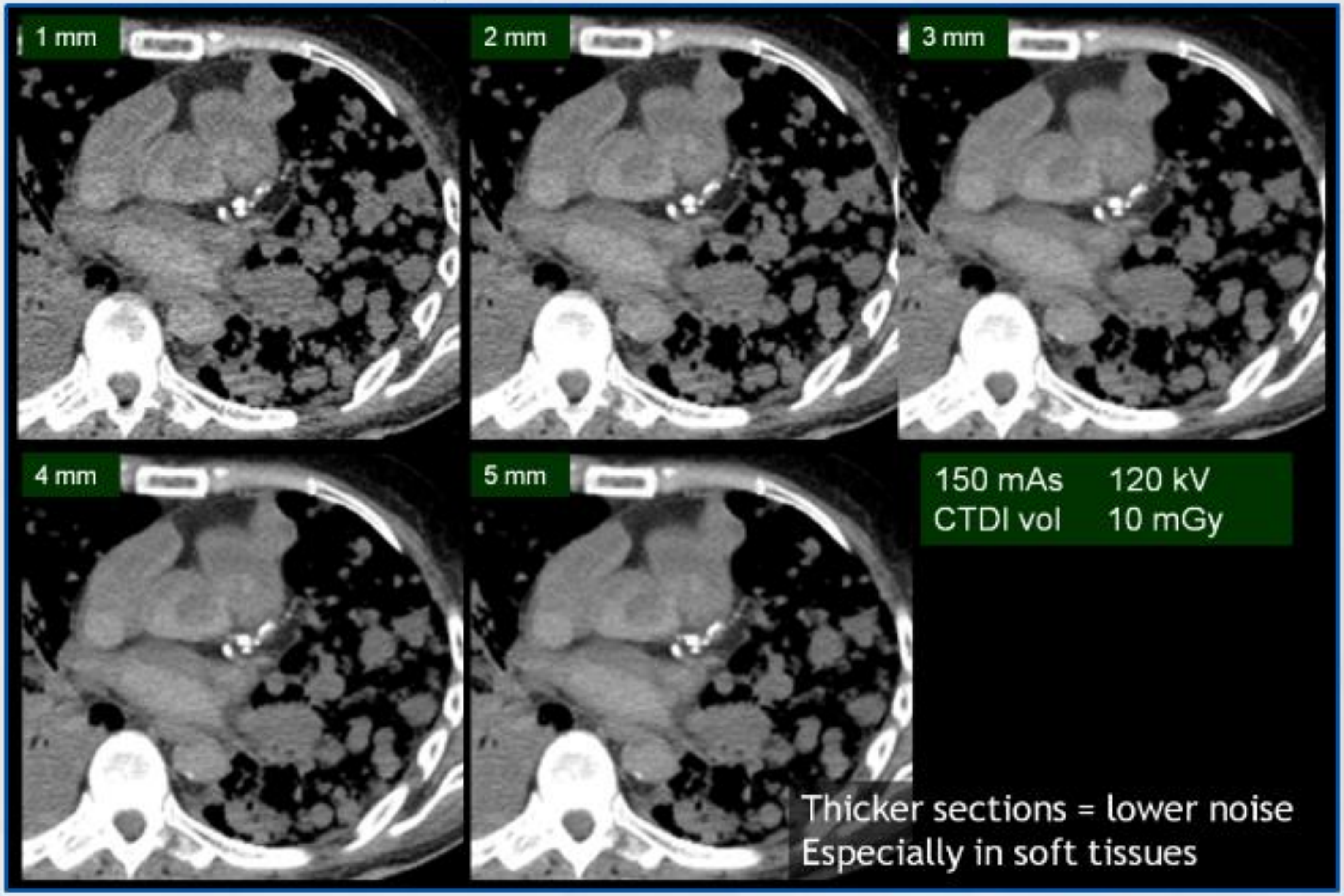


IMAGE THICKNESS AND MEDIASTINUM: NOISE



RECONSTRUCTION KERNEL

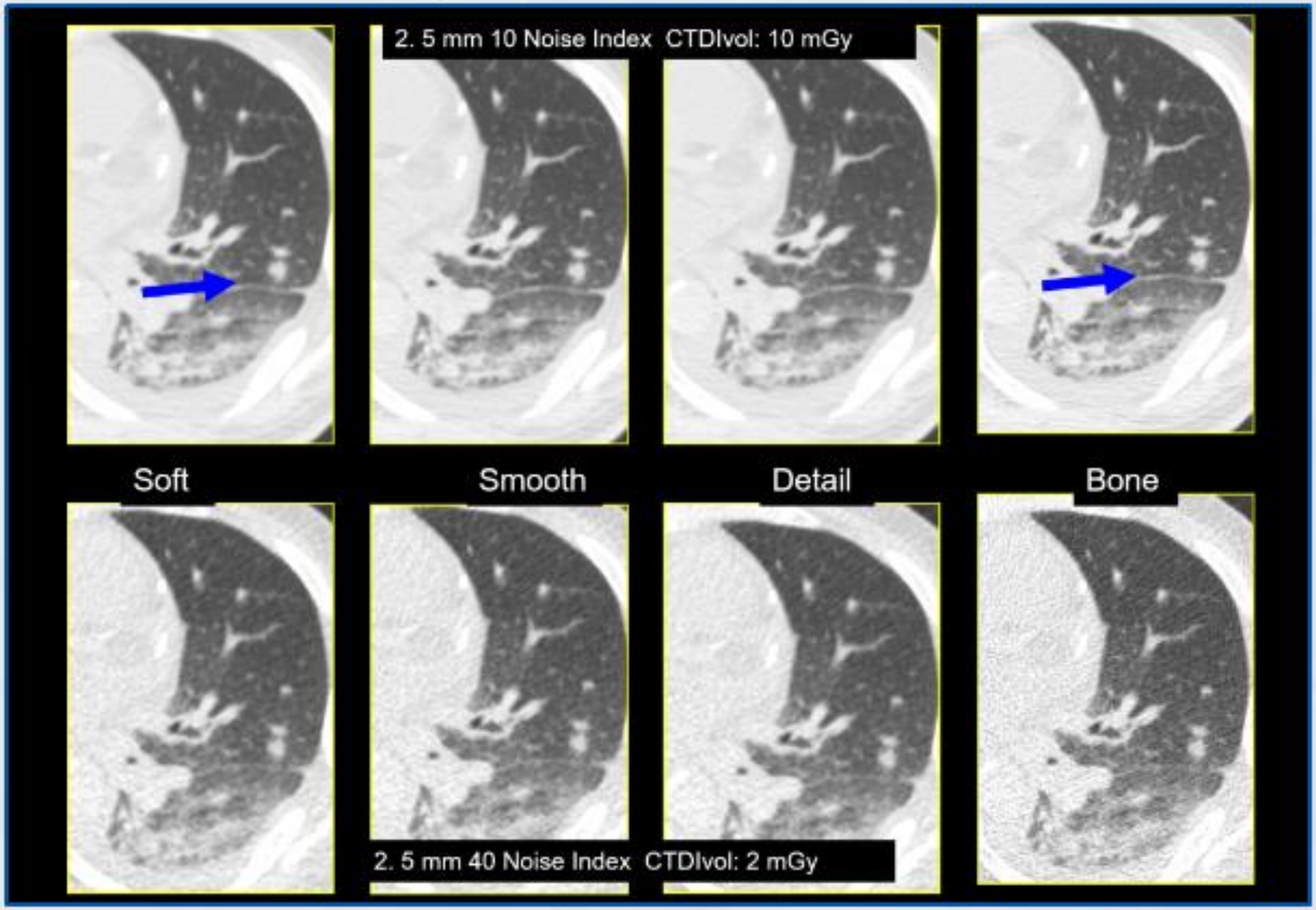
Represents a feature on the scanner which influences the smoothness and sharpness of images in transverse plane

B20 — B31 — B50 — B70

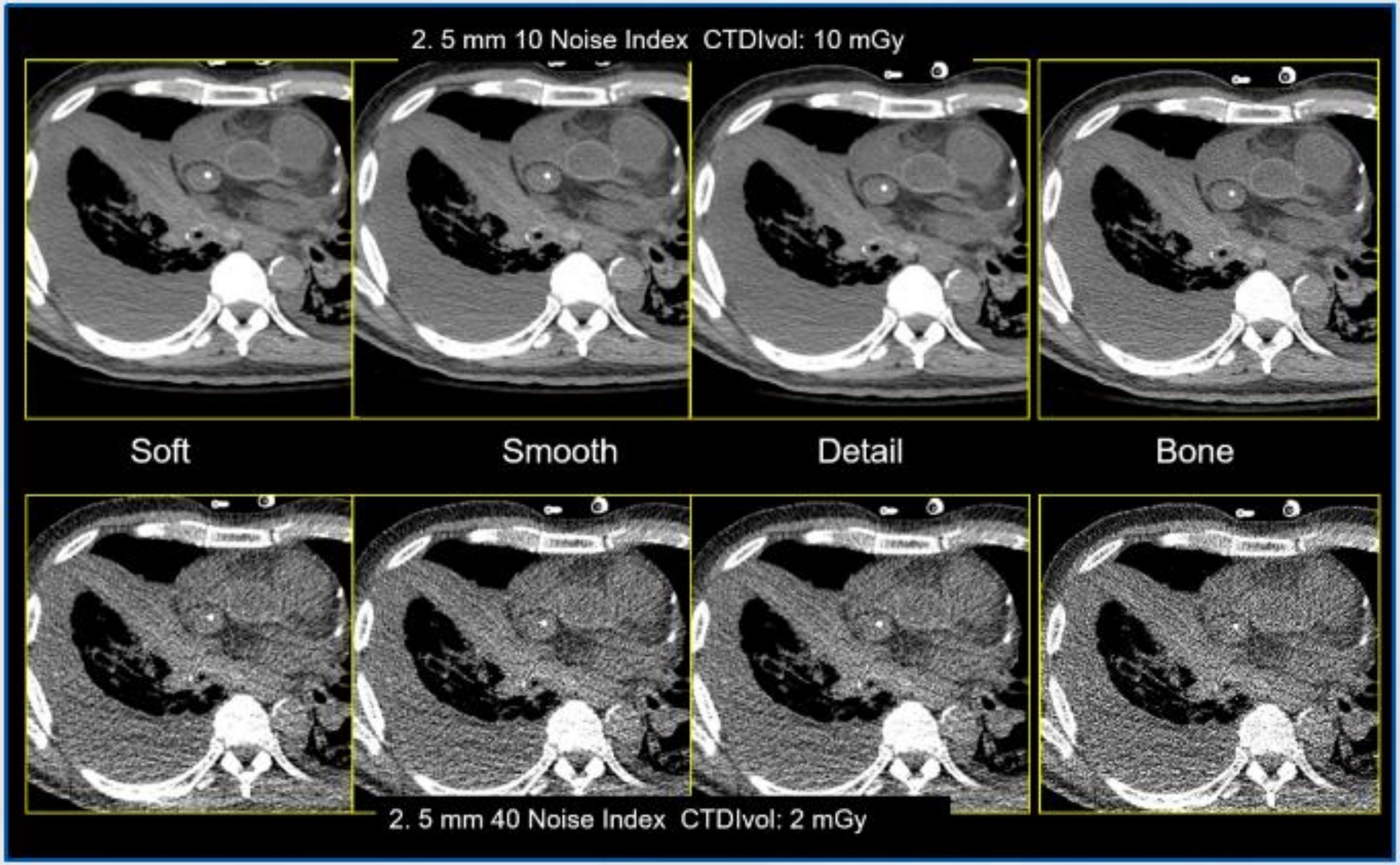
Lower noise	→	Higher noise level
Poorer edge delineation		Better edge delineation
Better contrast		Poor contrast

Standard — Details — Lung

RECONSTRUCTION KERNEL & LUNGS: NOISE AND DETAILS



RECONSTRUCTION KERNEL & MEDIASTINUM: NOISE

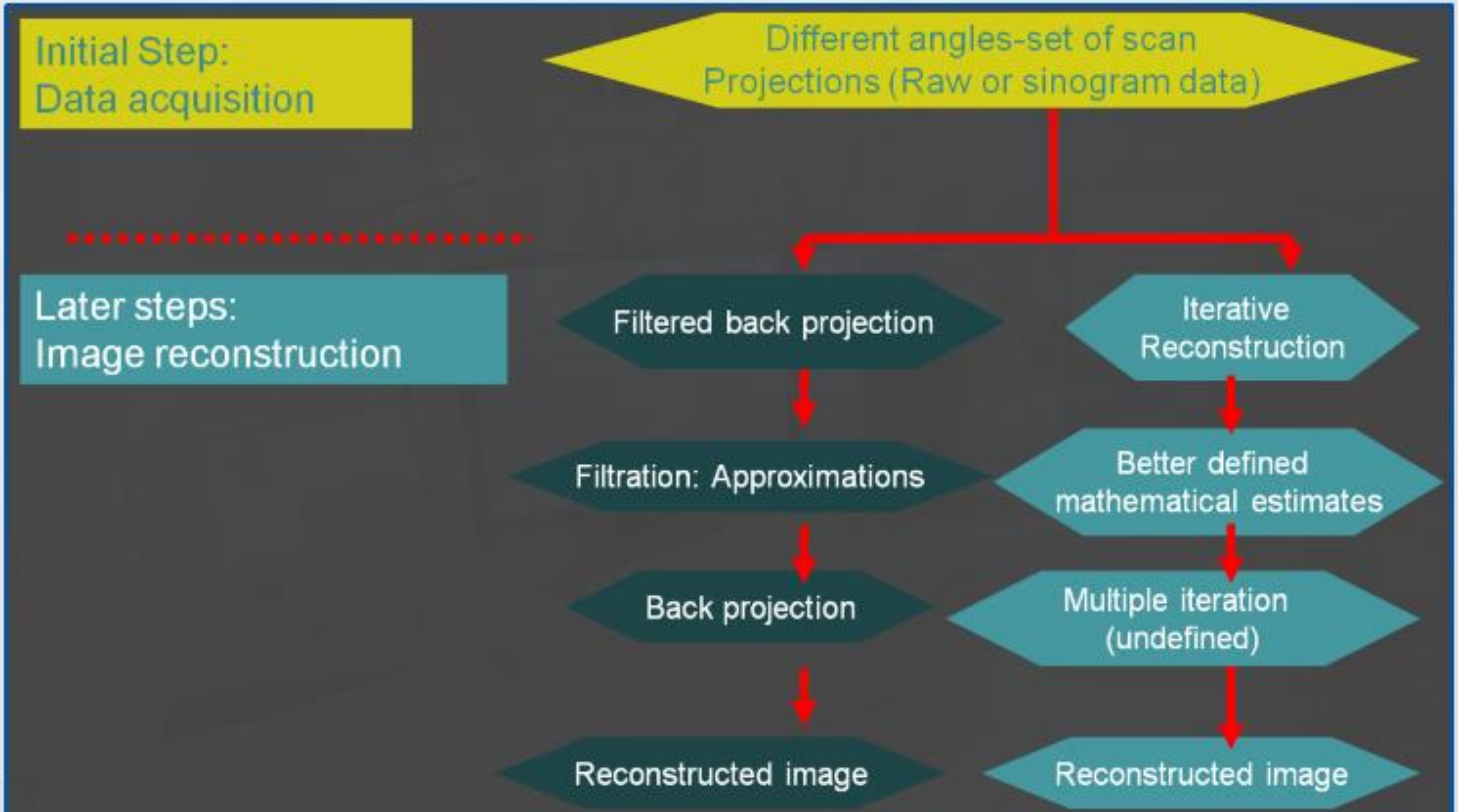


RECONSTRUCTION TECHNIQUES

- Analytical image reconstruction (filtered back projection, FBP):
  - image reconstruction algorithm which back projects the sinogram to the 2D image domain, keeping few workable assumptions
  - More prone to increased noise and artifacts at low dose.
  - Fast way to reconstruct CT images

- Iterative image reconstructions (IRT) are newer techniques
  - incorporates better mathematical CT model and iterates to reduce inconsistencies in the image reconstruction
  - Lower noise and artifacts at low dose.
  - Generally slower than FBP

IMAGE RECONSTRUCTION



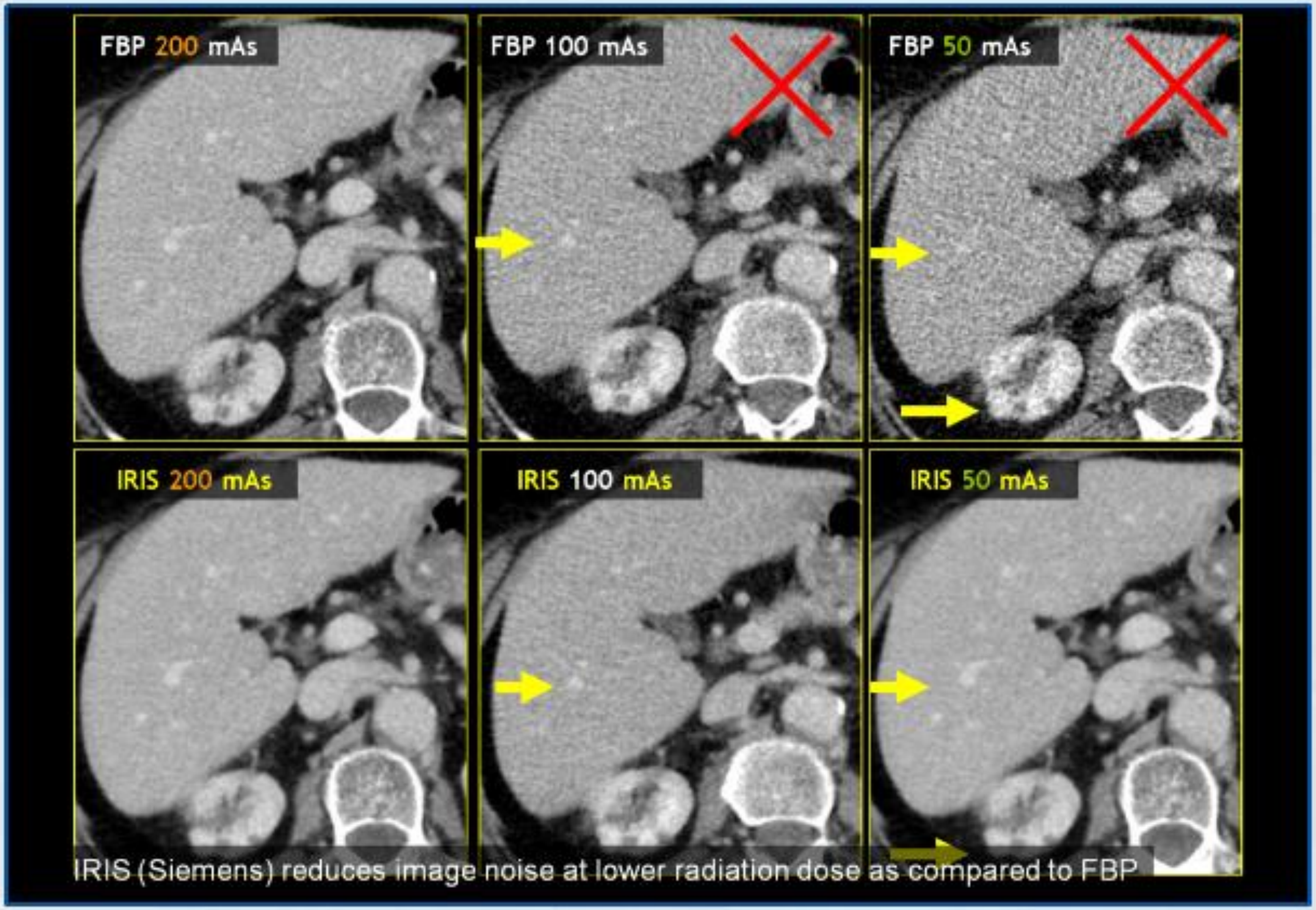
ITERATIVE RECONSTRUCTION TECHNIQUE (IRT)

- Most IRT result in changes in image appearance compared to FBP
- Most IRT come in different strengths of noise reduction potential
- Initial implementation of IRT should generally start at low strength
- IRT do not reduce dose by itself but rather allow user to reduce dose compared to FBP

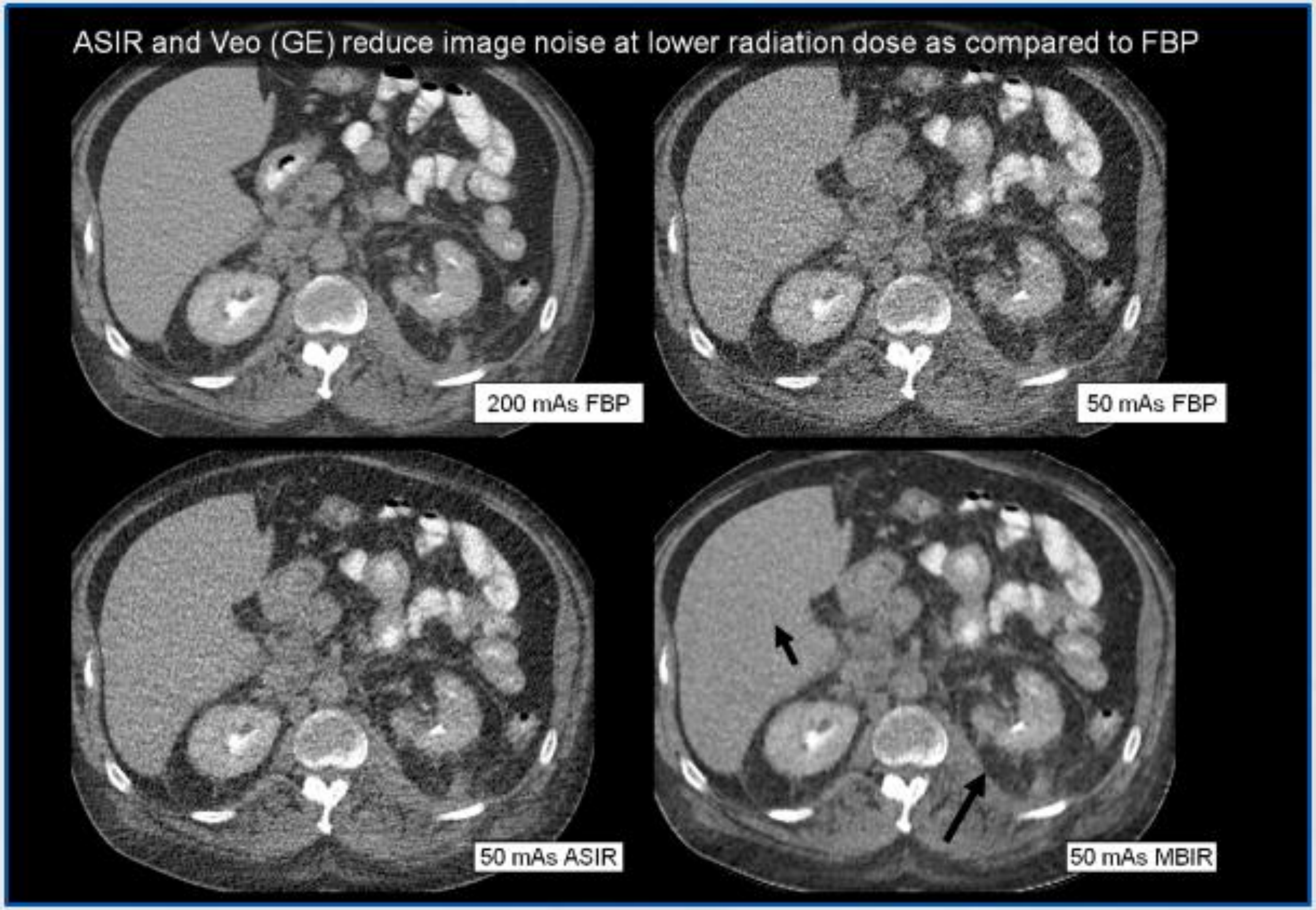
ITERATIVE RECONSTRUCTION TECHNIQUE (IRT)

GE	Philips	Siemens	Toshiba
ASiR Veo ASiR-V	iDose IMR	IRIS Safire Admire	AIDR AIDR 3D
ASiR level is selected at 10% increment (10-100%) with increasing percentage associated with lower noise	iDose level can be set on a scale of 1-7 with increasing number suggesting lower noise	These techniques work on a five point scale (1-5) with increasing number associated with lower noise	Three settings (mild, standard, strong) represent increasing strength of noise reduction.

IRT HELP REDUCE NOISE IN LOW DOSE IMAGES



IRT HELP REDUCE NOISE IN LOW DOSE IMAGES



TUBE CURRENT (mA)

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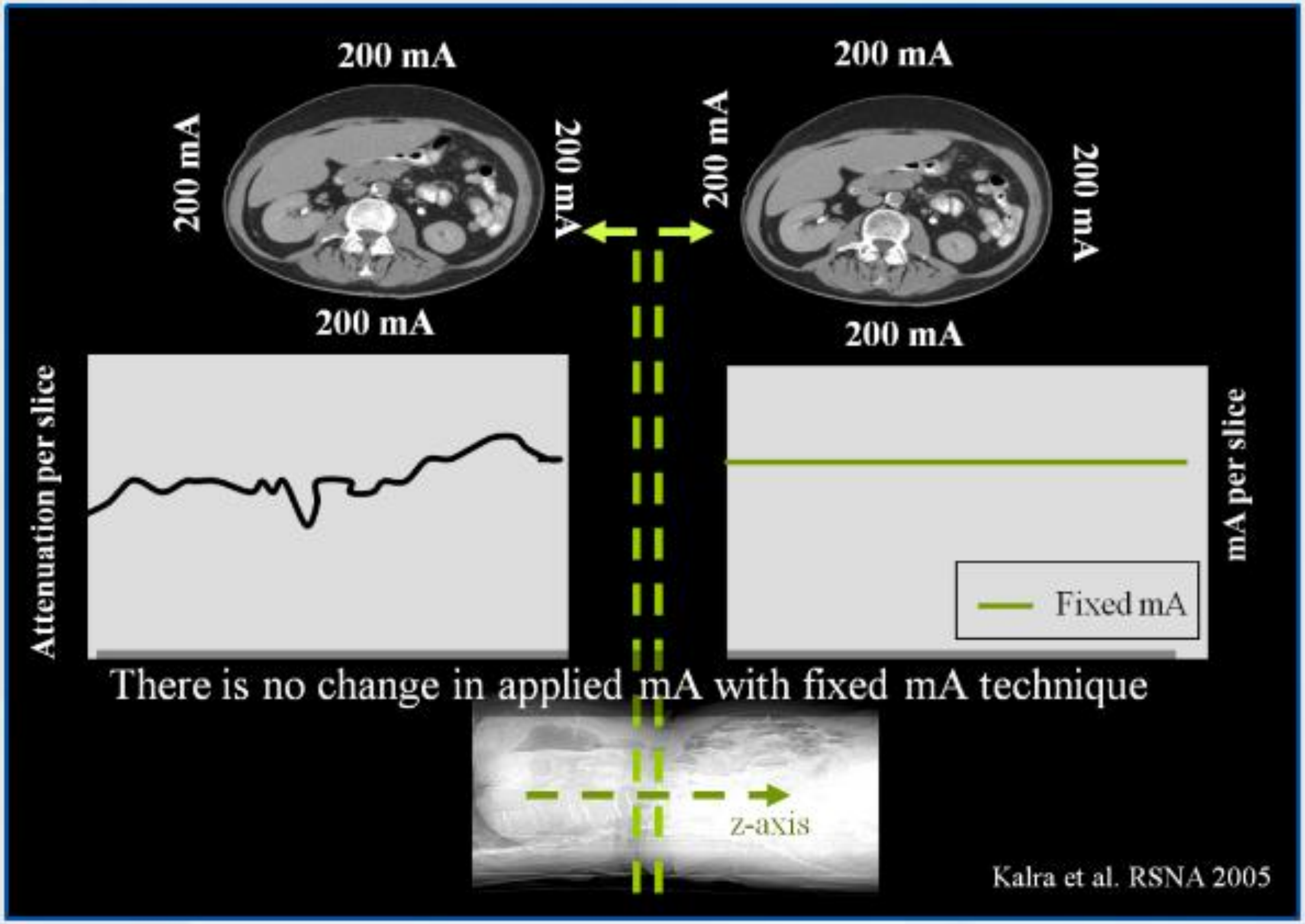
GE	Philips	Siemens	Toshiba
mA	mAs/slice	Effective mAs	mA

FIXED mA


200 mA
200 mA
200 mA
200 mA
200 mA
200 mA
200 mA
200 mA
Attenuation per slice
mA per slice
Fixed mA
There is no change in applied mA with fixed mA technique
z-axis
Kalra et al. RSNA 2005

AUTOMATIC EXPOSURE CONTROL (AEC)

- Defined as a set of techniques that enable automatic adjustment of the tube current in the x-y plane (angular modulation), along the z-axis (z-axis modulation), or both (combined modulation) according to the size and attenuation characteristics of the body part being scanned and achieve constant CT image quality with lower radiation dose.

- Analogous to the automatic exposure-control or photograph-timing techniques used in conventional radiography

- Adjust mA to better indicators of patient size than weight and cross-sectional diameters

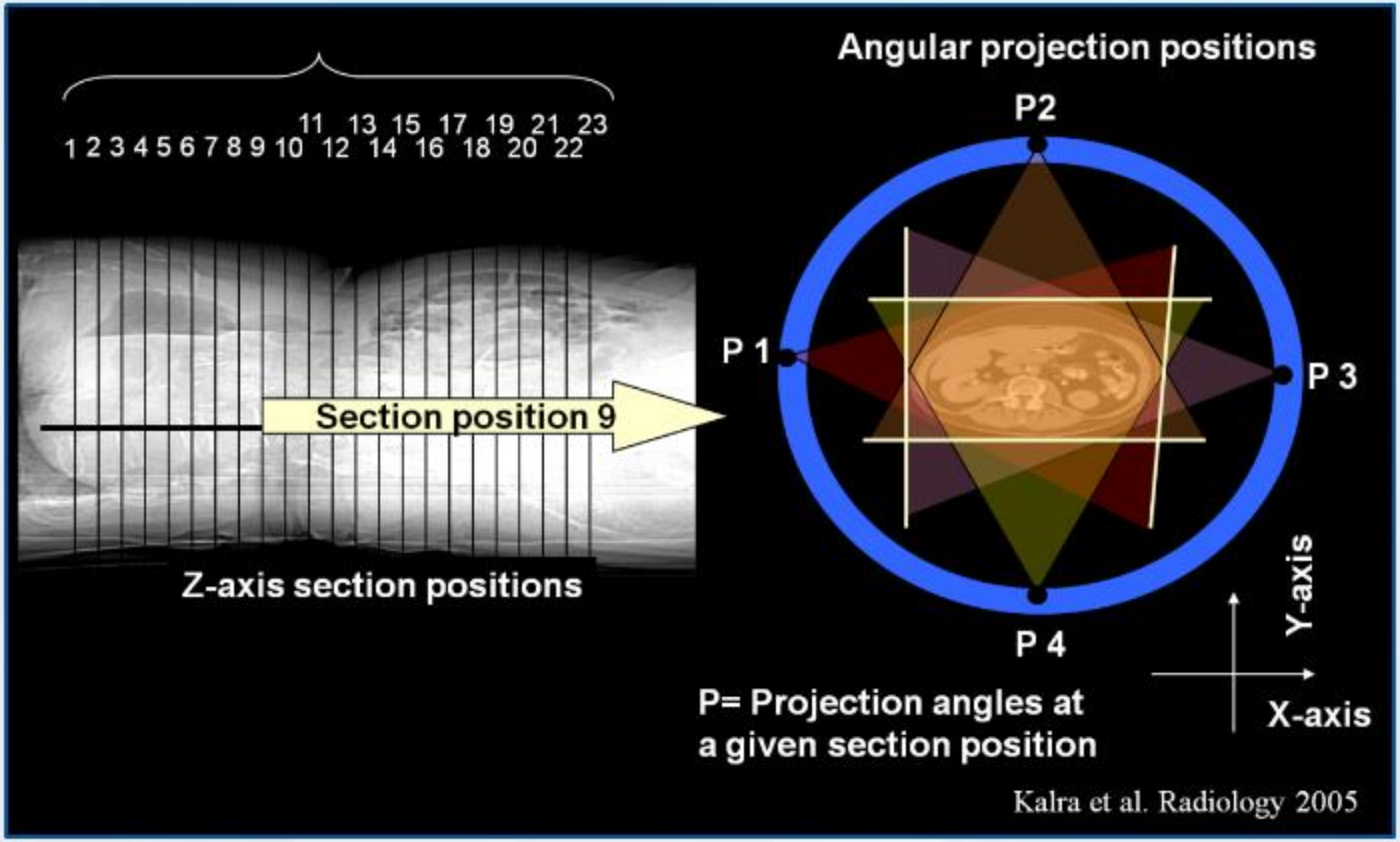
- These are generally attenuation profile:
  - Patient cross-sectional dimension
  - Attenuation or "density"

- Word "automatic" is a "misconception"

- AEC requires important user input to operate optimally

- AEC changes mA to selected slice thickness, pitch, kVp

PROJECTIONS AND POSITIONS



AUTOMATIC EXPOSURE CONTROL (AEC)

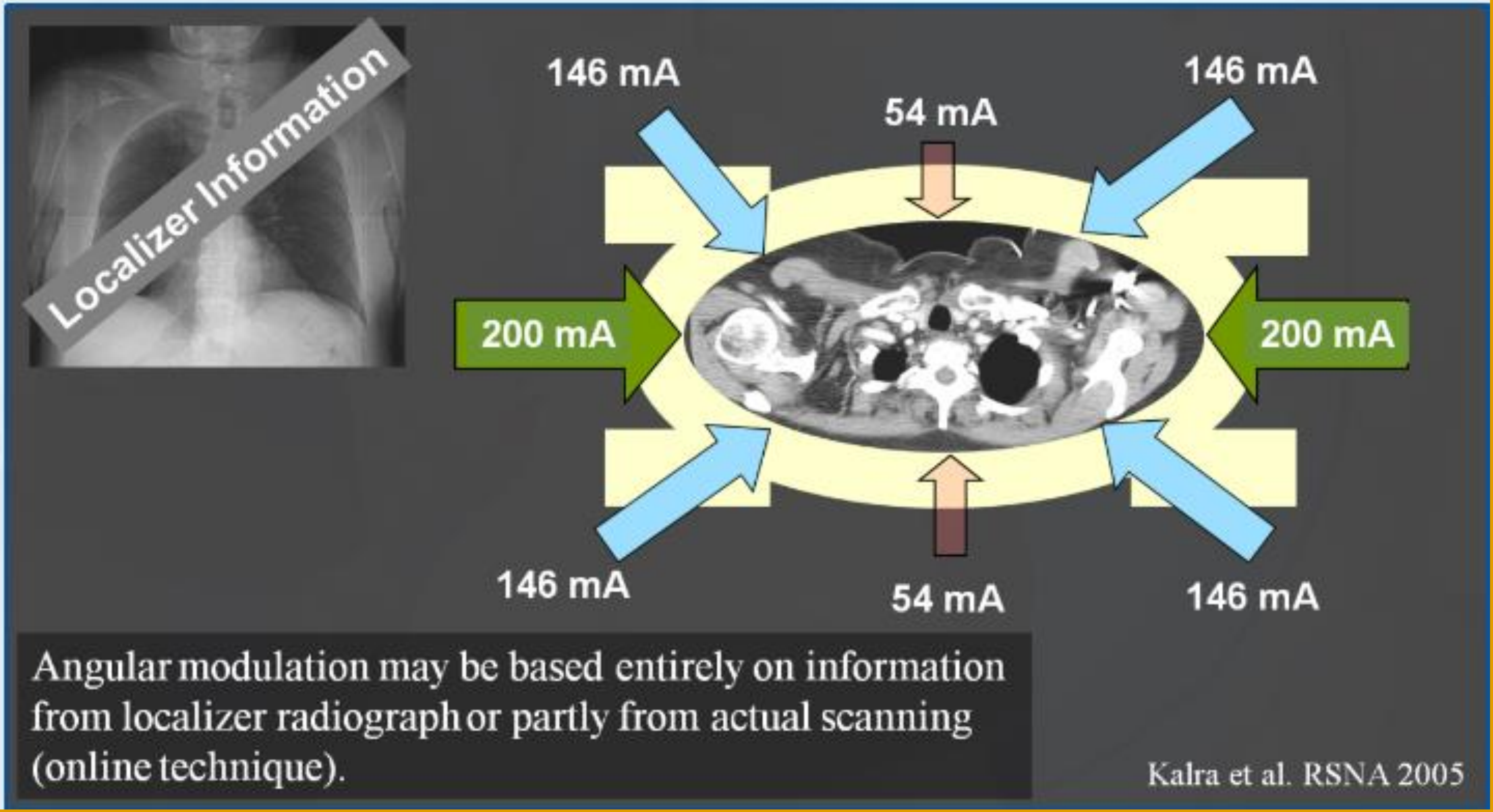
- Maintains image quality (noise) by adapting current to changing body size and attenuation.
  - Slice-to-slice (longitudinal or z-axis modulation)
  - Within each slice (angular or x-y modulation)
  - Both: z- and angular- (xyz/combined modulation)
  - ECG modulated tube current or ECG pulsing

AEC TECHNIQUES

Vendors	Z-axis	Angular	Combined
GE	Auto mA	Smart mA	Auto mA 3D
Philips	Z - DOM	Dose right dose Modulation (DOM)	-
Siemens	Z-axis exposure control (ZEC)	CARE Dose	CARE Dose 4D
Toshiba	Real Exposure Control (Real EC)	-	SURE Exposure 3D

ANGULAR AEC OR XY MODULATION

Angular AEC involves change in mA at different angular projections



ANGULAR MODULATION

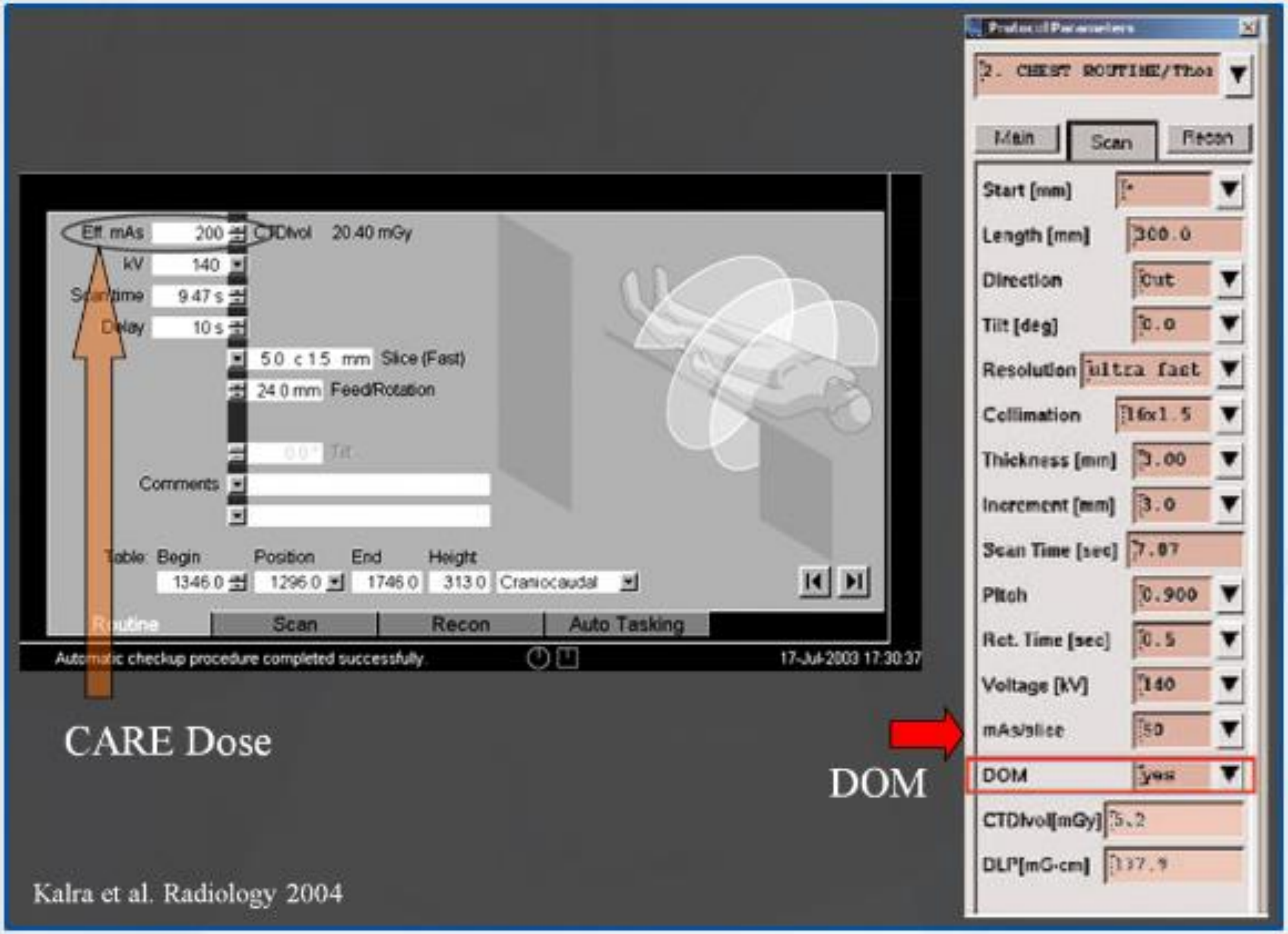
In Practice:

- User specifies mA or effective mAs (mAs/pitch)
- Scanner modulates current for each slice
  - Real-time (CARE Dose, Siemens; DOM, Philips)
  - Scout image (Smart mA, GE; Sure Exposure, Toshiba)

Limitation:

- Appropriate mA or effective mAs is pre-requisite to dose optimization

ANGULAR MODULATION



ANGULAR AEC

22% Dose Reduction

Fixed Current = 200 mAs

Angular AEC = 159 mAs

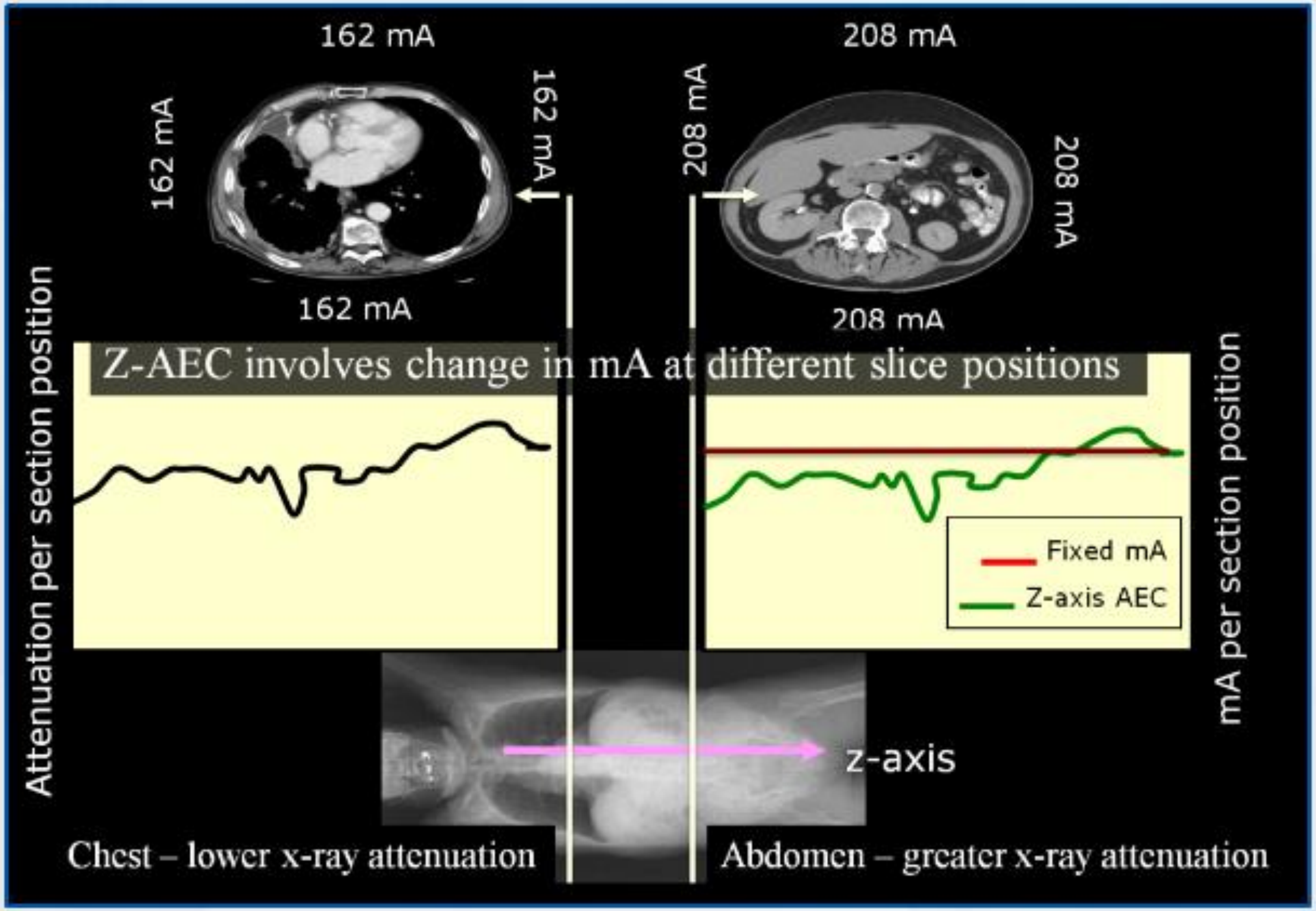
10-60% dose reduction (mean reduction 22%) compared to fixed mA without loss of image quality

Kalra et al. Radiology 2004

LONGITUDINAL MODULATION (Z-AEC)

- User specifies image quality parameter based on required image quality
- Different CT vendors use different nomenclature for image quality parameters
- Information from localizer radiograph (one or both) used to adapt mA
- Limitations: Users decide desired noise or image quality for different clinical indications

LONGITUDINAL MODULATION (Z-AEC)



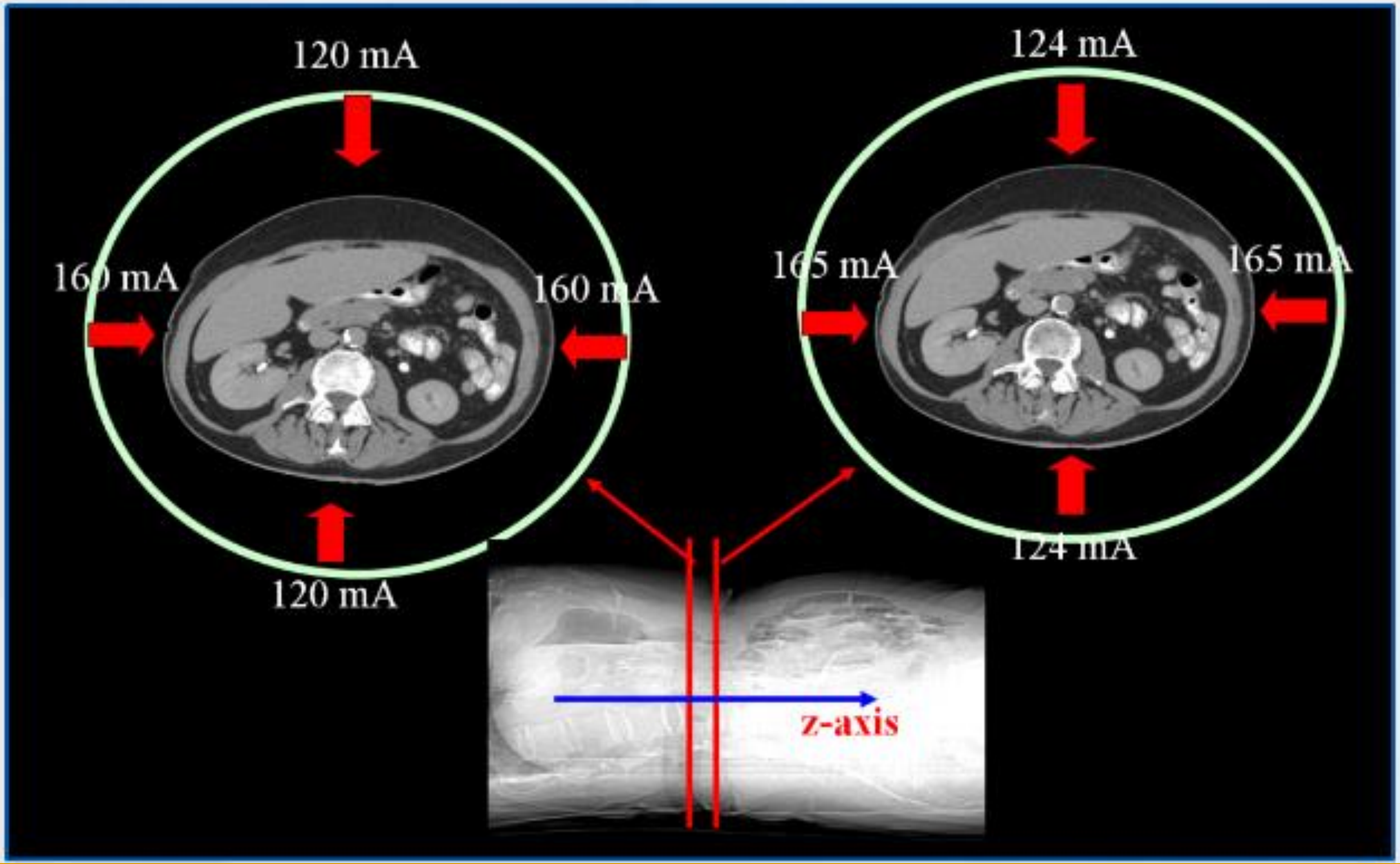
LONGITUDINAL MODULATION (Z-AEC)

	Parameter	Description
Auto mA GE	Noise index Minimum-Maximum mA	User defined noise in overall image User defined mA range for achieving noise index
Z-DOM Philips	Baseline mAs	Used as reference to obtain constant image quality along the z-axis
CareDose 4D* Siemens	Quality reference mAs	Means image quality similar to that obtained with specified effective mAs in a standard size adult
Sure Exposure 3D* Toshiba	Standard deviation	Implies user requires images with specified noise (standard deviation)

(* Imply combined modulation technique)

COMBINED MODULATION

Combined modulation (angular and longitudinal) combines the two AEC techniques



COMBINED MODULATION

- Combines angular and longitudinal modulation techniques
- Application is similar to longitudinal modulation technique
- Users have to specify the required image quality metric like in longitudinal modulation
- May provide additional radiation dose reduction as compared to separate use of angular and longitudinal modulation techniques

AUTO mA & AUTO mA 3D (GE)

- Auto mA = longitudinal modulation
- Auto mA 3D = Longitudinal modulation + Smart mA (x-y)
- Image quality parameter: Noise Index
- User must specify required noise index for application
- Noise index is noise (SD) in image of uniform phantom.
  - Lower noise index = less noise = higher dose
  - Higher noise index = more noise = lower dose

AUTO mA & AUTO mA 3D (GE)

- Choice of noise index depends on clinical indication
  - Routine abdomen needs lower noise index (better quality) compared to higher noise index (lower quality- lower dose) for kidney stone CT
  - Likewise, routine chest CT (higher tissue contrast) needs higher noise index compared to routine abdominal CT (lower tissue contrast)

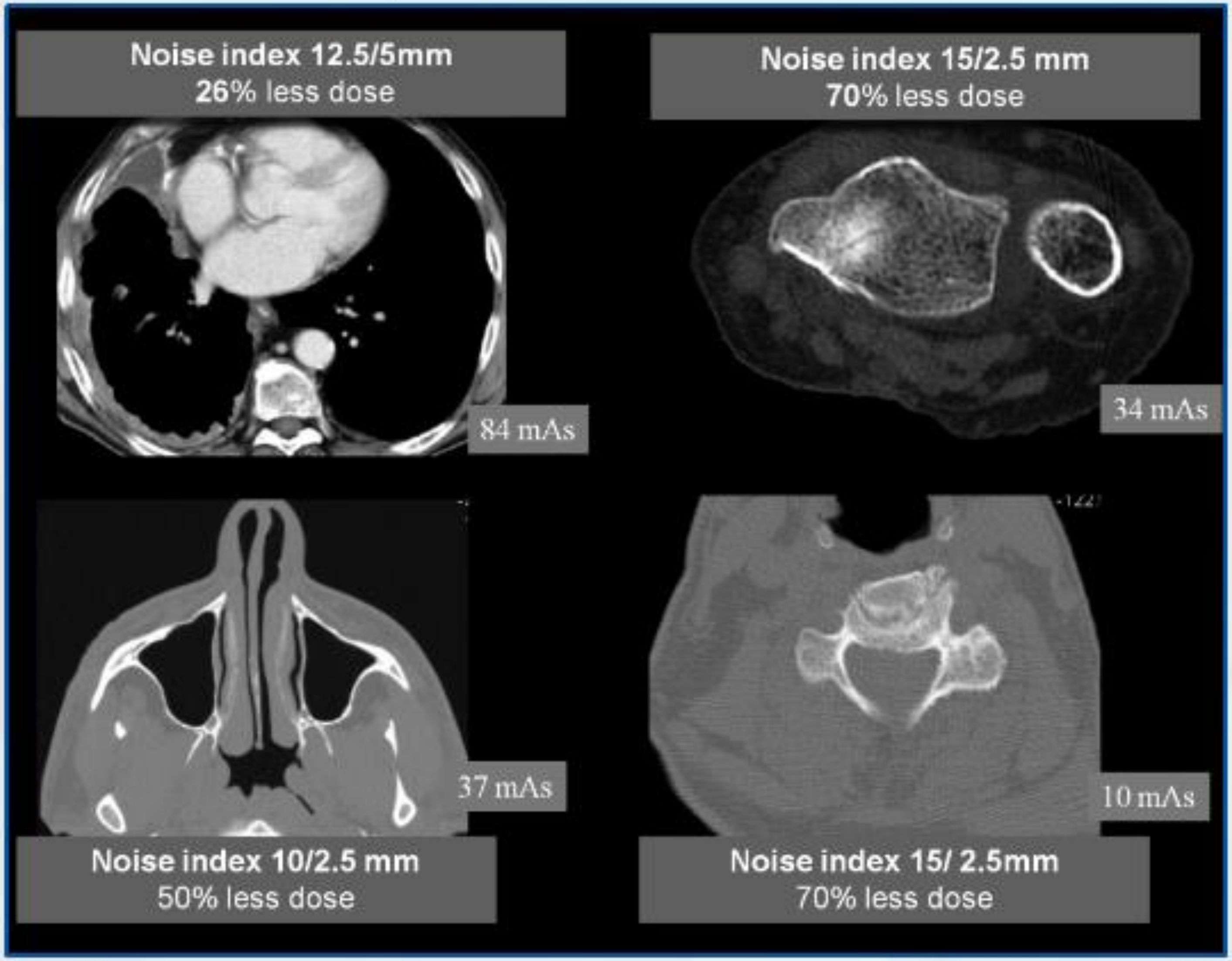
- Minimum and maximum mA are needed to control the extent of tube current change

- Uses the last acquired localizer radiograph to determine patient size for estimation of tube current

- Like other AEC techniques, it is profoundly affected by off-centering of the patient

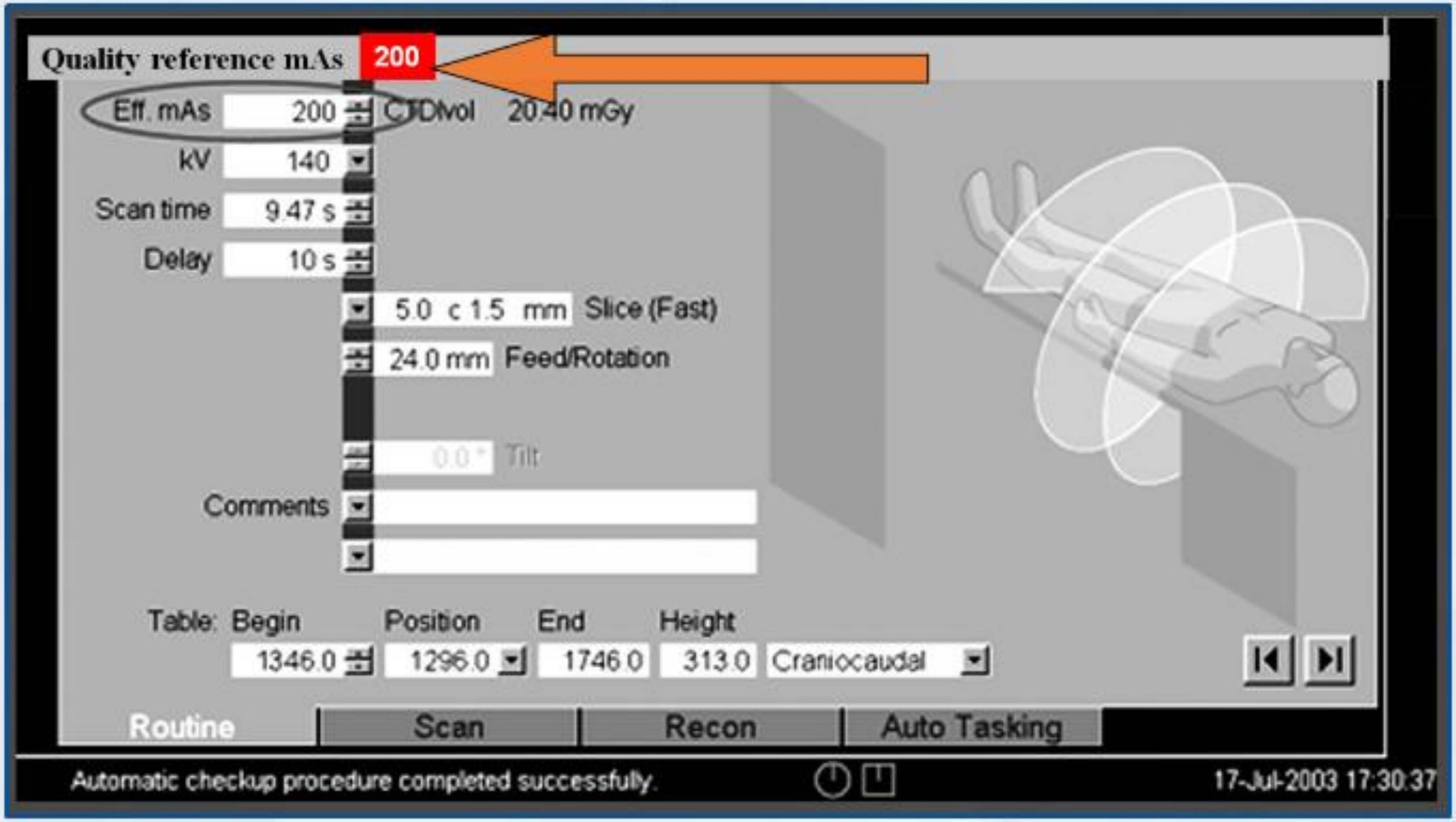
- Noise index is not independent of prospective slice thickness
  - Allow increase in noise index with decrease in slice thickness to keep constant dose compared to thick slices

AUTO mA & AUTO mA 3D (GE)



ZEC AND CARE DOSE 4D (SIEMENS)

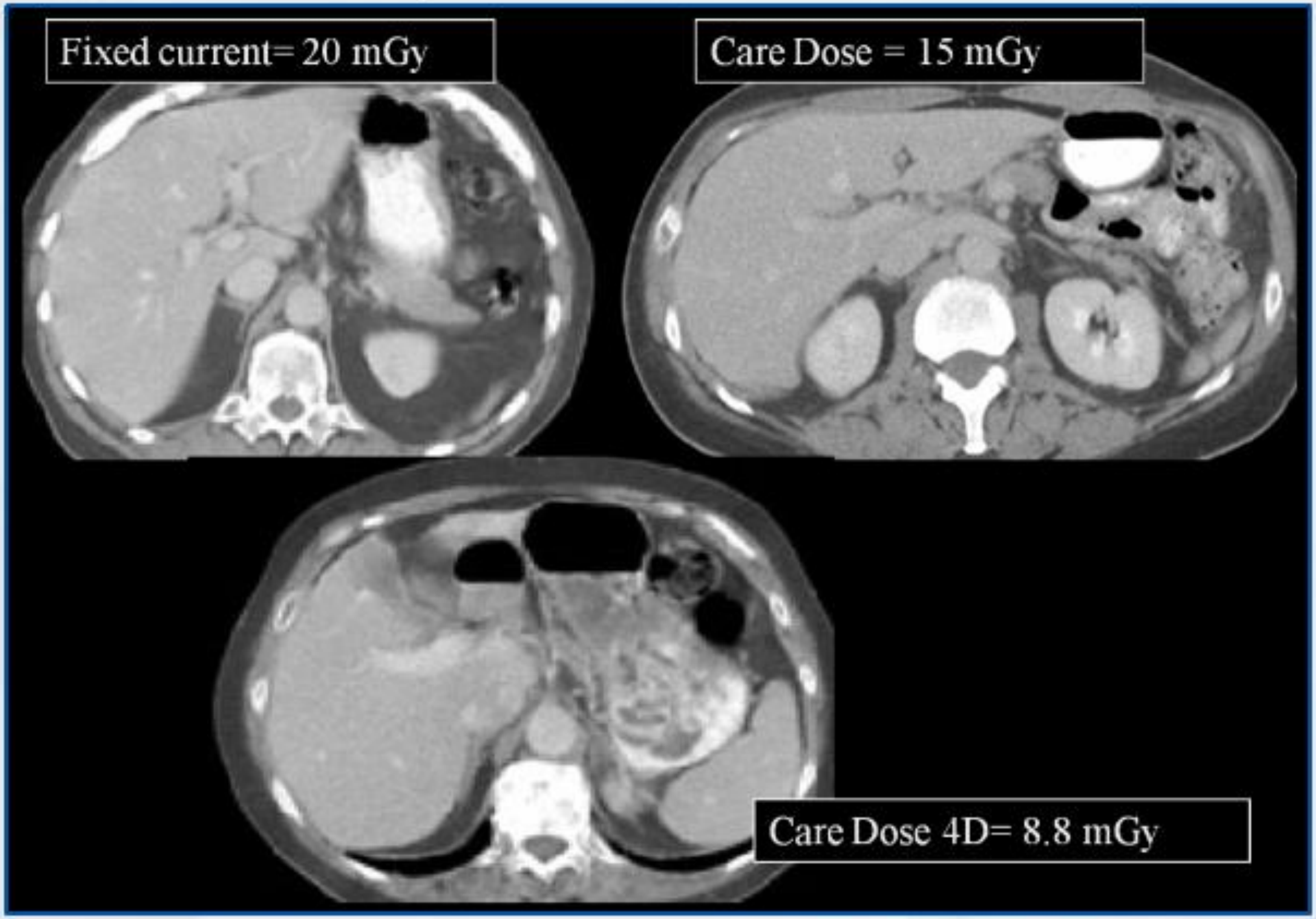
Requires user to suggest quality reference mAs (QRM)



ZEC AND CARE DOSE 4D (SIEMENS)

- QRM implies average effective mAs for a reference patient
- Reference patient is defined as
  - Typical adult with weight of 70-80 kg (for adult CT)
  - Typical child with weight of 20 kg (for pediatric CT)
- Instead of specifying the mA range, this technique allows users to control strength of mAs change for different size patients (Slim or Obese)
  - For slim: weak decrease, average decrease and strong decrease settings control extent of mAs decrease
  - For obese: weak increase, average increase, strong increase settings control extent of mAs increase

CARE DOSE 4D, SIEMENS



ECG BASED TUBE CURRENT MODULATION

- Decreases radiation dose by 20-50% depending on heart rate by performing temporal modulation of mA based on ECG compared to fixed mA throughout cardiac cycle
- mA can be decrease during certain phases of R-R interval as desired by the users
- Extent of decrease in mAs is about 5-20% of the baseline mAs

PRACTICAL IMPLEMENTATION OF AEC

- Several studies have reported substantial dose reduction with use of AEC without compromising desired image quality
- Most body CT exams must be performed with AEC
- AEC techniques will change the mAs based on patient size
  - For "x" image quality, a smaller patient will get lower dose than a larger patient
  - Extent of change of radiation with AEC can be changed by changing image quality
  - Strength of change in mAs with AEC can also be controlled

CAVEATS OF AEC: CLINICAL INDICATION

- AEC techniques recognize the patient size to adapt mAs and radiation dose
- AEC does not recognize the clinical indication
- Users must change image quality to adjust dose according to clinical indications
  - Routine abdomen (higher quality) than kidney stone
  - Routine chest (higher quality) than lung nodule follow up CT
- Bottom line: Make indication specific CT protocols

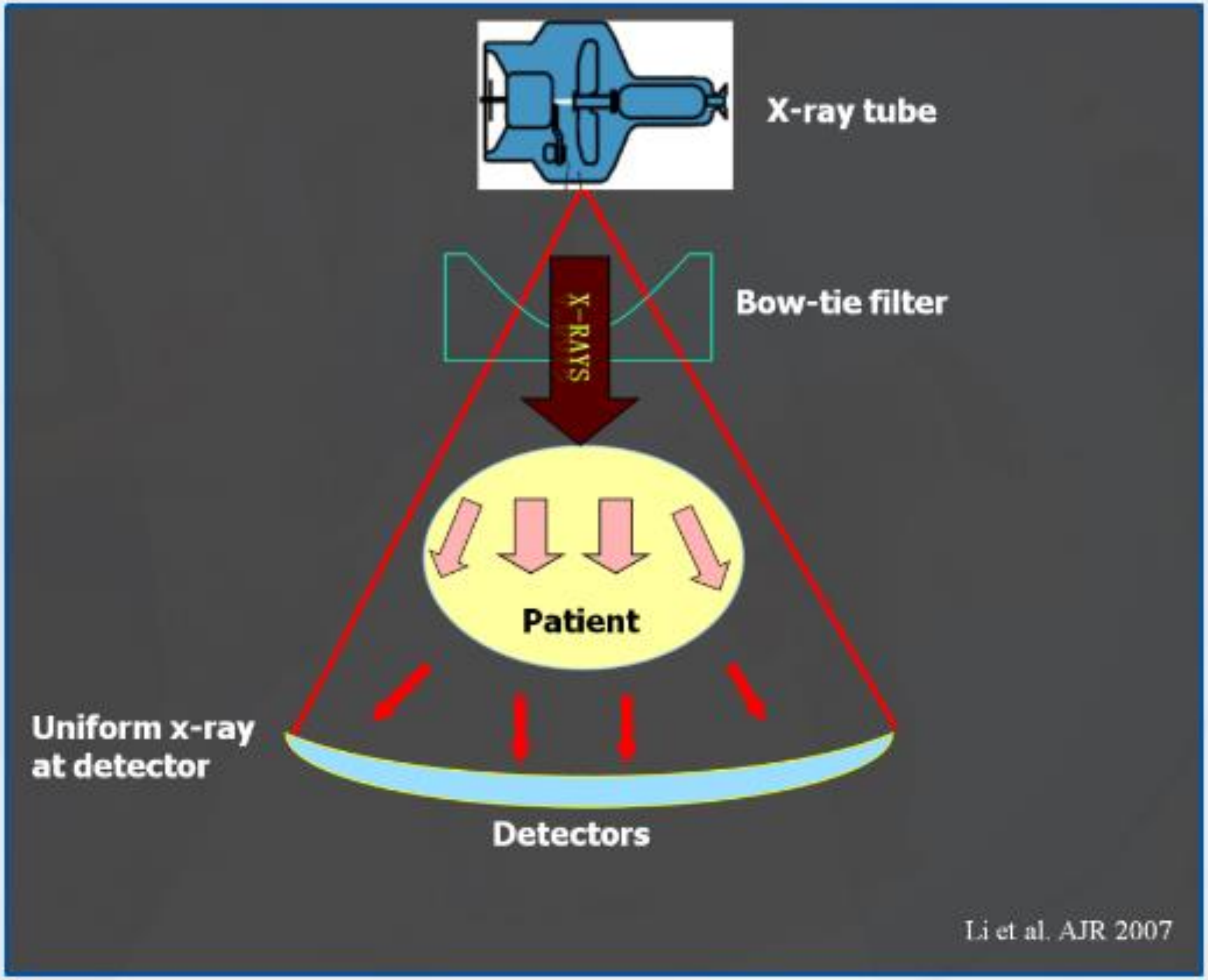
CAVEATS OF AEC: CENTERING OF PATIENT

- Importance of adequate centering of the patient in the gantry is paramount to optimal AEC operation
  - Height of the table
    - Avoid too low or too high heights to avoid off-centering
  - Side to side centering
    - Avoid placing patient to one side of the table
- Off-centering can lead to severe artifacts and mis-calculation of required mAs with AEC

X-RAY FILTRATION

- Decrease "soft X-rays" that constitute absorbed radiation but never reach detectors
- Efficient X-ray filters selectively remove these soft rays and decrease absorbed dose
- Bow-tie or beam shaping filters reduce surface radiation dose by minimizing dose in thinner portions of patient anatomy

PATIENT CENTERING IN GANTRY WITH IN BOW-TIE FILTER

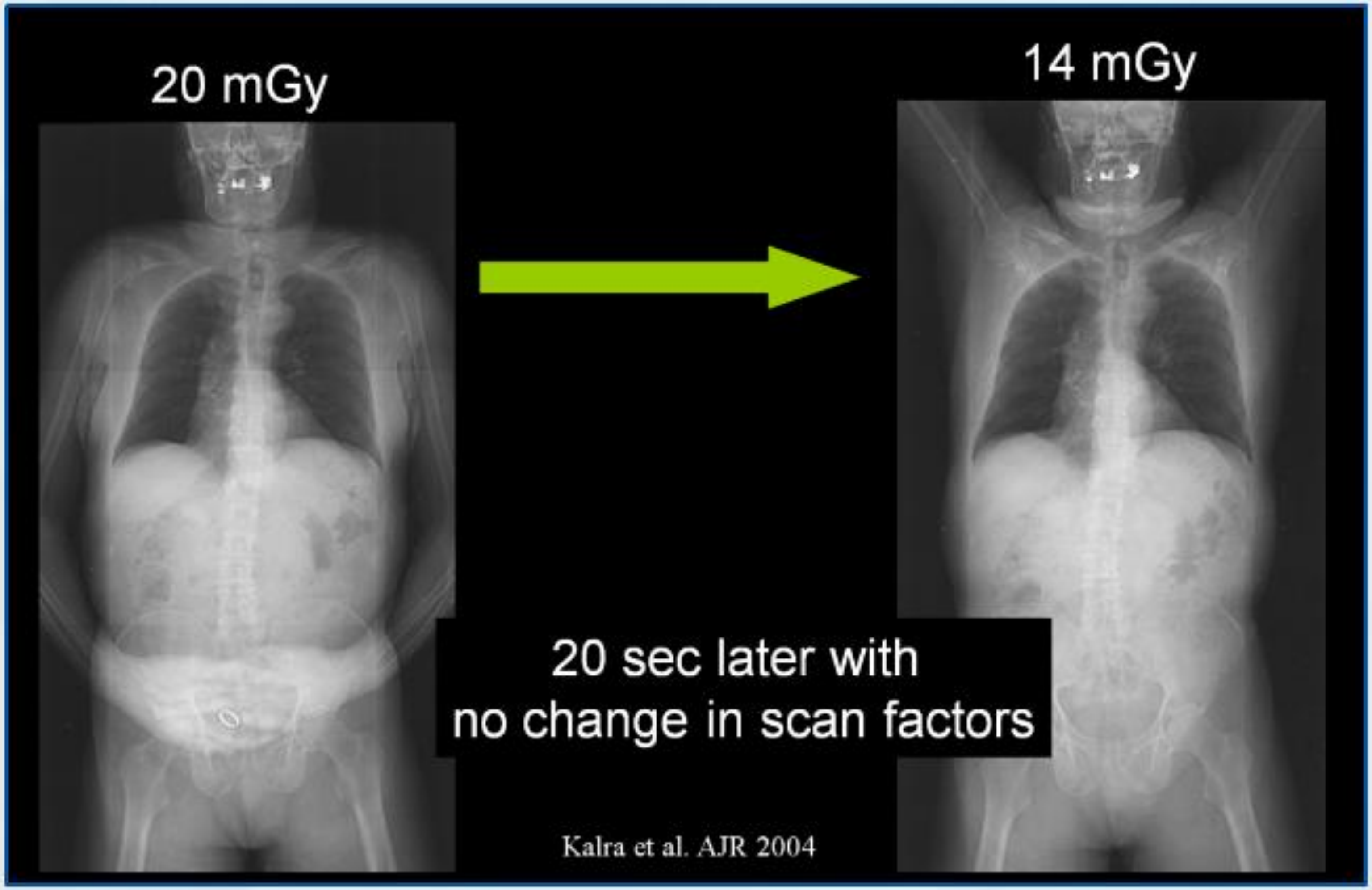


AEC CAVEATS: POSITION OF ARMS

- AEC techniques can not recognize arms from other body regions (chest or abdomen)

- When performing chest and abdomen CT
  - Arms placed by the side of body for localizer and CT: mAs and dose increased with AEC
  - Arms placed by the side for localizer but raised for CT: mAs and dose increased with AEC
  - Arms raised above head for localizer and by side for CT: Lower mAs applied with AEC than needed

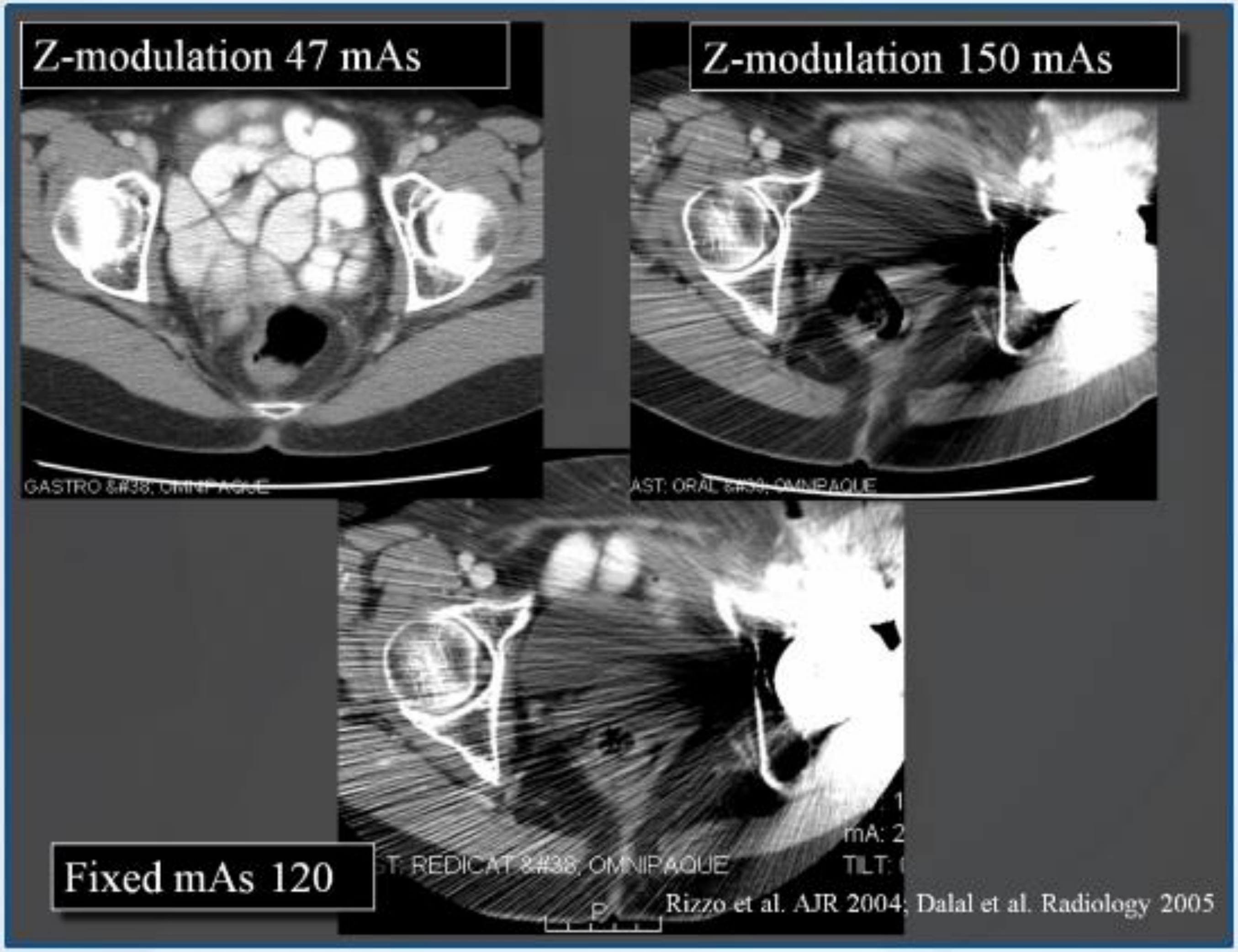
AEC CAN'T RECOGNIZE ARMS FROM THE BODY IN THE LOCALIZER



AEC CAVEATS: METALLIC PROSTHESIS

- Certain AEC techniques do not recognize metallic implants from body tissues in the localizer radiograph
  - These techniques increase radiation dose in region of large metallic prosthesis without change in severity of artifacts
- Other techniques recognize and exclude metallic implants when estimating mAs from the localizer

LONGITUDINAL MODULATION: METALLIC IMPLANTS



Rizzo et al. AJR 2004; Dalal et al. Radiology 2005

AEC CAVEATS: IMAGE QUALITY REQUIREMENTS

- AEC techniques require users to specify desired image quality as a starting point for dose modulation

- Selection of image quality for different clinical indications is not easy
  - Review of literature helps identify some guidelines
  - Gradual change and trial helps set appropriate levels

CORRECT!

It is correct that development and introduction of AEC to modern MDCT scanners has helped reduce radiation dose while maintaining image quality. Multiple publications have reported that AEC can help reduce radiation dose to both adults and children. However, AEC requires careful patient centering as off-centering can lead to miscalculation of mAs needed to produce desired image quality. AEC adapt mAs based on patient size or attenuation but users have to adapt AEC to adjust doses for different CT protocols or clinical questions. If image quality parameter for AEC is set too high, radiation dose with AEC can increase.

RADIATION DOSE MANAGEMENT IN CT

MODULE 4: TUBE POTENTIAL IN CT

TUBE POTENTIAL (kV)

- Represents potential difference between cathode and anode, which drives electrons across X-ray tube
- Unit is kilovoltage (kV)
- kV change has a profound effect on radiation dose and noise
- Radiation dose $\propto$ Tube current
- Radiation dose $\propto (kV)^2$

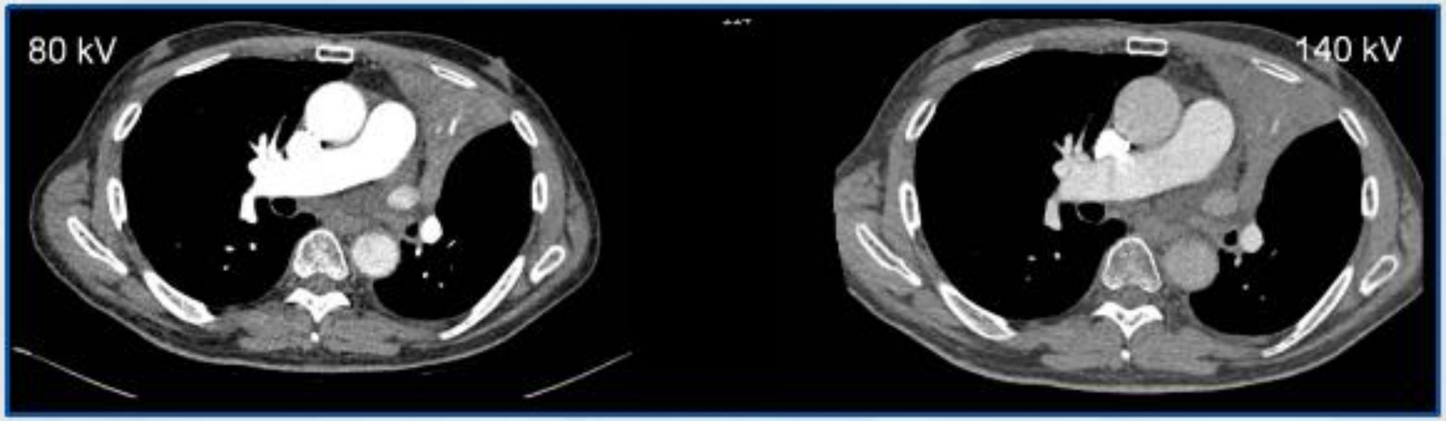
kV & RADIATION

Compared to 80 kV,

- X-ray output at 100 kV is 1.5 times higher
- X-ray output at 120 kV is 2.5 times higher
- X-ray output at 140 kV is 3.4 times higher

kV	Relative CTDIvol
80 kV	0.4
100 kV	0.7
120 kV	1.0
140 kV	1.4

kV & QUALITY



KV	CT numbers (iodine)	Image noise	Radiation dose
KV decrease	Increase	Increase	Decrease
KV increase	Decrease	Decrease	Increase

- Decrease in kV brings X-ray energy closer to the k-edge of iodine, which results in its increased X-ray attenuation and higher HU
- For contrast enhanced CT: kV reduction improves image contrast while reducing dose

SELECTING THE RIGHT kV

- kV can be selected or specified manually
  - Most common and widely available
- kV can be automatically selected by CT
  - Available from some vendors (Siemens & GE)
  - Unlike AEC which varies mA, automatic kV selection technique does not modulate kV but only picks a best kV for the entire CT exam
- Most scanners allow 4 choices of kV
  - 80, 100, 120, 140 (some have 135 instead of 140)
- Some scanners only have 3 available kV
  - 80, 120 and 140 kV
- Some scanners have 5 available kV
  - 70, 80, 100, 120, 140 kV (some Siemens CT)
- Some scanners have even more!!
  - 70, 80, 90, 100, 110, 120, 130, 140, 150 (Force)

TUBE POTENTIAL (kV)

- Most scanners require users to specify a fixed kV for CT protocols
  - Generally, smaller patients (particularly children) should be scanned at low kV (70-100 kV)
  - Generally, CT angiography or contrast enhanced CT can be scanned at low kV (80-100 kV)

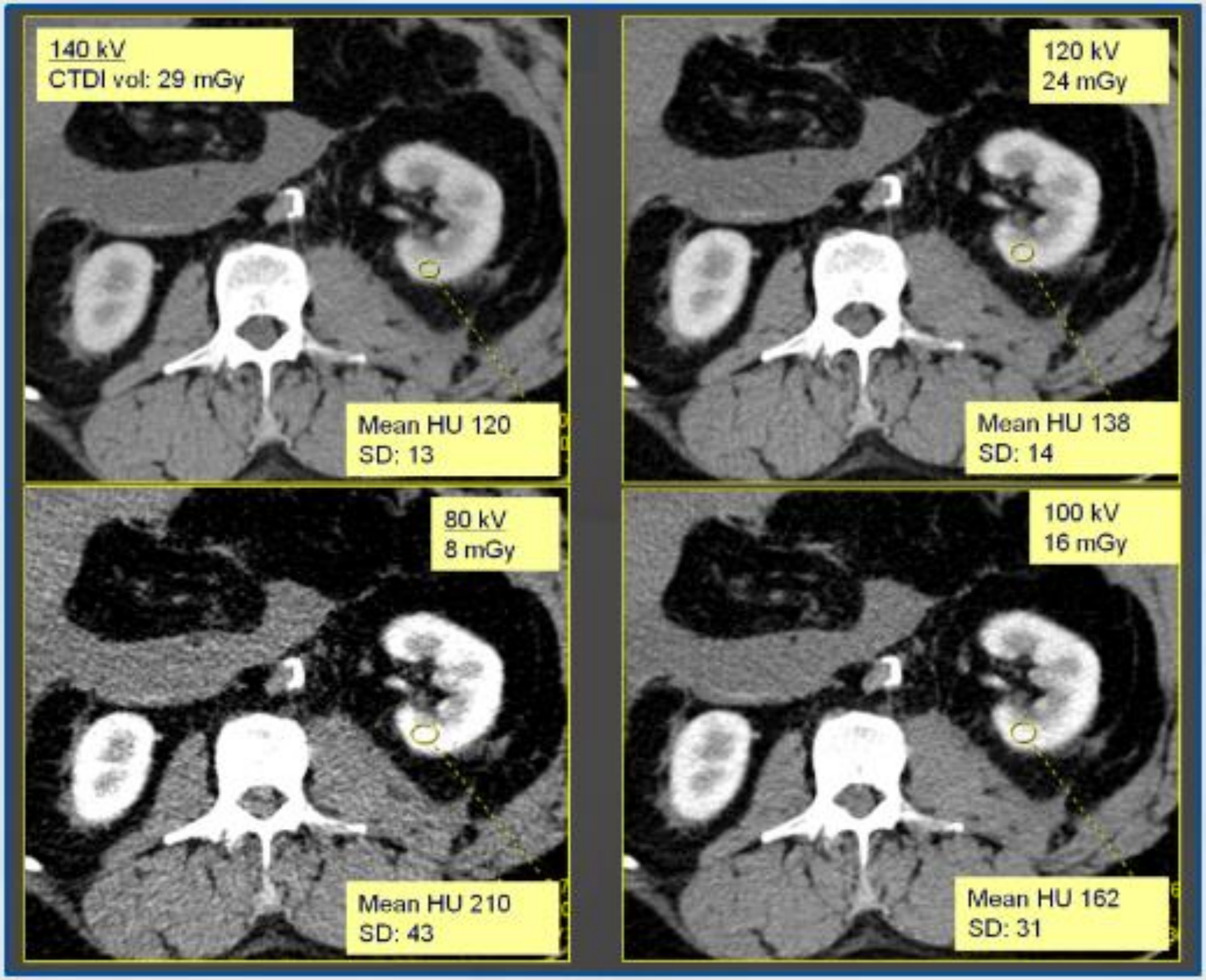
- Some CT have automatic kV selection where CT scanner picks up the right kV.
  - Care kV (Siemens)
  - kV Assist (GE)

kV EFFECTS

kV decrease #	kV increase #
Noise increases May need mA increase Newer CT have high mA limit Iterative reconstruction reduce noise	Noise decreases Can use lower mA Older scanners have low mA limit FBP may need higher kV for some
Photon starvation and beam hardening artifacts possible if KV is too low if patient is too large	Photon starvation and beam hardening artifacts may decrease if KV is high if patient is small
Image iodine contrast improves Contrast volume may be reduced	Image iodine contrast deteriorates Larger contrast volume may be needed
Radiation dose is reduced	Radiation dose is increased

If other scan parameters are held constant

kV AND ITS EFFECT ON HU, NOISE (SD) & DOSE



kV ADJUSTMENTS

Lower kV (≤100 kV)	Higher kV (>100 kV)
Most body CT in children (< about 80 kg)	Very large children (> about 100 kg)
Most CTA of neck and chest (80-100 kg)	Large shoulders - CTA of neck (>100 kg)
Post-contrast chest CT (< 100 kg)	Large patients (> 100 kg) for chest CTA angiography or post-contrast chest CT
Arterial phase CT of abdomen and abdominal CTA (up to 80 kg)	Portal venous phase CT of abdomen Abdominal CTA or arterial phase CT (>80 kg)
Extremities CTA	
Very low dose CT: Lung nodule follow up Lung cancer screening CT colonography (80 kg)	Subtle lesions of the abdomen Low attenuation liver lesions Pancreatic cancer staging Solid renal tumor

Newer CT systems and iterative reconstruction techniques can enable use of lower kV.
More frequently and in larger patients compared to older scanners with FBP.

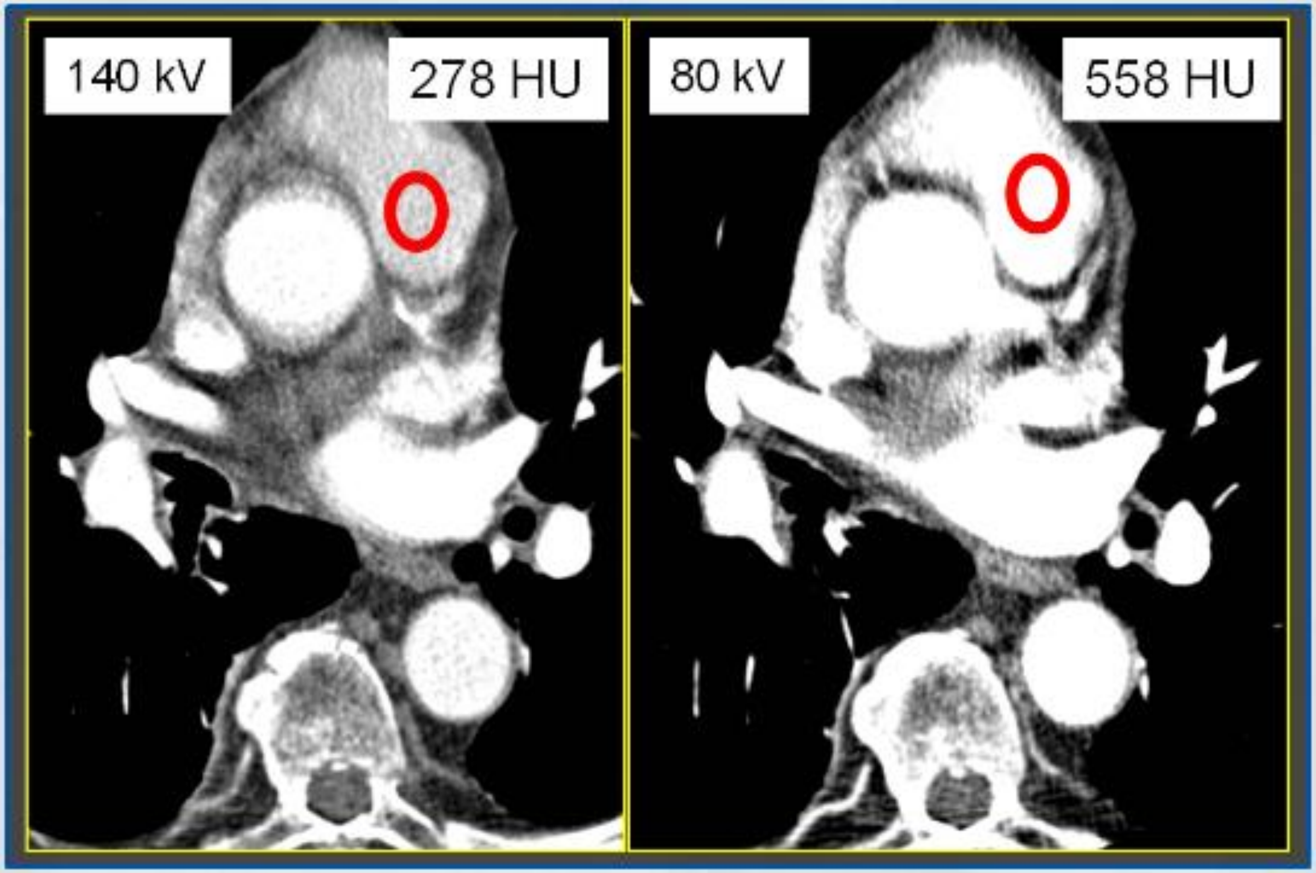
kV AND HEAD CT

- Most often routine head CT in adults are performed at 120 kV
- Most children can be scanned at $\leqslant$ 100 kV
- CT angiography of head and neck should be performed at $\leqslant$ 100 kV (< 80-100 kg)
- CT for ventricular shunt patency and craniosynostosis should be performed at lower kV
- Avoid low kV in patients with large shoulders undergoing neck CT or CT angiography

kV AND CHEST CT

- Most chest CT can be scanned at ⩽ 100 kV (in patients 80-100 kg)
- Pulmonary embolism CT can be at 80 or 100 kV (in patients 80-100 kg)
- Lung nodule follow up CT and lung cancer screening CT can also be performed at ⩽ 100 kV
- All pediatric chest CT can be performed at 80/100 kV (less than 80 kg)
- When available 70 kV should be used for chest CT in infants

CT PULMONARY ANGIOGRAPHY AT LOW kV

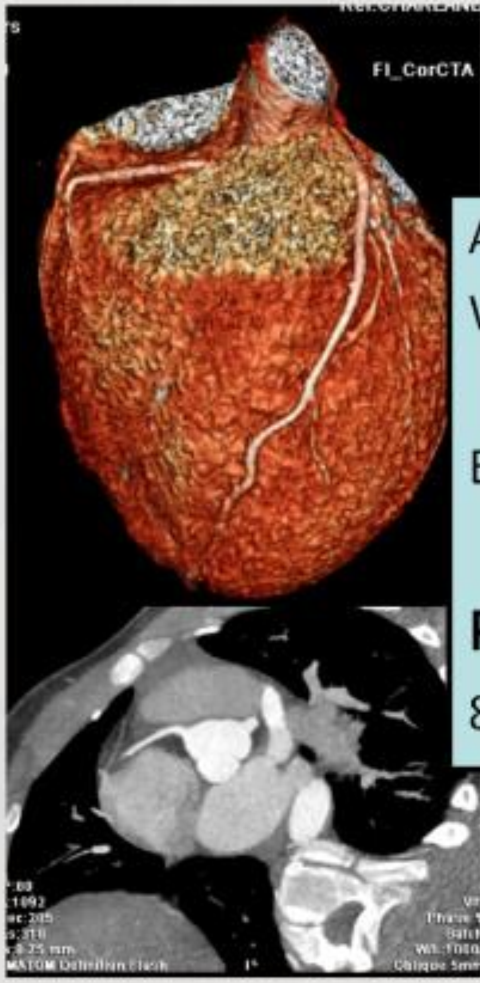


With reduction in kV, radiation dose decreases while HU number & image contrast increase

kV AND CARDIAC CT

- Contrast enhanced coronary arteries allow lower kV use
- Most coronary CT angiography in patients less than 30 kg/m^2 can be and should be performed at 80-100 kV
- Most children should also be scanned at 80 kV for coronary CT angiography, since major concern is anomalous coronary arteries

CARDIAC CT AND LOW kV

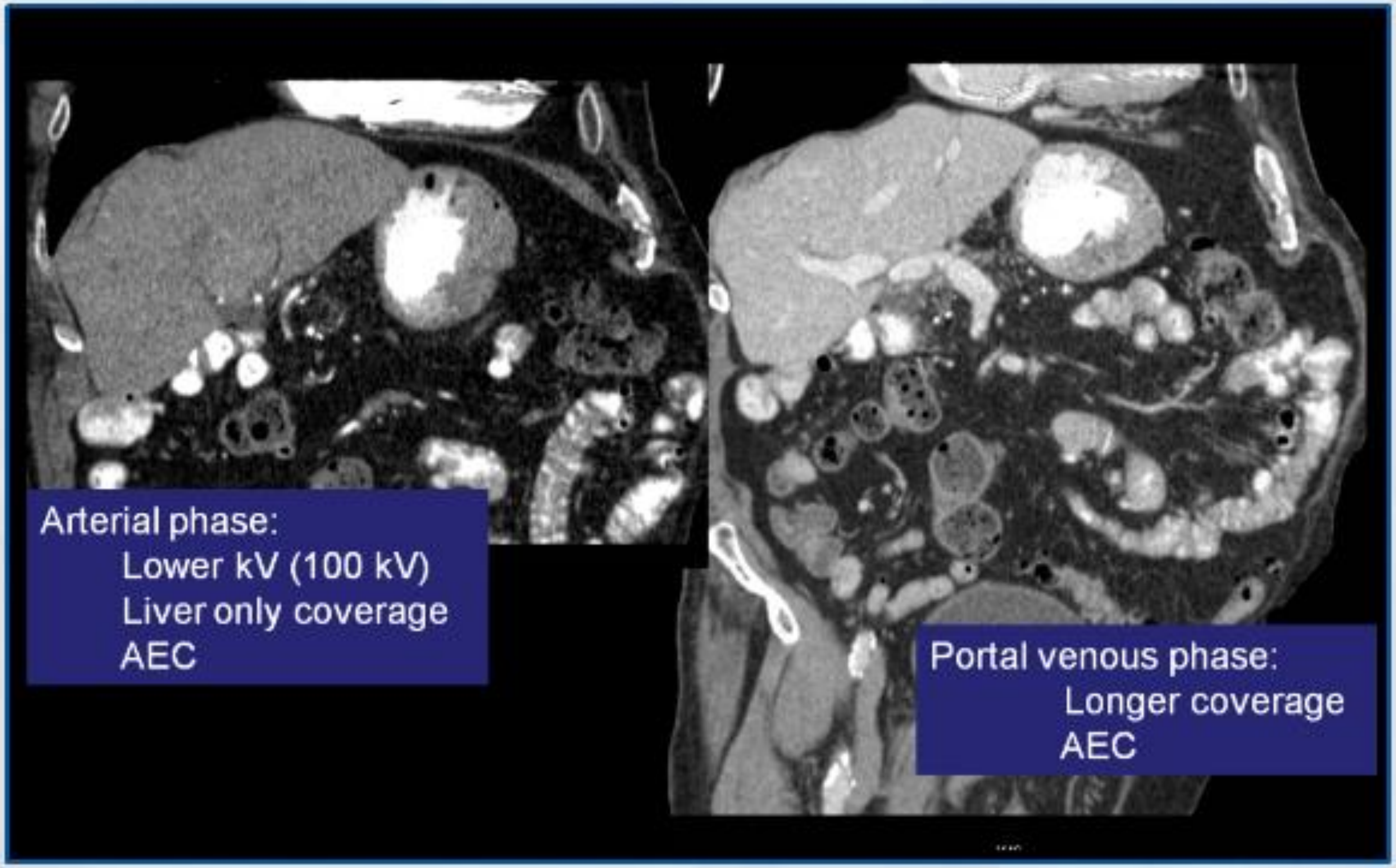


Age 14 years Weight 60 kg EKG gated CCTA **Pitch 3.4** 80 kV	Age 65 years Weight 140 kg Non gated Pulm. veins **Pitch 3** 100 kV

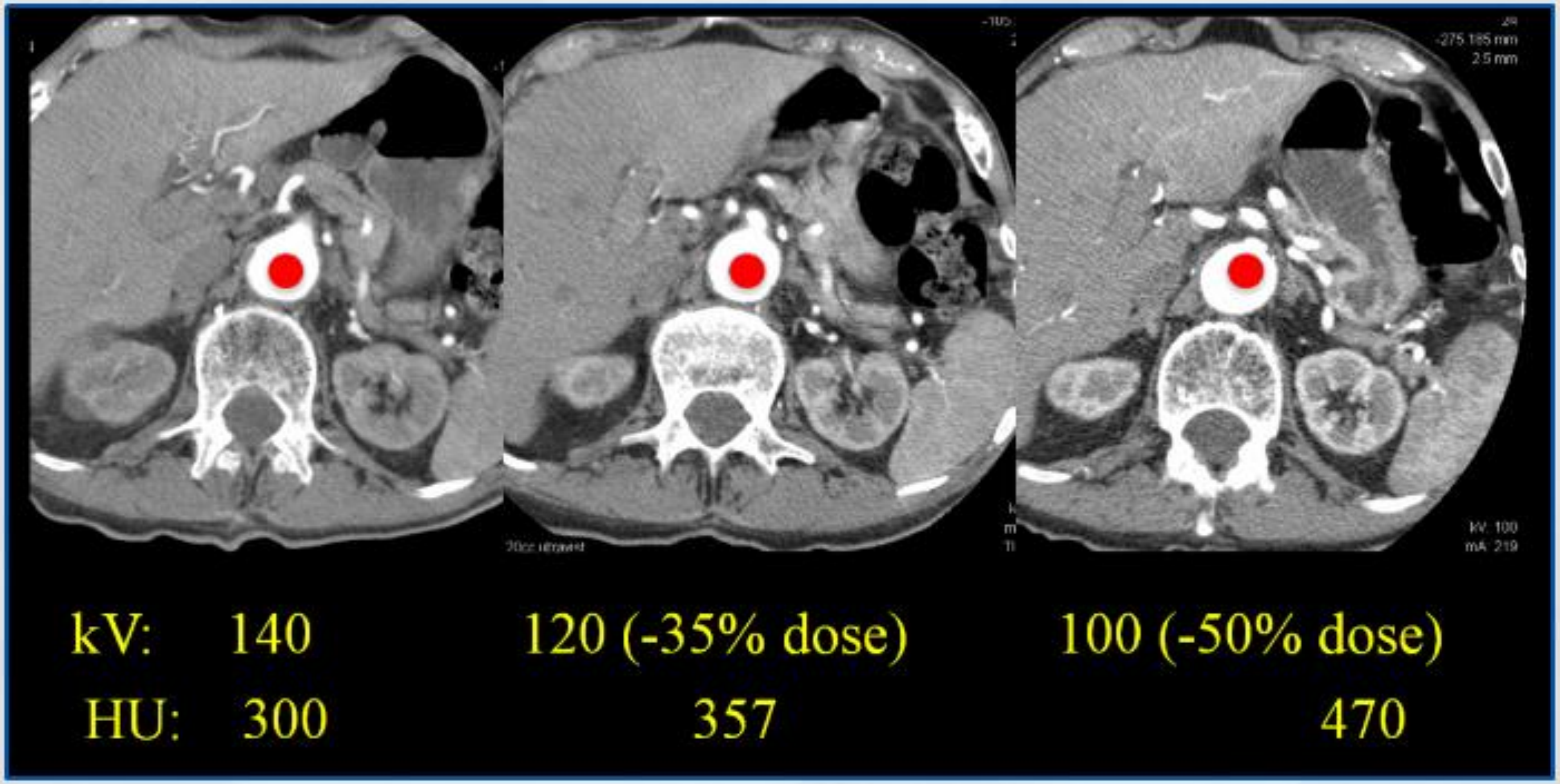
kV AND ABDOMINAL CT

- Most abdominal CT are performed at 120 kV
- With iterative reconstruction techniques, many abdominal CT in non-obese patients are being performed at 100 kV
- CT angiography and arterial phase abdominal CT with high iodine presence should be scanned at lower kV ($\leqslant$ 100 kV) in most non-obese patients
- Newer CT with higher mAs limit (800-1300 mAs) are expected to increase use of lower kV in abdomen

MULTIPHASE LIVER CT: DOSE REDUCTION



kV, DOSE & HU

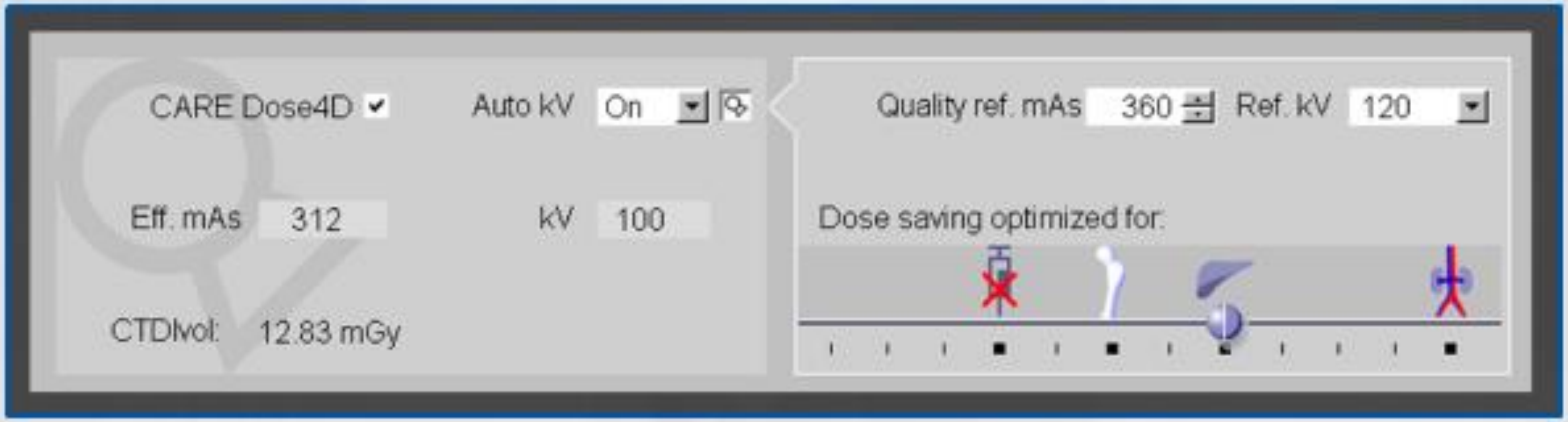


AUTOMATIC kV SELECTION

- System automatically identifies optimum kV setting (Care kV, Siemens)
  - Body habitus (from planning radiograph)
  - Exam type (non-contrast, bone, standard contrast, vascular)
  - System limits (tube current)

- System automatically proposes kV and corresponding mAs values to maintain constant contrast to noise ratio

- kV Assist (GE) also works on similar principles for selecting optimal kV



DETECTOR CONFIGURATION

- Detector configuration of multidetector-row helical CT can be defined as the number of data channels along patient length (or z-axis) multiplied by the effective detector row thickness of individual data channel
- Represented as
  - Number of data channels x effective detector row width
- Determines the X-ray beam width or beam collimation

GE	Detector configuration
Hitachi	Detector configuration
Neusoft	Collimation (N x T)
Philips	Collimation (N x T)
Samsung Neurologica	Detector configuration
Siemens	Detector configuration
Toshiba	Detector configuration

DETECTOR CONFIGURATION

- In variable detector arrays MDCT (scanners with variable effective detector row width), wide detector configuration can limit the z-axis resolution (minimum section thickness)
  - Ex: For a 16-channel MDCT scanner, 16 x 1.25 mm (20 mm) is wider and more dose efficient than 16 x 0.625 mm (10 mm) but 20 mm detector configuration will not provide <1.25mm slices
  - Thus, decision regarding detector configuration should be based on required slice thickness for such scanners

TABLE FEED

- Table feed in helical scan mode is defined as distance travelled by the gantry table in a 360° rotation of the X-ray tube
- Measured as mm/rotation
- Also called table speed or couch feed

GE	Speed
Hitachi	Table speed
Neusoft	Table speed
Philips	Table speed
Samsung Neurologica	Table speed
Siemens	Table feed
Toshiba	Couch speed

PITCH

- Pitch for helical CT is defined as a ratio of table feed per 360° rotation of the X-ray tube and total nominal beam width
  - Pitch = Table feed (mm)/nominal beam width (mm)
- Pitch has no units
- Changes in pitch should be made based on requirement of scanning speed rather than dose

GE	Pitch
Hitachi	Pitch
Neusoft	Pitch
Philips	Pitch
Samsung Neurologica	Pitch
Siemens	Pitch
Toshiba	CT pitch factor

PITCH: SPECIAL CONSIDERATIONS

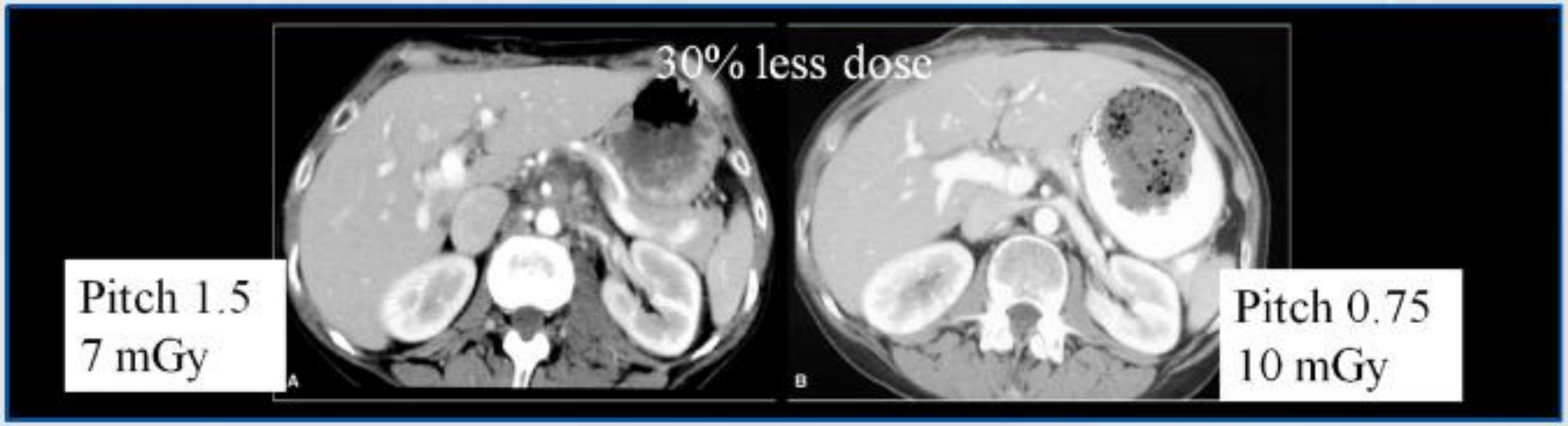
- On single X-ray tube MDCT, pitch is generally up to 1.5, since greater pitch will lead to skipped data
- On dual source MDCT, pitch> 1.5 is feasible, since two independent helices fill the gaps in data
  - Such high pitch (>1.5) leads to much faster scanning at substantially lower dose compared to lower pitch values
    - Cardiac CT angiography
    - Scanning unco-operative patients
    - Scanning little children without need for sedation

PITCH: CAVEATS

- Some vendors (Philips and Siemens) completely compensate for changes in pitch, so dose does not change with pitch change
  - Change pitch to make the scan faster or slower
- Other vendors (GE and Toshiba) do not compensate entirely for change in pitch, so higher pitch has lower dose and vice versa
  - Change in pitch results in change in dose and speed

DETECTOR CONFIGURATION, TABLE FEED & PITCH

- Inter-linked parameters on MDCT scanners
- Implies that change in one parameter often results in change in other parameters



EFFECTS ON SPEED & DOSE

Parameters	Change	Radiation dose	Scanning speed
Pitch	+	No change for some Decreased dose for some	Increased
	-	No change for some Increased dose for some	Decreased
Det. Configuration	+	Greater dose efficiency Greater over-ranging	Increased
	-	Lower dose efficiency Lower over-ranging	Decreased
Table feed	+	No direct effect on dose	Increased
	-		Decreased

OVER-RANGING

- Over-ranging may be defined as additional radiation dose due to extra half rotation at the beginning and the end of a helical CT acquisition
- The additional half rotations are required to generate the first and last slices of helical acquisition
- The half rotations results in patient dose without generation of images

OVER-RANGING

- Extent of over-ranging is directly proportional to pitch and beam width
  - Higher pitch results in greater over-ranging
  - Wider beam width has greater over-ranging

	Direction in scan range	Organs affected by over-ranging
Head CT	Above head Below head	None Eyes
Chest CT	Above chest Below chest	Thyroid Abdominal organs
Abdomen CT	Above abdomen Below abdomen	Breasts Testes in males

OVER-RANGING: IMPLICATIONS ON SCAN PARAMETER CHOICE

- For short scan length: over-ranging can represent a significant portion of overall dose
  - Thus, short scan ranges should be scanned at lower pitch and lower beam collimation
    - Ex: Small joints, small regions of interest, head CT
- For longer scan length: over-ranging represents a small portion of overall dose
  - Thus long scan ranges can be scanned with faster pitch and wider beam collimation to decrease scan times
    - Ex: Chest CT, abdomen CT, extremity CT

OVER-RANGING: SOLUTIONS

- Adaptive dose shields (Siemens and Philips): Dynamic beam collimators reduce the over-ranging by collimating the X-ray beam at the start and end of the helical scanning
- Hybrid reconstruction technique (GE Healthcare): Enables generation of images in the over-ranging portion of the X-ray beam to reduce extent of un-used X-ray beam

CHOICE OF DETECTORS, FEED & PITCH

Region of interest	Pitch	Detector configuration	Table feed
CT head helical	< 1 (overlapping)	Narrow	Slow
CT chest	≥ 1	Wide	Fast
CT chest (uncooperative)	Highest possible	Widest possible	Fastest possible
CT abdomen	≥ 1	Wide	Fast
CT abdomen (uncooperative)	Highest possible	Widest possible	Fastest possible
Small children (body CT)	Highest possible	Widest possible	Fastest possible

Choice of pitch and detector configuration can change based on the MDCT scanner and required slice thickness

RADIATION DOSE MANAGEMENT IN CT

MODULE 6: CT DOSE METRICS AND TRACKING

RADIATION DOSE MEASUREMENTS

OBJECTIVES

- To understand basic CT dose metrics:
  - CTDIvol
  - DLP
  - SSDE
- To understand advantages and logistics of different dose tracking options for CT

RADIATION DOSE MEASUREMENTS

Dose comparisons between radiography and CT in terms of surface dose are not appropriate

RADIATION DOSE MEASUREMENTS

- Two standardized dose metrics displayed on modern day CT scanners
  - CT dose index volume (CTDIvol)
  - Dose length product (DLP)

- Size-specific dose estimates (SSDE) have been proposed

CTDI$_{VOL}$

- CTDIvol is a standardized method to measure radiation output from the scanner.
  - These dose measurements are obtained from 16 or 32 cm diameter acrylic phantoms at CT factories
    - 16 cm for head CT
    - 32 cm for body CT
  - Phantom size used for its calculation is displayed on CT
  - Measured in milligray (mGy)
  - CTDIvol does not represent actual patient doses
  - Represents average dose within each slice

DOSE LENGTH PRODUCT (DLP)

- DLP is product of CTDIvol (mGy) and length of scanned area (cm).
  - DLP is also calculated by the scanner based on CTDIvol
  - Represents integrated dose over the entire scanned area
  - Unit is mGy.cm
  - Again, DLP does not represent patient-specific dose

CURRENT DOSE DISPLAYS ON CT

The Good!

- Provides information on amount of dose from the exam
- Useful to track across patients and protocols: Registry and Audit
- Compare and improve protocols across institutions.
- Regulatory compliance

The Bad!

- Phantom dose only (16 or 32 cm only)
- No patient body size compensation
  - Underestimates for small patients
  - Overestimates for large patients
- Does not account body composition

WANTED: Preferably Viable! Better dose descriptor to account for size, and body region of the patient

SIZE-SPECIFIC DOSE ESTIMATES (SSDE)

- American Association of Physicists in Medicine (AAPM) report # 204 introduced SSDE for CT
- Helps convert CTDIvol into patient size specific doses using conversion factor derived from
  - Antero-posterior (AP) width
  - Lateral width
  - Sum (AP + lateral) width
  - Effective diameter (square root of (AP x lateral width))

SIZE-SPECIFIC DOSE ESTIMATES (SSDE)

- Extends application of CTDIvol to patient size beyond 16 and 32 cm
- Still does not account for patient composition, similar to CTDIvol
- Still does not represent actual organ doses, like CTDIvol
- Should not be used to estimate specific patient doses

CURRENT POST- SCAN DOSE DISPLAY

- Legacy (really old) CT
  - No automatic post-scan dose capture!!
- Legacy (not that old) CT
  - Dose information page
    - Looks different for different CT vendors
    - Image capture of mathematical data!!
- Newer CT systems
  - DICOM Dose Structured Reports capture doses and scan parameters in an downloadable, analyzable format
  - Dose information page (sticks around!)

HOW SCAN PARAMETERS AFFECT CT DOSES?

Scan parameters	Effect on $CTDI_{vol}$ &/or DLP #
Axial scan mode	No over-ranging (extra radiation at the start and end of scanned volume)
Helical scan mode	Over-ranging present at start and end of scanned volume
Tube current	Direct relationship $mA \propto CTDI_{vol}$
Tube potential	Stronger direct relationship $Dose \propto (kV)^2$

If all other scan parameters are held constant

HOW SCAN PARAMETERS AFFECT CT DOSES?

Scan parameters	Effect on Dose #
Pitch	Some scanners do not allow change in dose with change in pitch Other CT scanners, $CTDI_{vol}$ decreases with increasing pitch and vice versa
Gantry rotation time	Relationship identical as mA and dose. Direct linear relationship with $CTDI_{vol}$
Scan length	Does not affect $CTDI_{vol}$ Direct linear relationship between scan length and DLP

If all other scan parameters are held constant

MORE DOSE TERMS: DIAGNOSTIC REFERENCE LEVELS (DRLs)

- DRL is a reference dose for identifying level of radiation dose for a diagnostic X-ray exam
  - Typically at 75th percentile of observed doses from survey of facilities (doses at 75% facilities are below DRL)
  - Different countries and organizations have different DRLs for same CT protocols

- DRLs help in CT radiation dose optimization efforts

- DRLs are for average size patients and are often higher for smaller patients and lower for large patients

MORE DOSE TERMS: NOTIFICATION & ALERT VALUES

- Notification value: Dose level of a series or scan that causes a pop up warning notice to be displayed prior to scanning
  - AAPM recommends values of 80 mGy (adult head), 50 mGy (adult torso)
- Alert value: Cumulative dose level of entire study (including both done and being done) that results in a pop up alert to be displayed on the scanner
  - US FDA recommends alert value of 1 Gy
- Both values help radiographers in case of exceeding specified dose levels

DOSE TRACKING: WHY BOTHER?

- Avoid new or duplicate CT exams
- Indicate need for scan parameter adjustment versus other scanners, protocols or facilities
- Know the outcome of optimization efforts
- Make judgment of need in patients who have already have multiple prior CT exams
- Check compliance with recommended DRLs

DOSE TRACKING: FREEWARE

- RADIANCE- Radiation Dose Intelligent Analytics for CT examinations (http://www.radiancedose.com)
- Dose Utility
- DoseRetriever
- GROK (Generalized Radiation Oncology Toolkit in PixelMed Library)
- OpenREM.org (http://openrem.org)

DOSE TRACKING: SHOULD WE DO IT?

Yes:

- Ensure that we do no harm (primum non nocere)
- Ensure that our CT doses are with in DRLs
- Identify and eliminate rogue protocols or practices
- Assess results of dose optimization initiatives
- Identify patients and protocols exceeding alert values
- Assess need for equipment upgrade or change

RADIATION DOSE MANAGEMENT IN CT

MODULE 7: KEY ASPECTS FOR CHEST CT PROTOCOLS

WHAT IS SO SPECIAL ABOUT CHEST CT?

- Lungs
  - Air causes less X-ray attenuation and so requires less radiation dose
  - Air results in high inherent tissue contrast versus most lesions and so can be imaged at lower dose
- Heart, blood vessels and lungs:
  - Pulsating structures require faster scanning
  - Short scan duration reduce respiratory motion artifacts as well
  - High contrast offers opportunities for low dose

CHEST CT DOSES MUST BE DIFFERENT FROM ABDOMEN

- Routine chest CT dose < routine abdomen CT doses
- Low dose lung nodule CT < low dose kidney stone CT
- Chest CT angiography < abdomen CT angiography
- Chest should have fewer multi-phase or pass studies

Time:	Feb 15, 2013, 10:44:16
Total DLP:	858.4 mGy*cm
Estimated Dose Savings:	20%

Dose

#	Description	Scan Mode	mAs	kV	CTDIvol [mGy]	DLP [mGy*cm]	Phantom Type[cm]
1	Scout	Surview	0	120	0.10	7.1	16 CM
4	CHEST SUPER D	Helical	92	120	6.78	273.7	32 CM
5	ABP THINS CA F/U	Helical	144	120	10.52	577.6	32 CM

DEVELOPING CT PROTOCOLS

"On the fly" protocol creation is not optimal

- Valuable time can be wasted for urgent CT
- Level of training between radiographers and between radiologists is different
- Errors can result in implementation since there are far too many scan parameters
- Consistency is difficult to achieve:
    - Same clinical indication and size: Similar doses
    - Different clinical indications or size: Different doses

ALL TIME WINNER FOR THE BEST CT DOSE REDUCTION STRATEGY

Appropriate clinical indication for CT

SPECIFIC CHEST CT PROTOCOLS

- All scan protocols must begin with the clinical indications for their use
- Scan protocols must be based on clinical indications
- Each scan protocol should address
  - Number of scan phases required
  - Scan range for each phase
  - Scan parameters for each phase
  - Dose adjustment for patient size

NEED: INDICATION DRIVEN PROTOCOLS?

- Certain things are ok at lower dose (lung nodules)
- Others need higher dose (mediastinal LN)
- Radiation doses and chest CT protocols:

CT lung nodule follow up < Routine chest CT post contrast < CT pulmonary embolism < Routine chest CT non contrast

CHEST CT PROTOCOLS: GOOD POINTS

Indication and size specific scan parameters

- Tube Current:
  - Prefer AEC over fixed mA
  - Can use fixed mA for very low dose CT protocols
  - Adjust mA for different clinical indications
    - Lower mAs for nodule follow up/lung cancer screening
    - Lower mAs for iterative reconstructions than FBP

- kV selection: Automated or Manual
  - Use lower kV for contrast enhanced chest CT
  - Use lower kV for CT angiography unless patient is large

CHEST CT PROTOCOLS: GOOD POINTS

- Pitch for chest CT
  - Non-overlapping pitch should be preferred to minimize scan duration and motion artifacts
    - Generally pitch for chest CT should be ⩾ 1 (Close to 1)

- Number of scan series for chest CT
  - Generally a single acquired series is enough for chest CT
  - Routine pre-contrast prior to post-contrast CT should be avoided
  - Diffuse lung Dz: Dose should not be multiple folds higher (helical vs. axial)

- Scan length: Must be limited to what is absolutely needed
  - Routine chest: lung apex to adrenal glands
  - Lung nodule follow up, pulmonary embolism, and lung cancer screening: Lung bases to apex

CHEST CT PROTOCOLS: GOOD POINTS

- Beam collimation:
  - Wider beam collimation for most routine CT: More efficient (esp. < 64 slice)
  - For variable detector array systems: Choice depends on required need for specific slice thickness
  - Ex: 16 x 0.75 mm if < 1 mm slice are required
  - Ex: 16 x 1.5 mm when >1.5 mm slices required

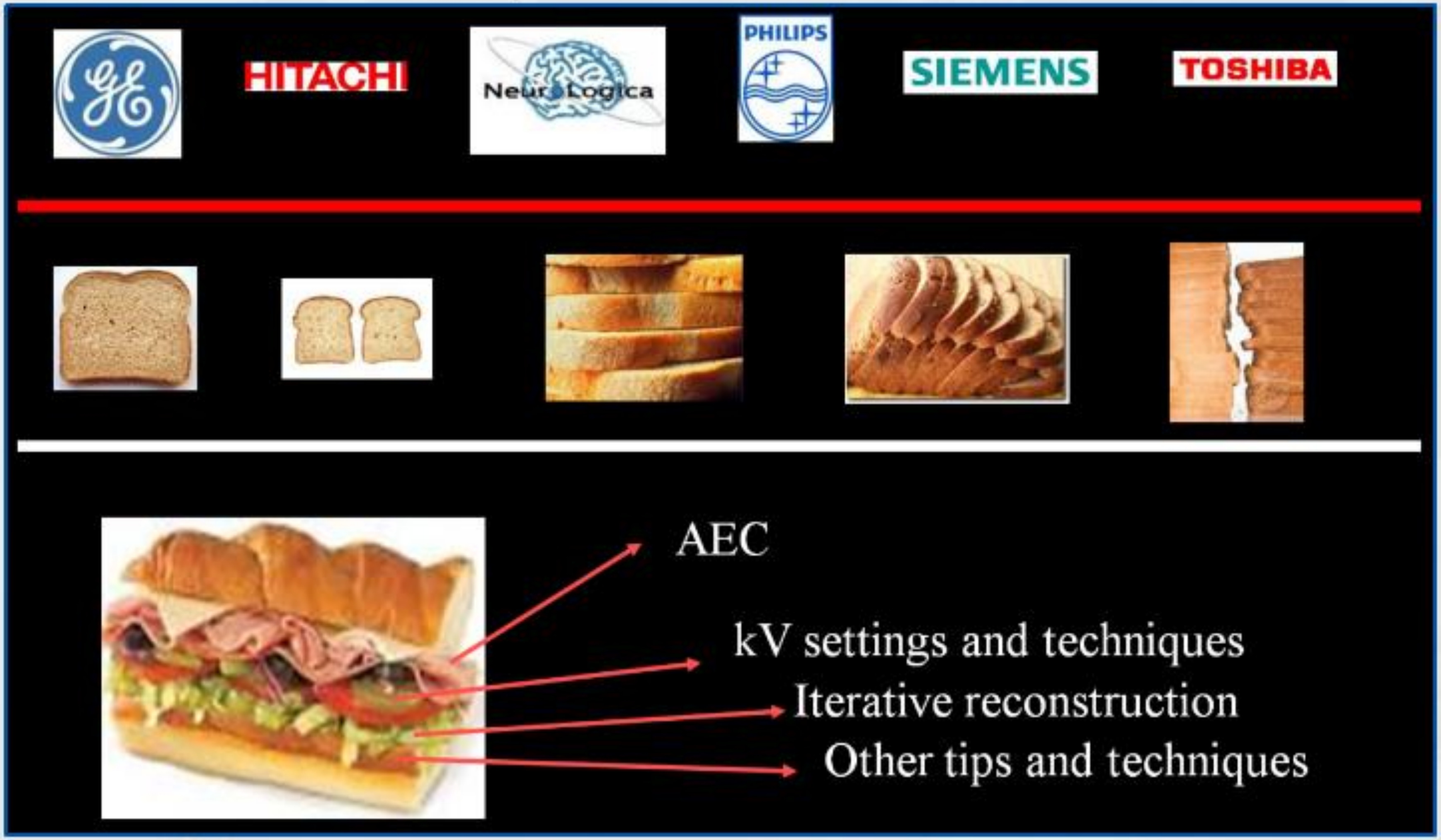
- Gantry rotation speed: Fast to minimize motion artifacts (0.4-0.5 s)

- Reconstruction kernels
  - Standard or detail: thinner slices (cardiac CT or CTA) or lower dose
  - Sharper: Bones and Lungs

INDICATION DRIVEN CT PROTOCOLS

Protocol	Clinical Reasons	Specific instructions
Routine chest with IV contrast	Masses, infections, trauma to lungs, mediastinum, pleural	Prone: Pleural effusion Low Dose
Routine chest without contrast	Elevated creatinine for above, Follow-up nodule in pt's with CA	Prone: Pleural effusion Low Dose
Lung nodule follow up	Follow up nodule without known malignancy	Non contrast Low dose
Diffuse lung disease protocol	e.g. Sarcoid, bronchiolitis obliterans, ILD, pulmonary fibrosis,	+ Expiratory & Prone images: Limited LD
Pulmonary Embolism	Suspected or known PE	Start from lung bases and not adrenals
Tracheal protocol	Tracheobronchomalacia Tracheal stenosis	Lower dose Inspiratory & expiratory images

KNOW THY SCANNER



SEARCH FOR THE OPTIMAL BLEND: THE MAGIC PROTOCOLS?

CHEST
1/19/10

CT PROTOCOL
HD 64 SLICE
GE Scanner

Parameter	Value
Scanner	Magique Optimale
Profile	1024 Stealth mode
KV	Scanner determined
mA	Scanner determined
Rotation time	Scanner determined
Slice thickness	0.1 mm, and 5 mm
Reconstruction kernel	Blend Edge sharp, substance soft
Recon Technique	MRT (magical recon technique)
CTDIvol	**0.1 mGy**
DLP	**6.0 mGy.cm**

LOCALIZER RADIOGRAPH

Chest - Routine

Indications:	Lung mass, lymphoma, adenopathy, infection, pneumonia, pulmonary obstructive disease, abnormal chest x-ray, lymphadenopathy, lump in chest, back pain, chest pain, hemoptysis, fatigue and malaise SP ablation	
IV Contrast:	370mg	65 cc under 200 lbs
		80 cc over 200 lbs
	Saline	40 cc
IV:	20 Gauge	
Oral Contrast:	Positive contrast for CHEST ONLY exams	
Delay:	35 sec	
Rate:	2-2.5 cc/sec	

SERIES 1:	**SCOUTS**	
Landmark		SN
Scout		AP and LAT
Technique		80 kV 20mA

SERIES 2:	**CHEST I+ 35 sec delay**	Recon 2: HRCT apex -CP
	CHE	
Scan delay		
Location		
Mode		
Time		
Thickness		
Detector		
Pitch		
Speed		
Interval		
Gantry Tilt		
SFOV		
kV		
DFOV		
ALG		
ASIR		
Patient Weight	Noi	
under 135 lbs		
136-200 lbs		
over 200 lbs		

SERIES 4:		
Location		
Mode		
Time		
Thickness		
Pitch		
Speed		
Interval		5 mm (limit to area of effusion)
Gantry Tilt		0
SFOV		Large
kV		100
mA		100
Noise Index		N/A
DFOV		skin to skin
API		Inspiration
ALG		ASIR 30 Standard

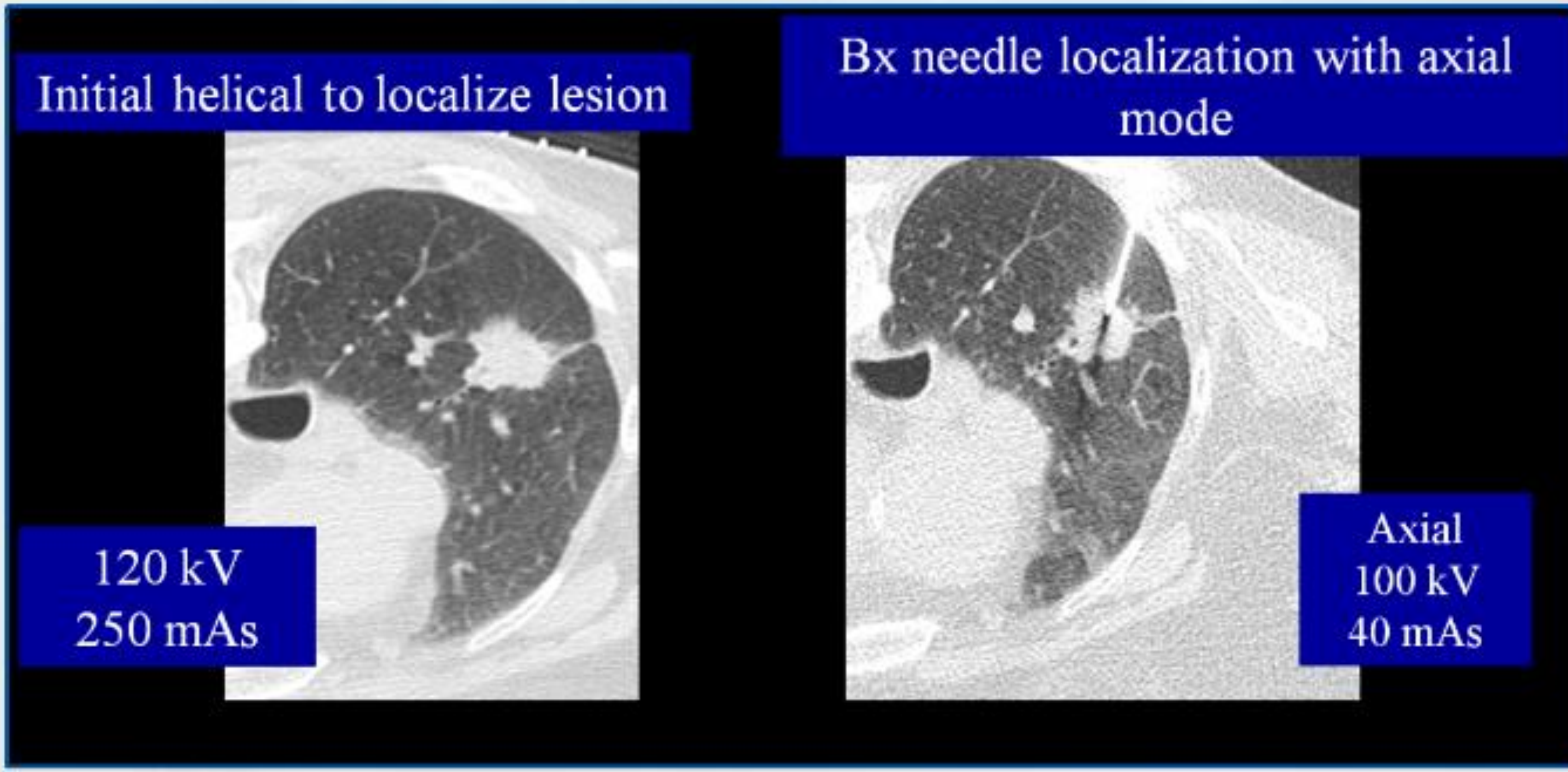
Remember good "centering" = good AEC and quality

Reduce dose for localizer radiograph

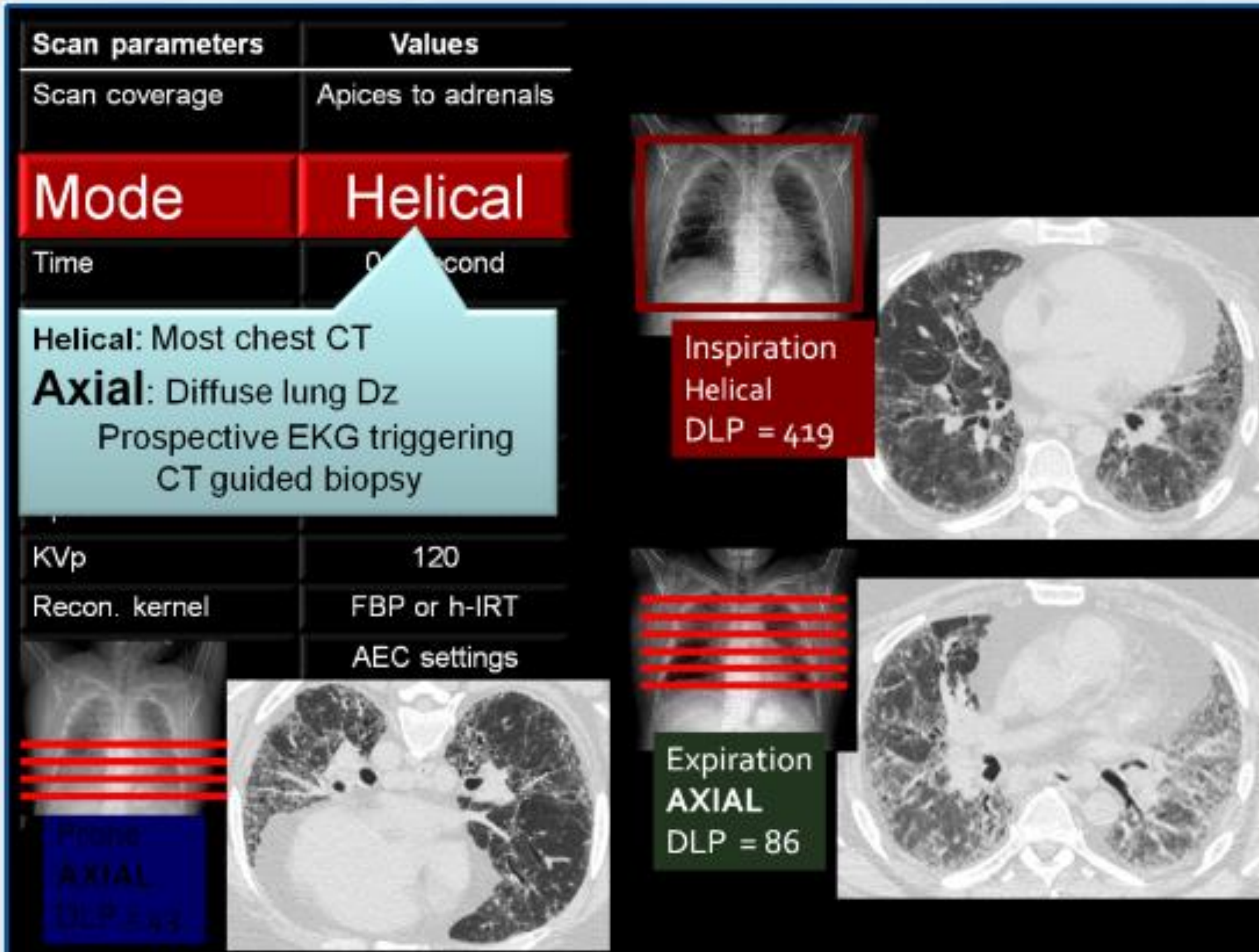
- Two localizers are better than one for good centering
- Considerable variation between how different vendors use these for AEC: Some use both localizers and others use the last one

DOSE REDUCTION WITH AXIAL MODE

After lesion localization, reduce dose for CT guided Bx
- Axial acquisitions
- Reduce scan length and mA &/or kV

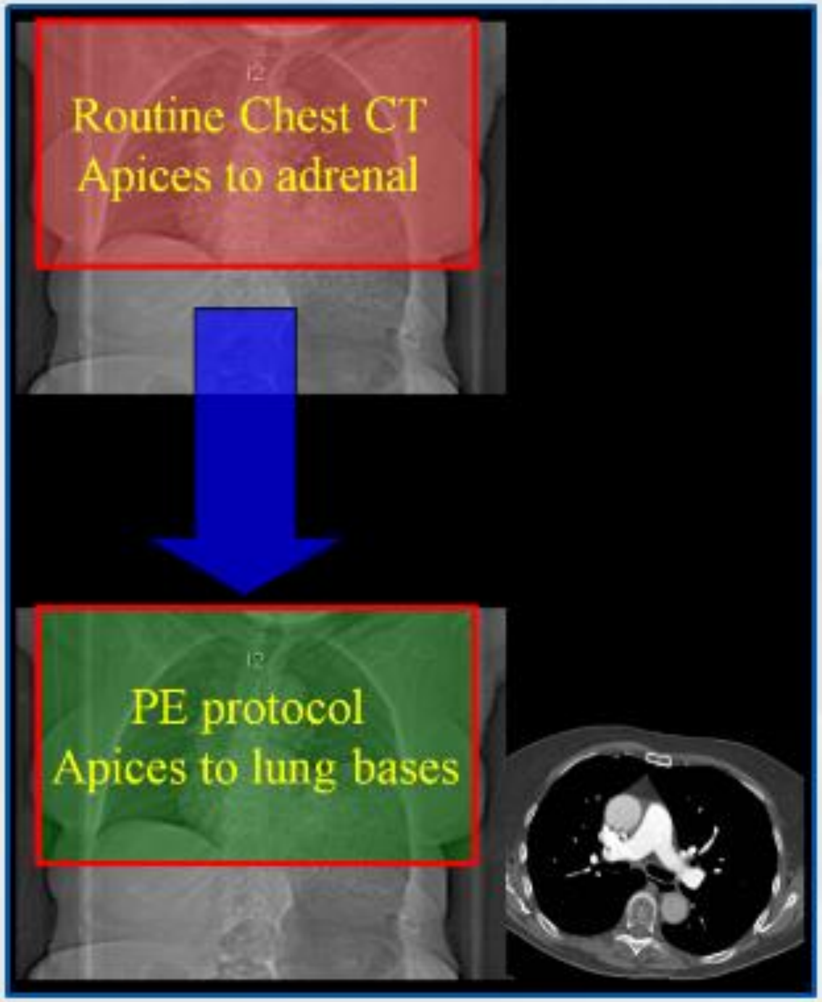


GOOD CT: DIFFUSE LUNG DISEASE. HELICAL VS AXIAL MODE



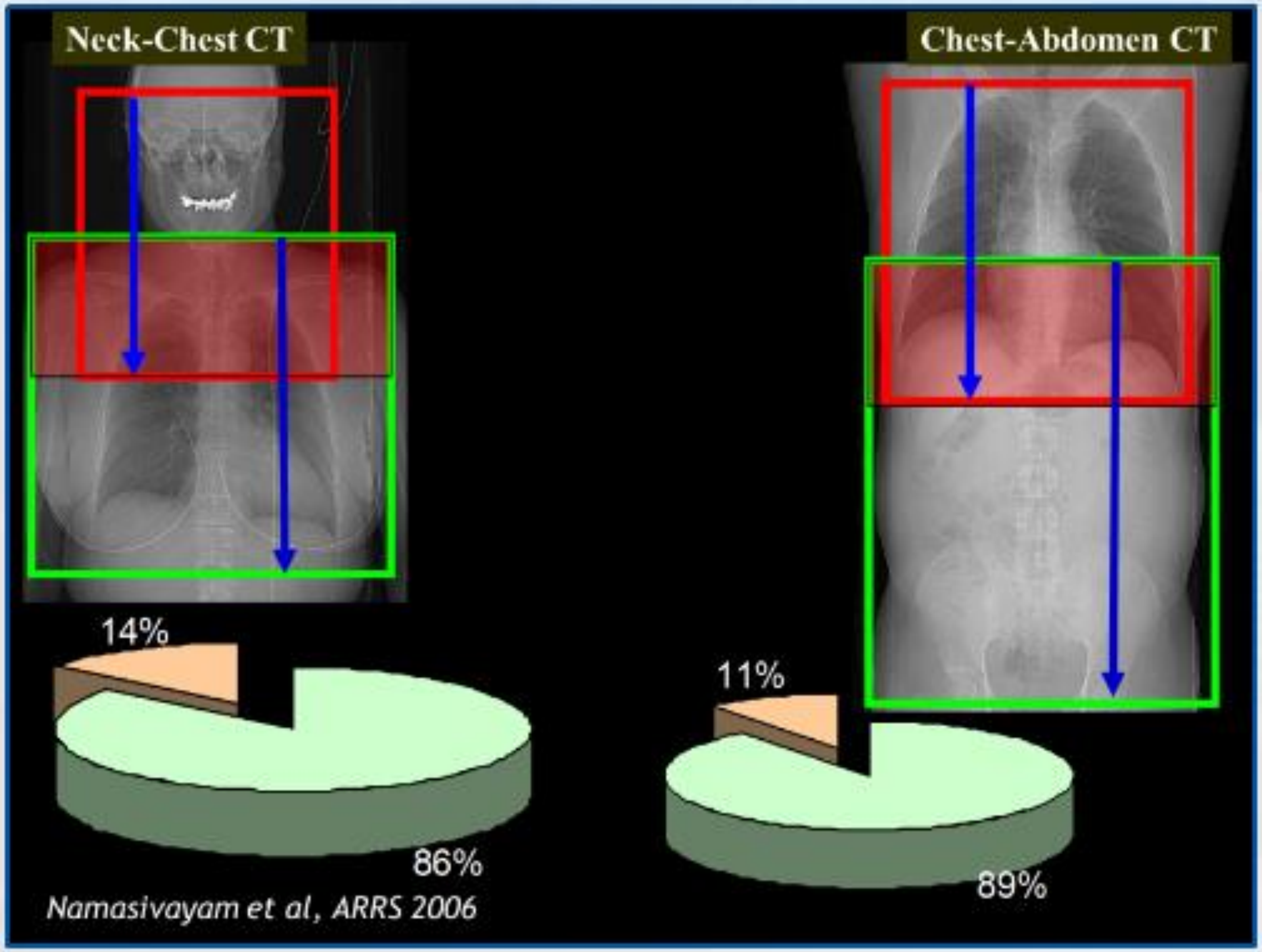
LIMITING SCAN LENGTH

Shorter length = smaller dose (when all other scan parameters are constant).



SCAN OVERLAP

Minimize scan overlap to reduce dose!



TUBE CURRENT FOR CHEST CT

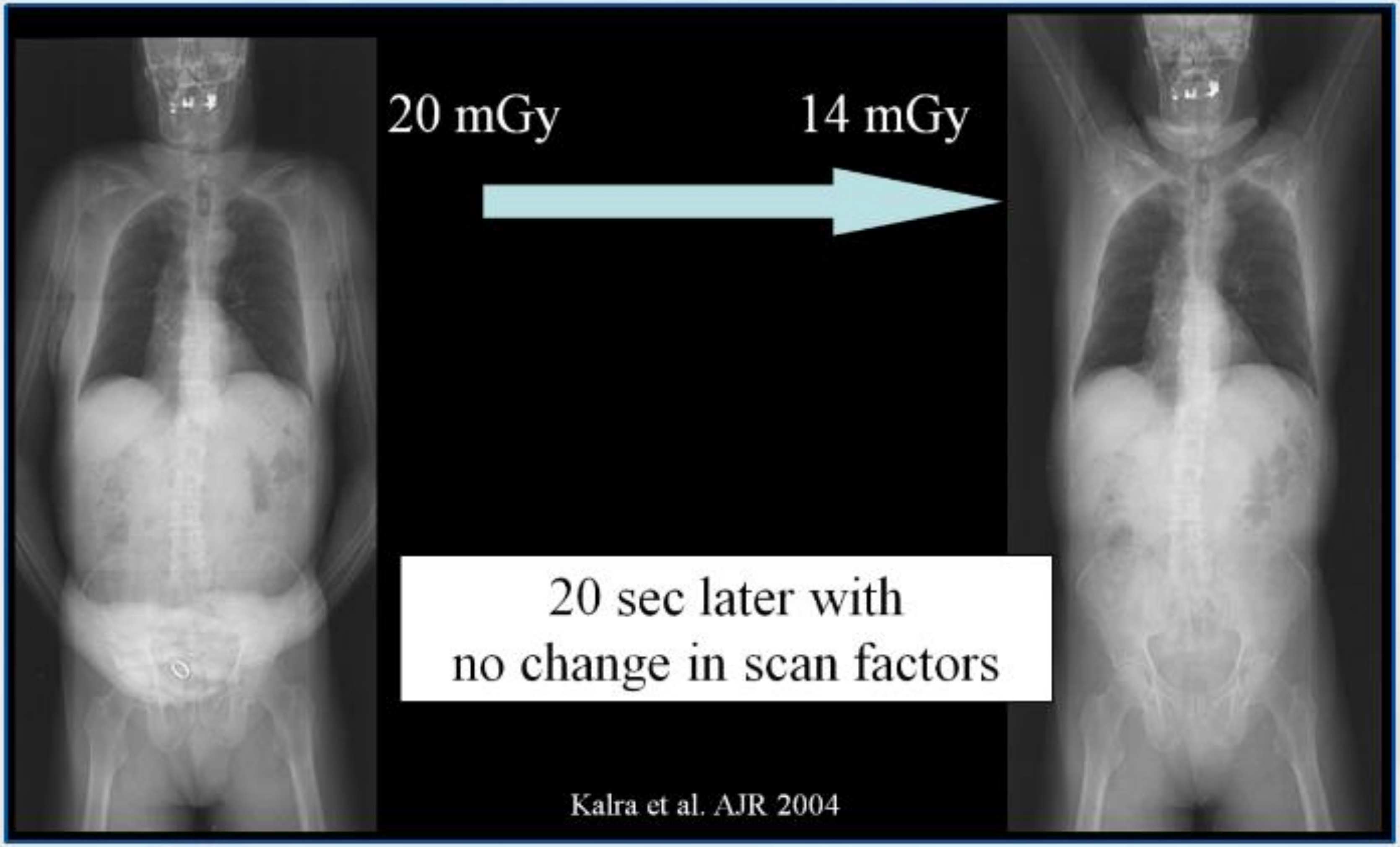
Substantial mA reduction
- Pulmonary nodule
- Pediatric lungs
- Follow up cystic fibrosis
- Pleural effusion drainage
- Lung cancer screening
- Central airways
- Needle localization for biopsy

Controlled mA reduction
- Mediastinal abnormalities
- Lymph node evaluation
- Large patient
- Cancer staging

AEC VERSUS FIXED TUBE CURRENT

- Most chest CT should be performed with AEC
  - AEC optimizes dose to patient size
  - You optimize AEC to clinical indication
- Know the quirks, ins and outs of your AEC
  - Lower image quality is needed for chest CT than for abdomen
  - Lower image quality is needed for lung nodule than routine chest
- Some indications, like lung nodule follow up CT can be scanned with very low fixed mAs

RAISE THE ARMS FOR AEC

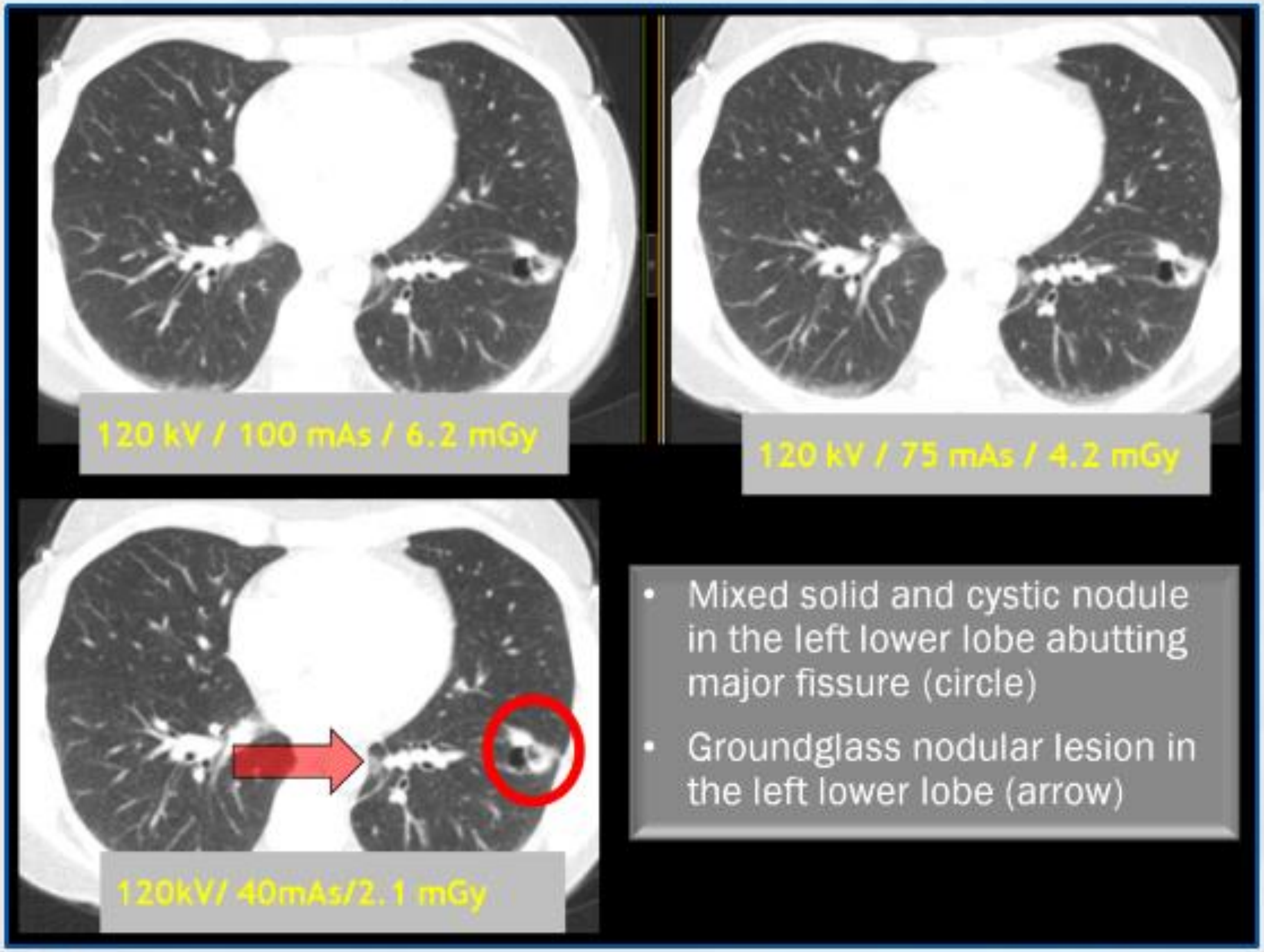


LUNG CANCER SCREENING

Scan parameters	General	Values (Ex)
Scan coverage	Apex to base	Apex to lung base
Mode	Helical	Helical
Time	Faster the better	0.5 second
Pitch	Pitch ≥ 1	0.984
Speed	Faster is better	40 mm/rotation
Recon. thickness	1 and 3 mm	1 or 1.25mm and 3 mm
Detector collimation	Wider is more efficient	16 X 1.25mm
KV	100-120	120
AEC or fixed mA	Either	AEC better than fixed mA
Target CTDI vol	1.5 - 3 mGy	-

Substantially lower mAs compared to routine chest CT
With iterative reconstruction, 30-40% lower dose possible

LUNG CANCER SCREENING



LUNG NODULE FOLLOW UP CT

Scan parameters	General	Values (Ex)
Scan coverage	Apex to bases	Apex to lung bases
Mode	Helical	Helical
Time	Faster the better	0.5 second
Pitch	Pitch ≥ 1	0.984
Recon. thickness	1 and 3 mm	1 or 1.25mm and 3 mm
Detector collimation	Wider is more efficient	Wider is better if at least 1.25 mm thin slices
KV	100-120 kV	120
AEC or fixed mA	Either	Prefer AEC over fixed
Target CTDI vol	1.5 - 3 mGy (FBP) Target lower for iterative reconstruction	-

Follow up protocol should be well defined
Whether Fleishner or ELCAP for > 4mm nodules

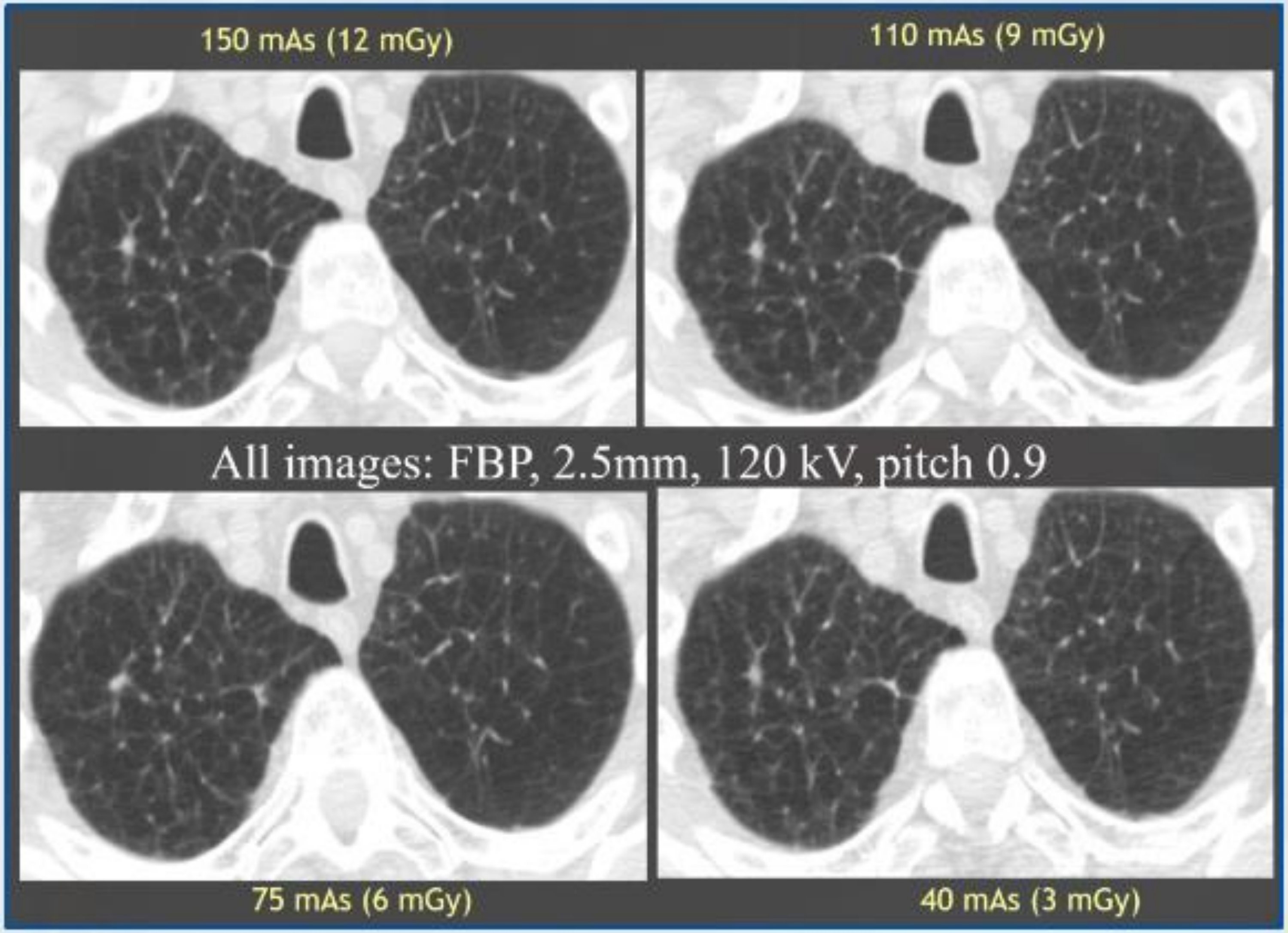
LOW DOSE FOR LUNG NODULES

- Low fixed mAs may be as good as AEC
- Dose reduction not only depends on appropriate scan parameters but also follow up need and duration

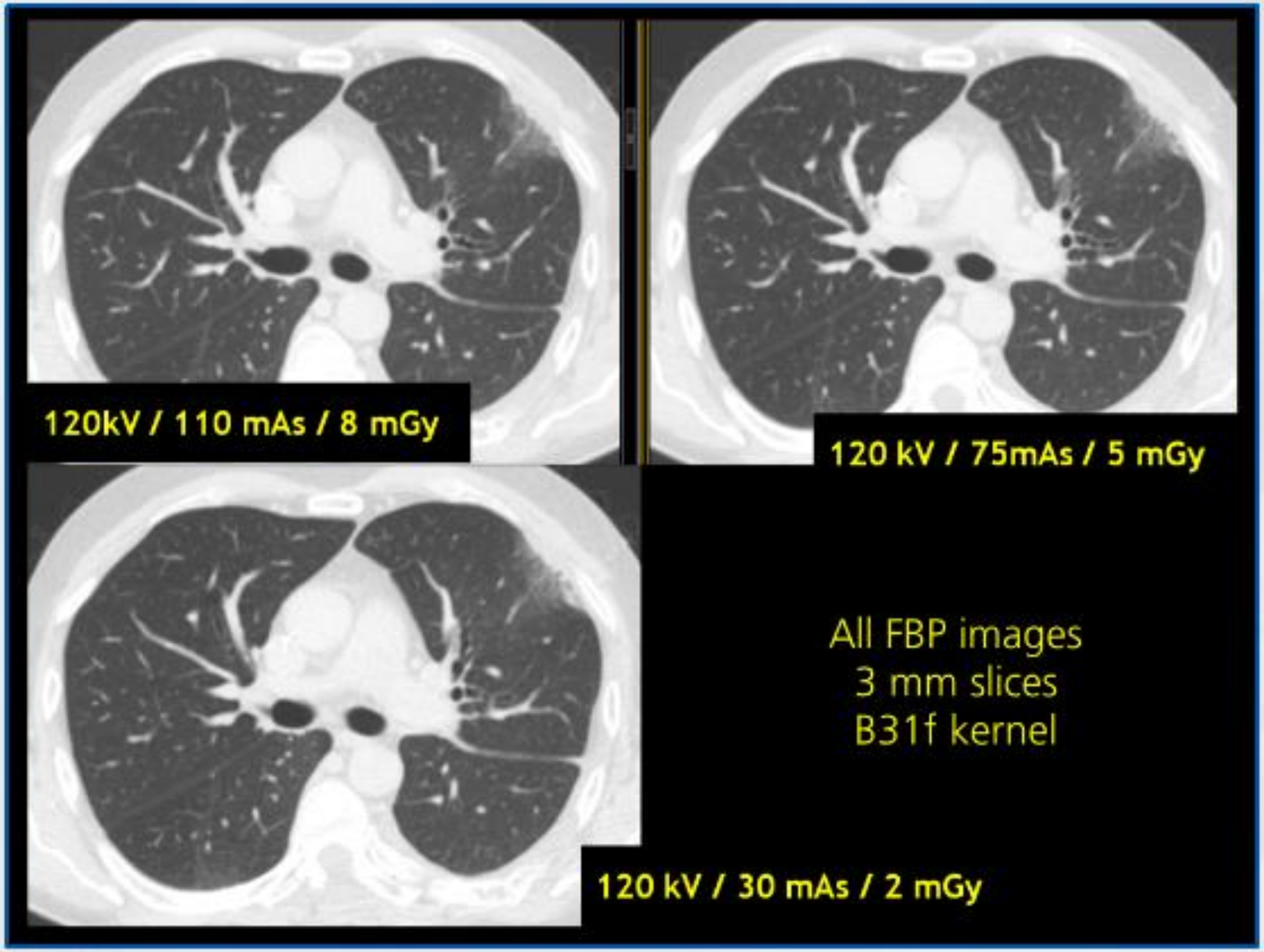
Study & year	kV	Standard mAs	Smallest aceptable mAs for lung nodules
Rusinek (1998)	120	200	20
Gartehnschlanger (1998)	120	200	30
Diederich (1999)	120	100	25
Nitta (1999)	120	50	6
Itoh (2000)	120	-	20
Karabulut (2002)	120	200	50

Kubo et al. AJR 2008

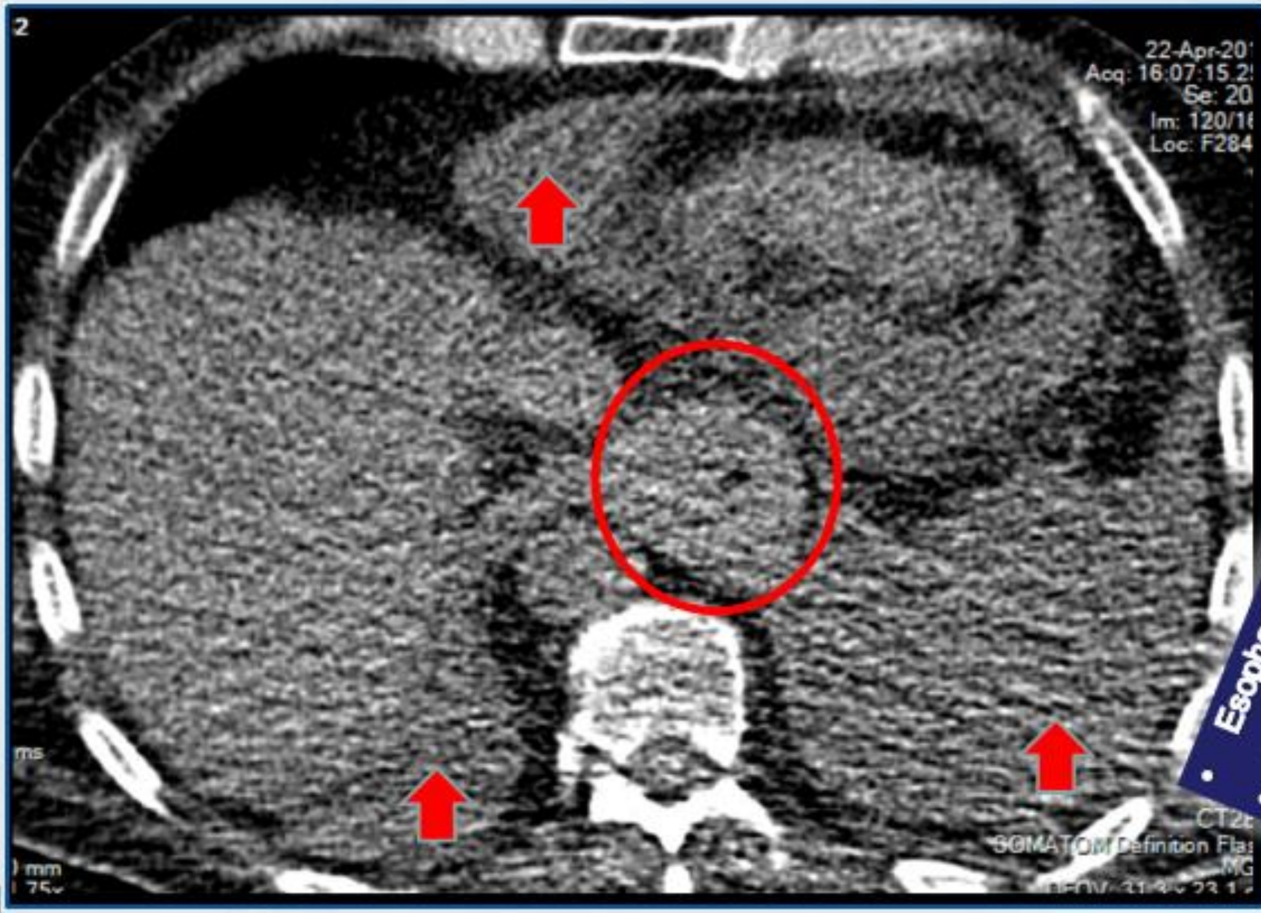
LUNG FINDINGS AT LOW RADIATION DOSE



LUNG FINDINGS AT LOW RADIATION DOSE



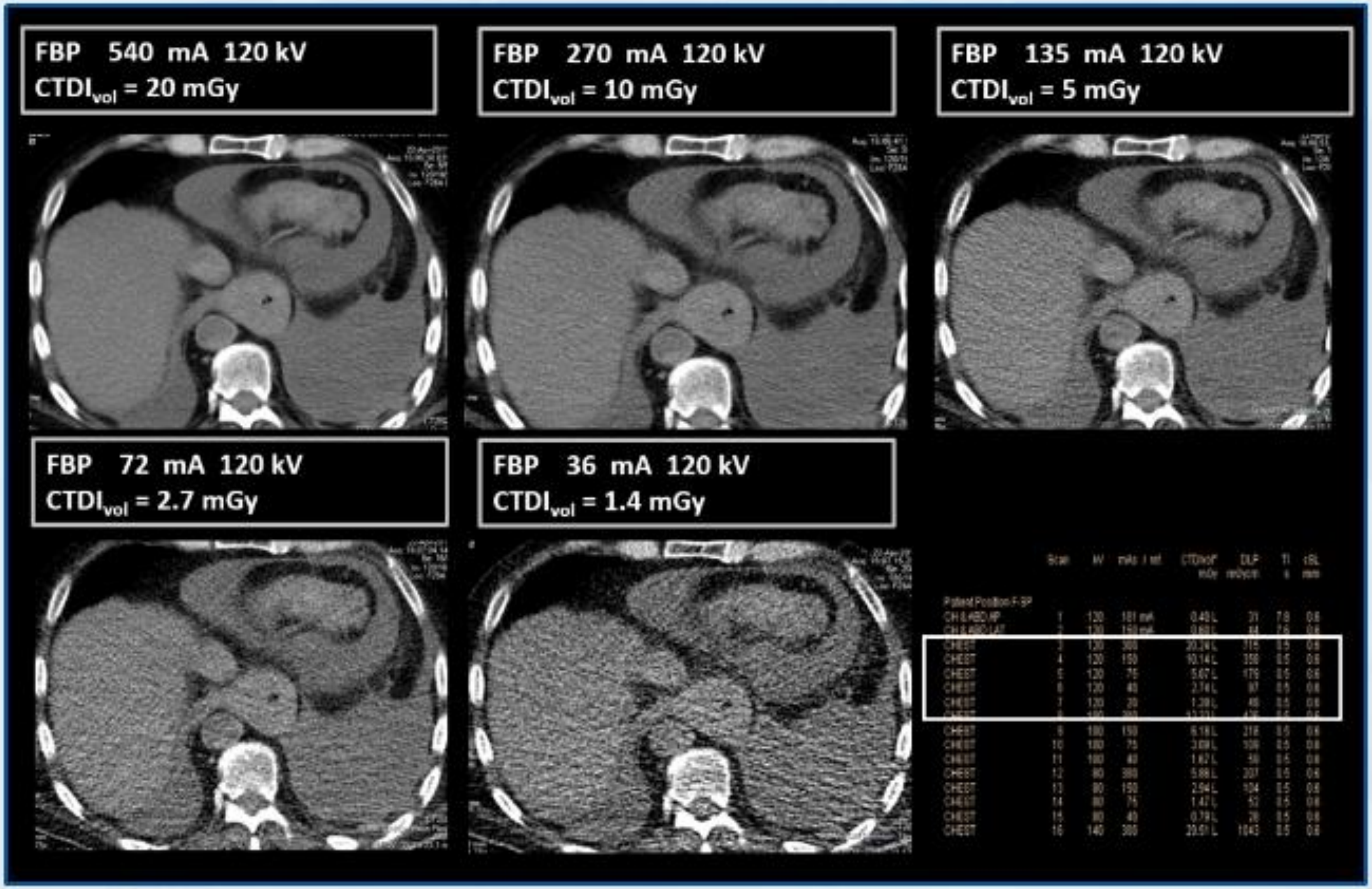
MEDIASTINUM



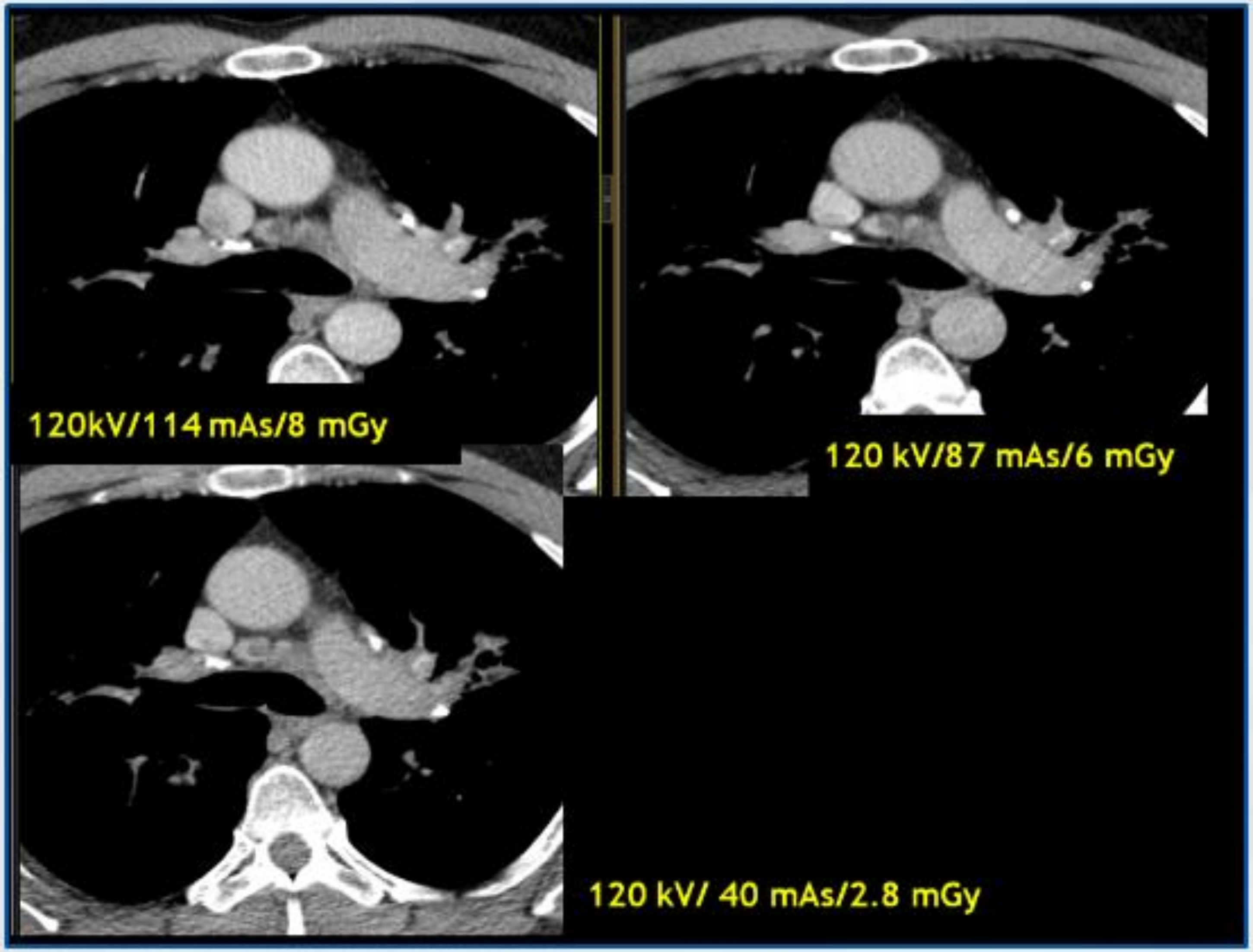
FBP
36mA 120 kV
$CTDI_{vol}$ = 1.4 mGy

- Esophageal mass
- Pericardial and pleural effusions

MEDIASTINUM

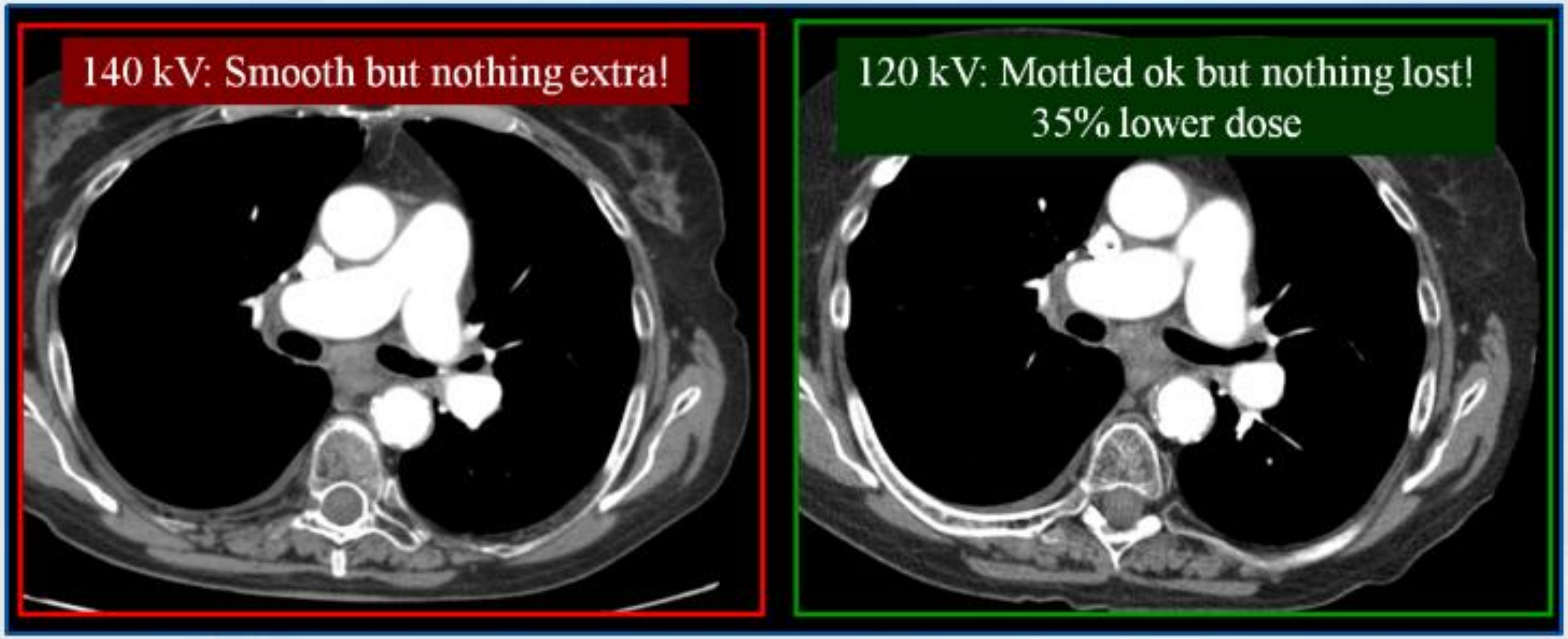


ROUTINE CHEST CT



kV REDUCTION: CHEST CT

- No use for 140 kV for chest CT : Kills contrast
- Routine chest CT in children: 80 or 100 kV (70 kV on some CT)
- Routine chest CT with contrast in adults ⩽100 kV for most patients
- Pulmonary embolism CT: ⩽100 kV for ⩽ 80 kg

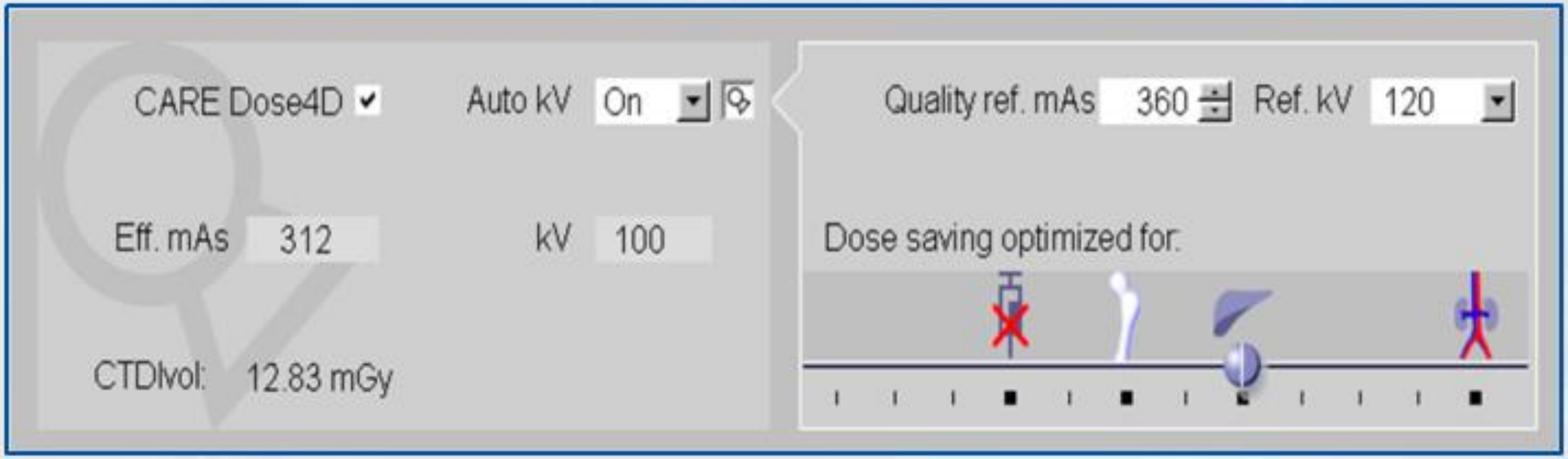


AUTOMATIC kV SELECTION

- Care kV, Siemens and kV Assist, GE

- System automatically identifies optimum kV setting (Care kV)
  - Body habitus (from planning radiograph)
  - Exam type (non-contrast, bone, standard contrast, vascular)
  - System limits (tube current)

- System automatically proposes kV and corresponding mAs values



TUBE POTENTIAL (kV): CHEST CT

Chest CT	kV
Children (<50 kg)	80
Adults	80 (< 50 kg); 100 (50-80 kg) 120 (> 80 kg or > 30 BMI)
Almost never	140

Encourage use of lower kV:

- Lung nodules FU
- Post contrast chest CT
- Chest CT angiography

DETECTOR CONFIGURATION AND BEAM COLLIMATION

Scan parameters	Values
Scan coverage	Apex to adrenals
Mode	Helical
Time	0.5 second
Recon. thickness	2.5 mm
Detector collimation	64 x 0.625 mm
KV	kV Assist
Recon. kernel	FBP or IRT
Patient Weight	AEC settings
<60 kg	32 NI (100-200)
61-90 kg	35 NI (100-250)
>91 kg	38 NI (100-400)

Prefer wider beam collimation

- Chest: Wider 64 >32 > 16

On 16 slice CT or lower, choice depends on desired slice width

- <1mm: smaller width- less dose efficient
- >1mm: wider width- more dose efficient

PITCH

Scan parameters	Values
Scan coverage	Apices to adrenals
Mode	Helical
Recon. thickness	2.5 mm
Pitch	0.984
Speed	40 mm/rotation
KV	kV Assist
Recon. kernel	FBP or IRT
Patient Weight	AEC settings
<60 kg	32 NI (100-200)
61-90 kg	35 NI (100-250)
>91 kg	38 NI (100-400)

- Many but not all scanners adapt mA to keep dose constant irrespective of pitch
- Scan speed and not dose should govern pitch
  - Pitch close to 1 suffices

EXCEPTIONS:

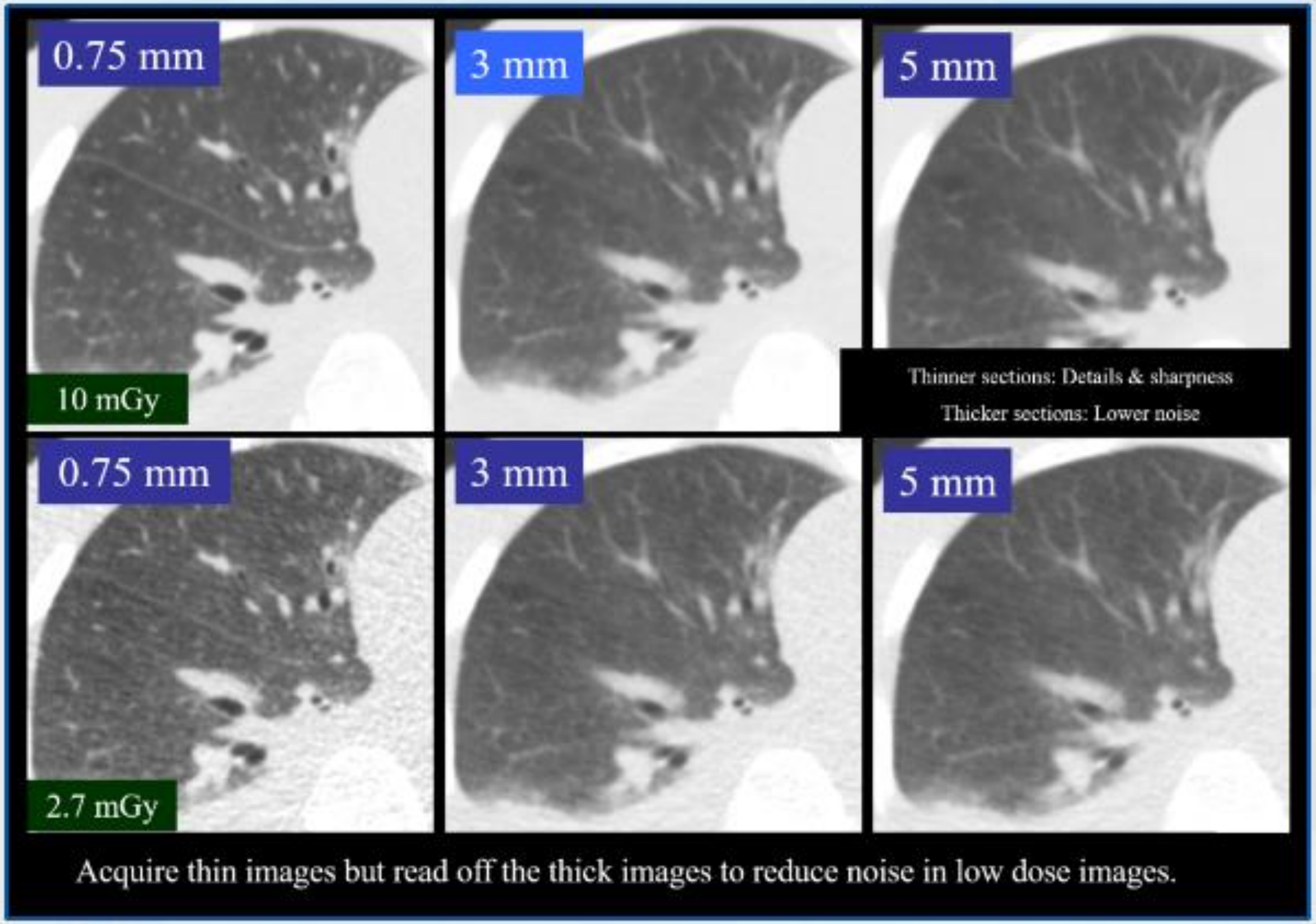
- Large patient: lower pitch
- Highest pitch and fastest rotation time for uncooperative patients and children are optimal

SCAN PHASES AND SECTION THICKNESS

- Scan series : Generally 1 series enough
  - No routine non-contrast CT before post contrast images
  - Diffuse lung diseases: Helical (low mA) or Axial (1 @ 10-20mm)
  - Tracheal protocol: Use lower dose overall, esp. expiration

- Slice thickness: Acquire thin, reconstruct thick and MPR
  - Beware of some scanners where prospective slice thickness is linked to mAs with AEC (Auto mA, GE)

CHEST CT RECONSTRUCTED AT VARIOUS SLICE THICKNESSES

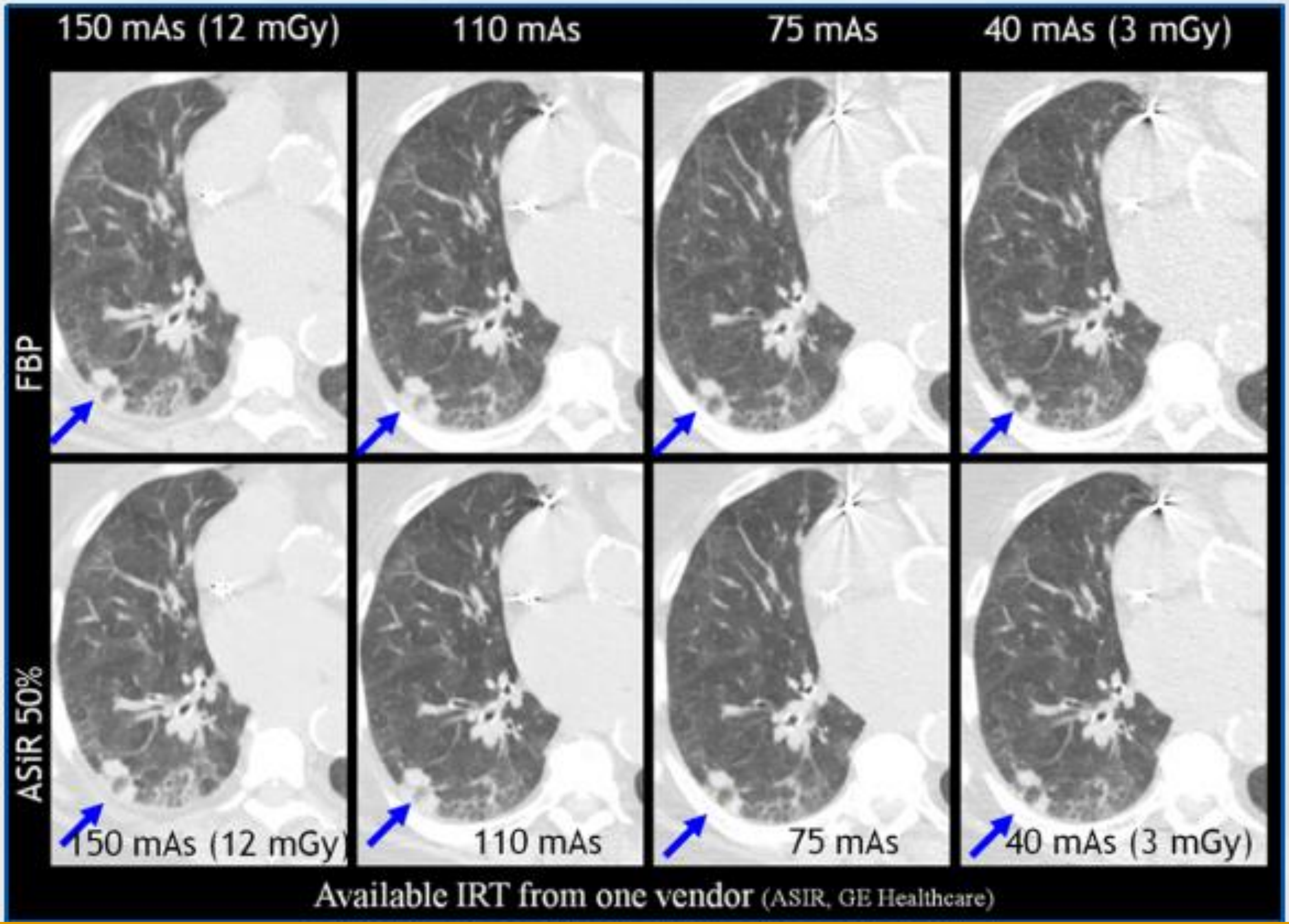


DOSE AND RECONSTRUCTION ALGORITHMS

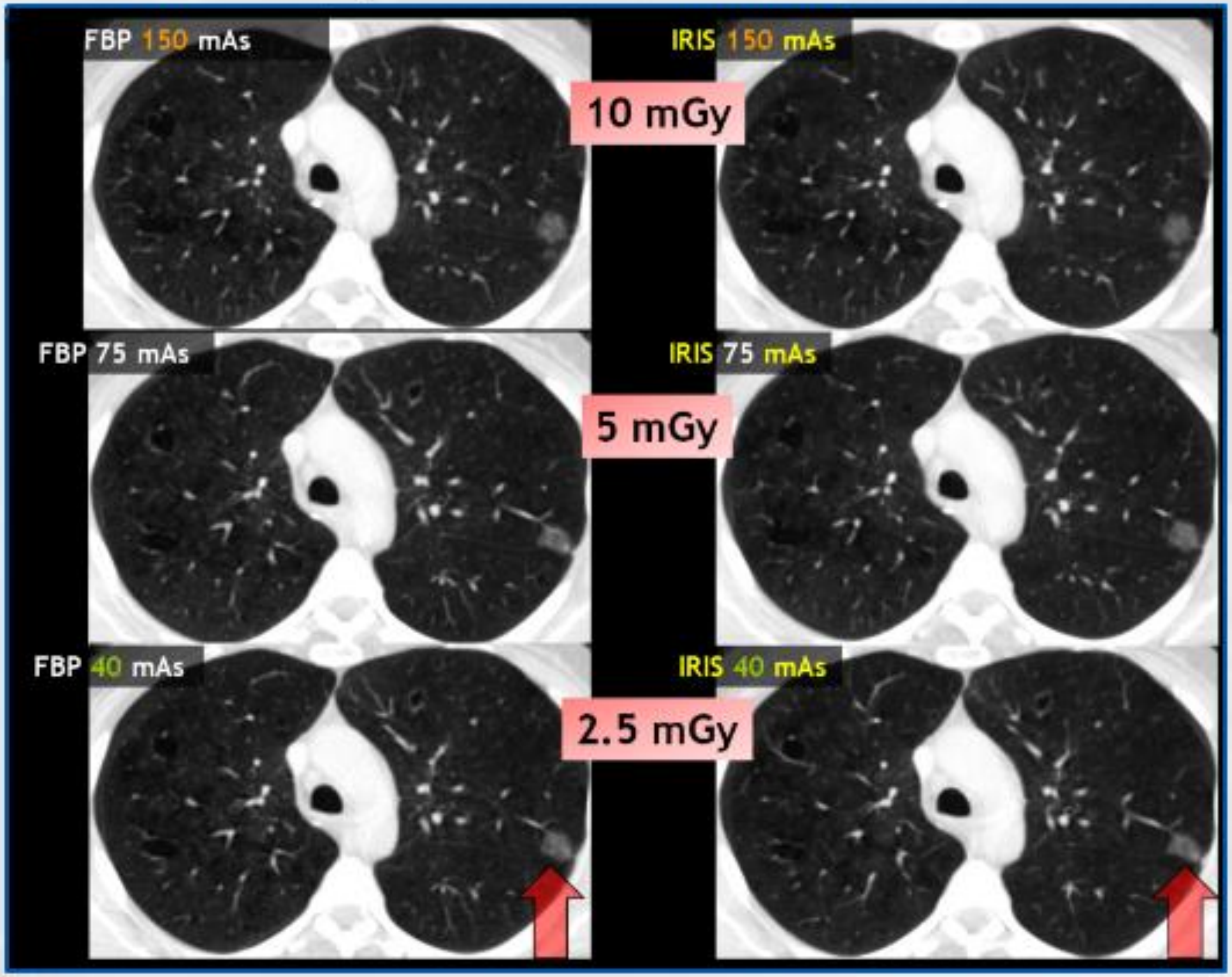
- FBP reconstruction algorithms have limited dose reduction capabilities due to:
  - Higher image noise in lower dose images
  - Lower artifact suppression

- Newer Iterative Reconstruction (IR) algorithm:
  - Lowers image noise as well as artifacts
  - At least 30-50% dose reduction with IR versus FBP technique
  - Start with low strength of IR at the outset and then gradually increase the strength and dose reduction.
  - Most modern MDCT scanners now come with 1 or more IR techniques

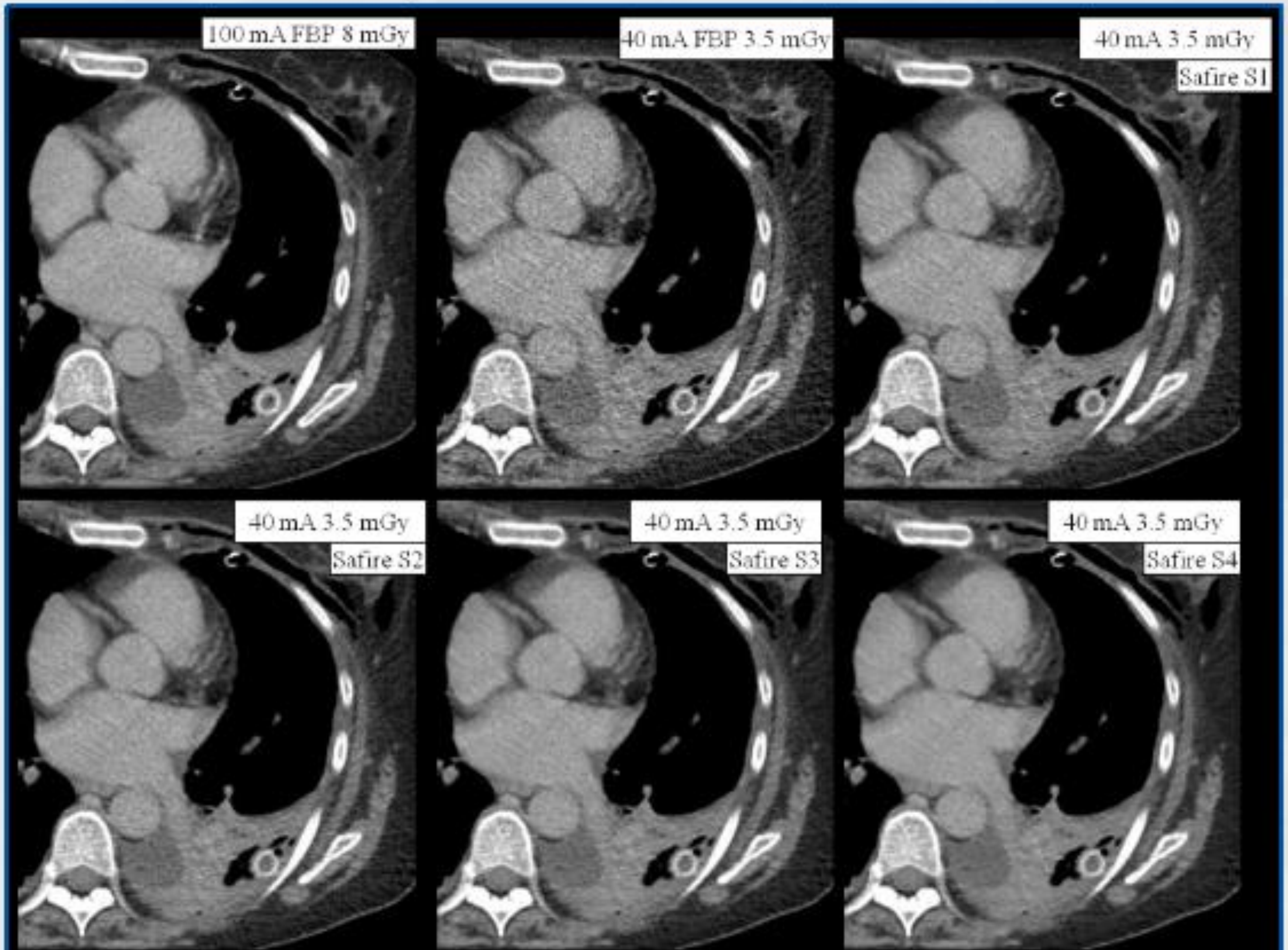
CHEST CT WITH FBP AND ITERATIVE RECONSTRUCTION



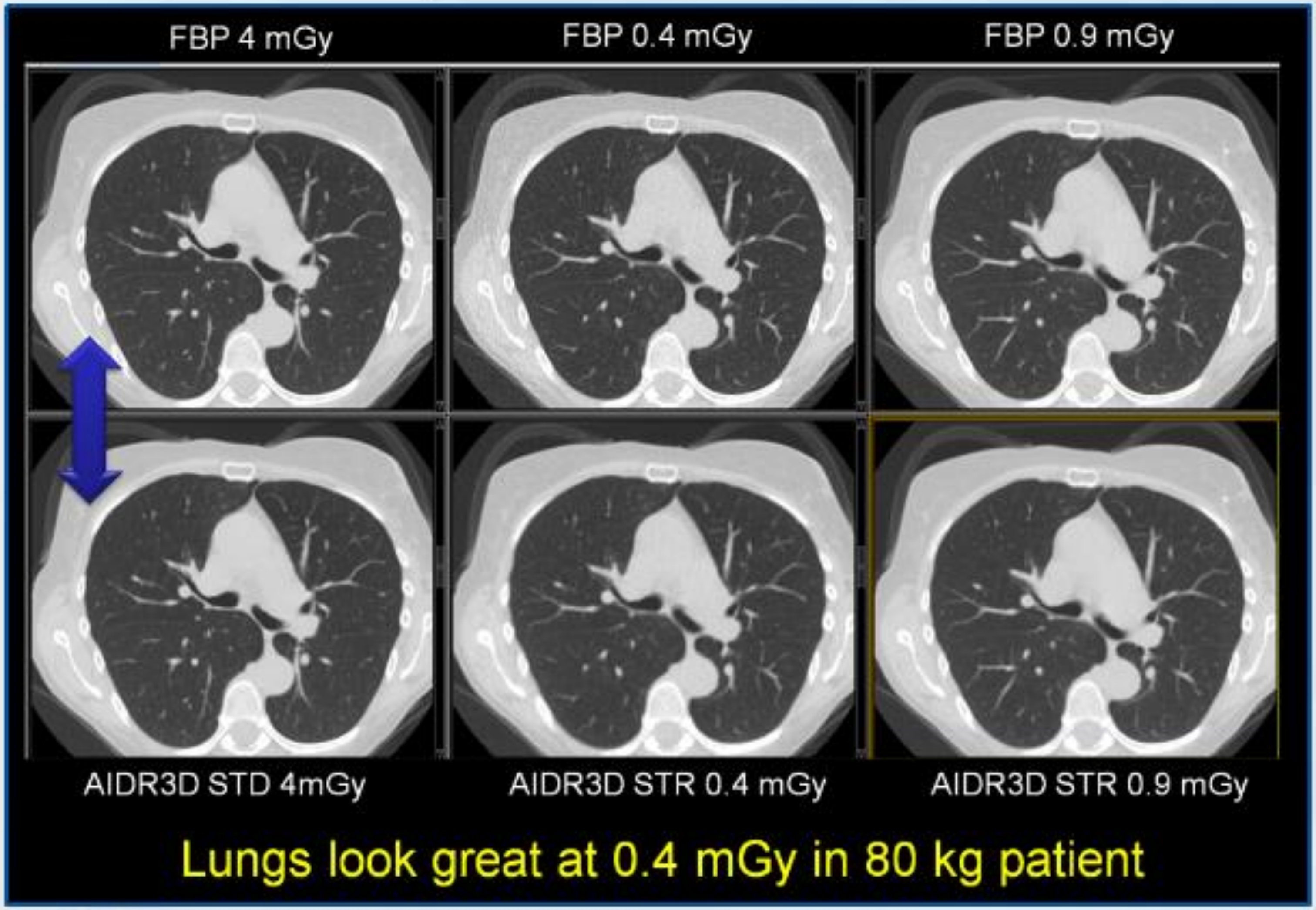
CHEST CT WITH FBP AND ITERATIVE RECONSTRUCTION



CHEST CT WITH FBP AND ITERATIVE RECONSTRUCTION



CHEST CT WITH FBP AND ITERATIVE RECONSTRUCTION



IS ABDOMEN UNIQUE FOR CT?

OBJECTIVES

- Understand key protocols based on clinical indications for abdominal CT
- Understand scan parameters used for abdominal CT
- Ensure proper use of multiple scanning passes in abdomen

PROTOCOLS: MEETING BASIC STANDARDS

Diagnostic Reference Levels and Achievable Doses for Adult and Pediatric CT ($CTDI_{vol}$)

	Patient Lateral (LAT) Dimension	CTDI Phantom Diameter (cm)	DRL (mGy)	AD (mGy)
Adult head [6,9]	16	16	75	57
Adult abdomen-pelvis [6,9]	38	32	25	17
Adult Chest [6]	35	32	21	14
Pediatric 5 year old head [6]	15	16	40	31
Pediatric 5 year old abdomen-pelvis [9]	20	16	20	14

Revised 2013 (Resolution 47)*

ACR–AAPM PRACTICE GUIDELINE FOR DIAGNOSTIC REFERENCE LEVELS AND ACHIEVABLE DOSES IN MEDICAL X-RAY IMAGING

DEVELOPING CT PROTOCOLS

"On the fly" protocol creation is not optimal

- Valuable time can be wasted for urgent CT
- Level of training between radiographers and between radiologists is different
- Errors can result in implementation since there are far too many scan parameters and protocols
- Consistency is difficult to achieve:
  - Same clinical indication and size: Similar doses
  - Different clinical indications or size: Different doses

APPROPRIATE CLINICAL REASON

Does not matter, chest or abdomen, head or big toe, the best way tackle dose remains…

SPECIFIC ABDOMINAL CT PROTOCOLS

- All scan protocols must begin with the clinical indications for their use.
- Scan protocols must be based on clinical indications
- Each scan protocol should then address
  - Number of scan phases required
  - Scan range for each phase
  - Scan parameters for each phase
  - Dose adjustment for patient size

NEED: INDICATION DRIVEN PROTOCOLS?

- Certain things can be seen at reduced dose
  - Urinary stones
  - CT colonography
  - CT enterography

- Others need higher dose to assess
  - Low attenuation liver lesions
  - Pancreatic neoplasms
  - Solid renal tumors (mediastinal LN)

CT colonography < CT urinary calculi < CT routine abdomen < CT biphasic or triphasic liver protocol

ABDOMEN CT PROTOCOLS: GOOD POINTS

- First, develop clinical indication specific protocols
- Then, ensure dose adjustment to patient size
- Tube current:
  - Perform abdominal CT with AEC
  - Avoid use of fixed mA for abdominal CT
  - Adjust mA for different clinical indications
    - Lower mAs for urinary stones/CT colonography
    - Lower mAs for iterative reconstructions than FBP
- kV selection: Automated or Manual
  - Use lower kV for small patients and children
  - Use lower kV for CT angiography (arterial phase) unless large patient

ABDOMEN CT PROTOCOLS: GOOD POINTS

- Scanning mode:
  - Helical acquisition for most abdomen CT
- Pitch for Abdominal CT
  - Non-overlapping pitch should be preferred to minimize scan duration and motion artifacts
    - Pitch should be $\leqslant 1$
- Beam collimation:
  - Wider beam collimation for most routine CT: More dose efficient
- Gantry rotation speed:
  - Fast to minimize motion artifacts (0.4-0.5 s)
  - May need to be slowed down for very large patients to increase mAs

ABDOMINAL CT PROTOCOLS: GOOD POINTS

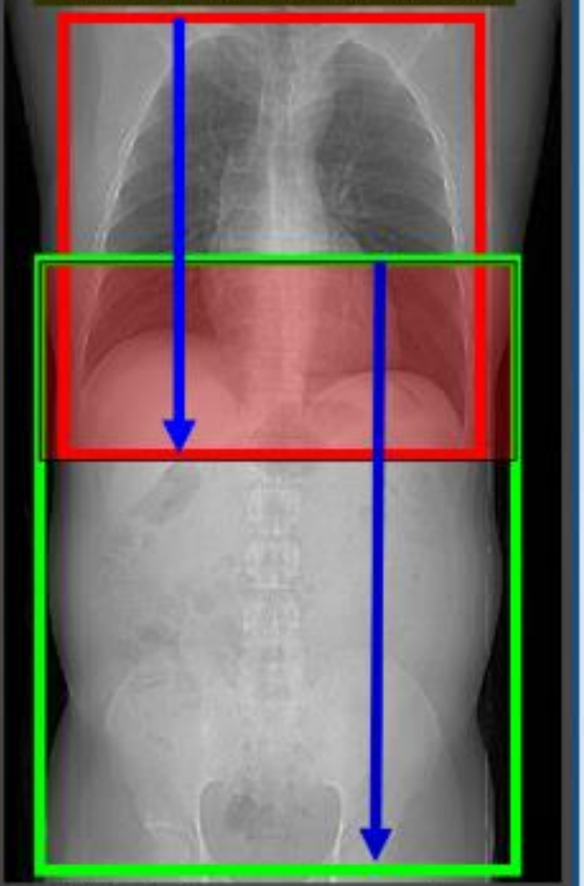
- Number of scan series for abdomen CT
  - Unfortunately, repeated scanning is common in abdomen
  - Routine pre-contrast prior to post-contrast CT should be avoided
  - When performing multiple phases, question need and technique

Multiple phases	Questions to ask and answer
Need?	Routine non-contrast phase before post-contrast: No Routine arterial and venous phases: No Routine delayed images: No
Same length?	Length for some phases can be less: Yes Ex: arterial phase liver or pancreas can be smaller length Ex: delayed phase: through the lesion only
Same dose?	Some phases can be acquired at lower dose: Yes Non-contrast: Lower dose Arterial phase: Lower kV to reduce dose Iterative reconstruction technique to enable dose reduction

SCAN LENGTH: ABDOMINAL CT

Indication	Coverage
Routine or R/O	Dome of liver - pubic symphysis
Delays	Through lesion only (not entire organ)
Kidney stone CT Urography	Top of kidneys - Symphysis
Dual phase liver	Arterial: Liver Portal venous: Entire abdomen
Appendix in young patients	Limited coverage: L3 to symphysis

Chest-Abdomen CT

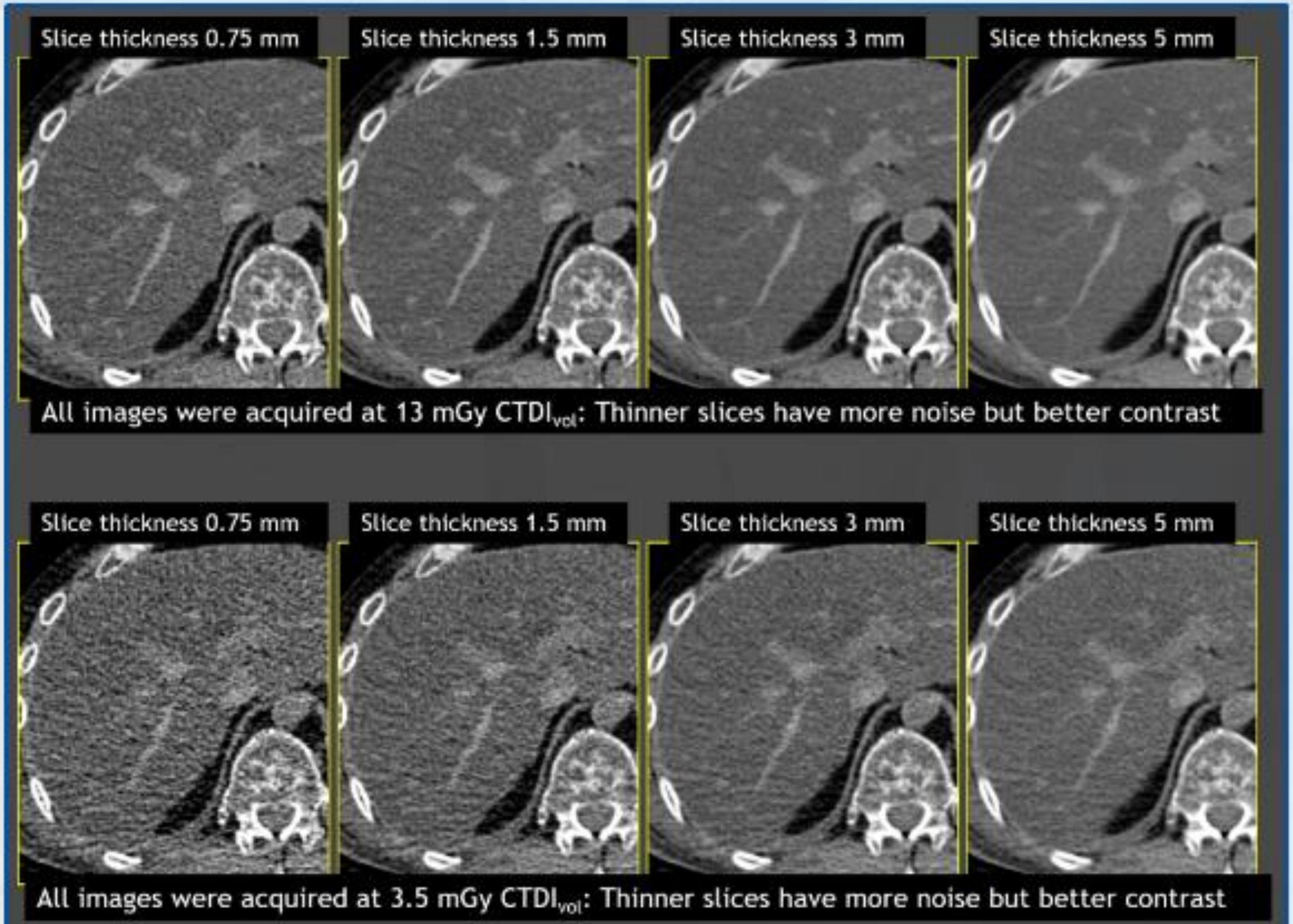


Minimize scan overlap

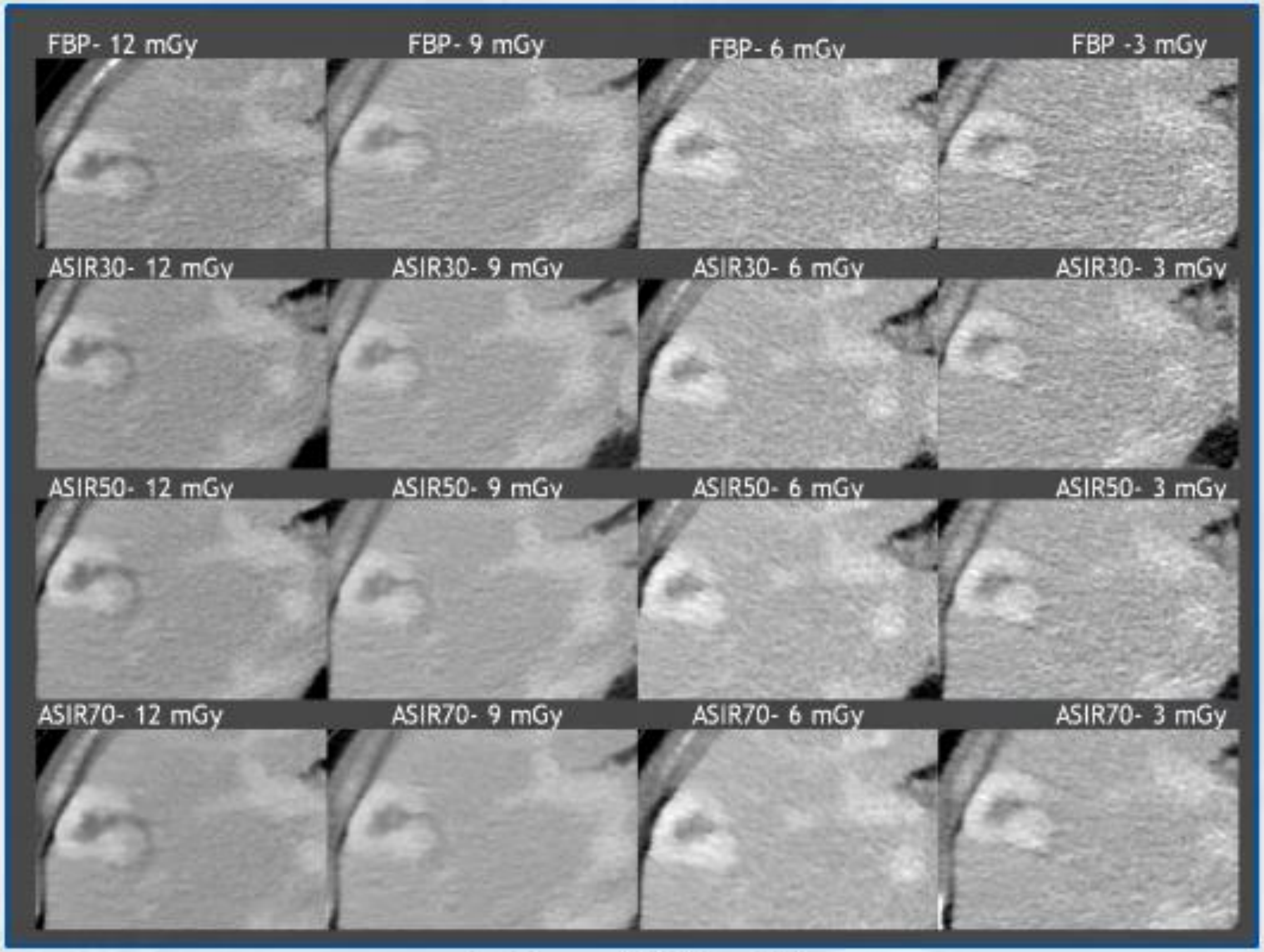
ITERATIVE RECONSTRUCTION (IR) IN ABDOMEN

- Several studies have shown reduced radiation doses with IR in abdomen CT
- Extent of dose reduction with IR relative to filtered back projection varies by clinical indication and patient size
- Generally speaking, 30-50% dose reduction can be anticipated versus FBP for abdominal CT

SELECT APPROPRIATE SLICE THICKNESS FOR ABDOMEN CT

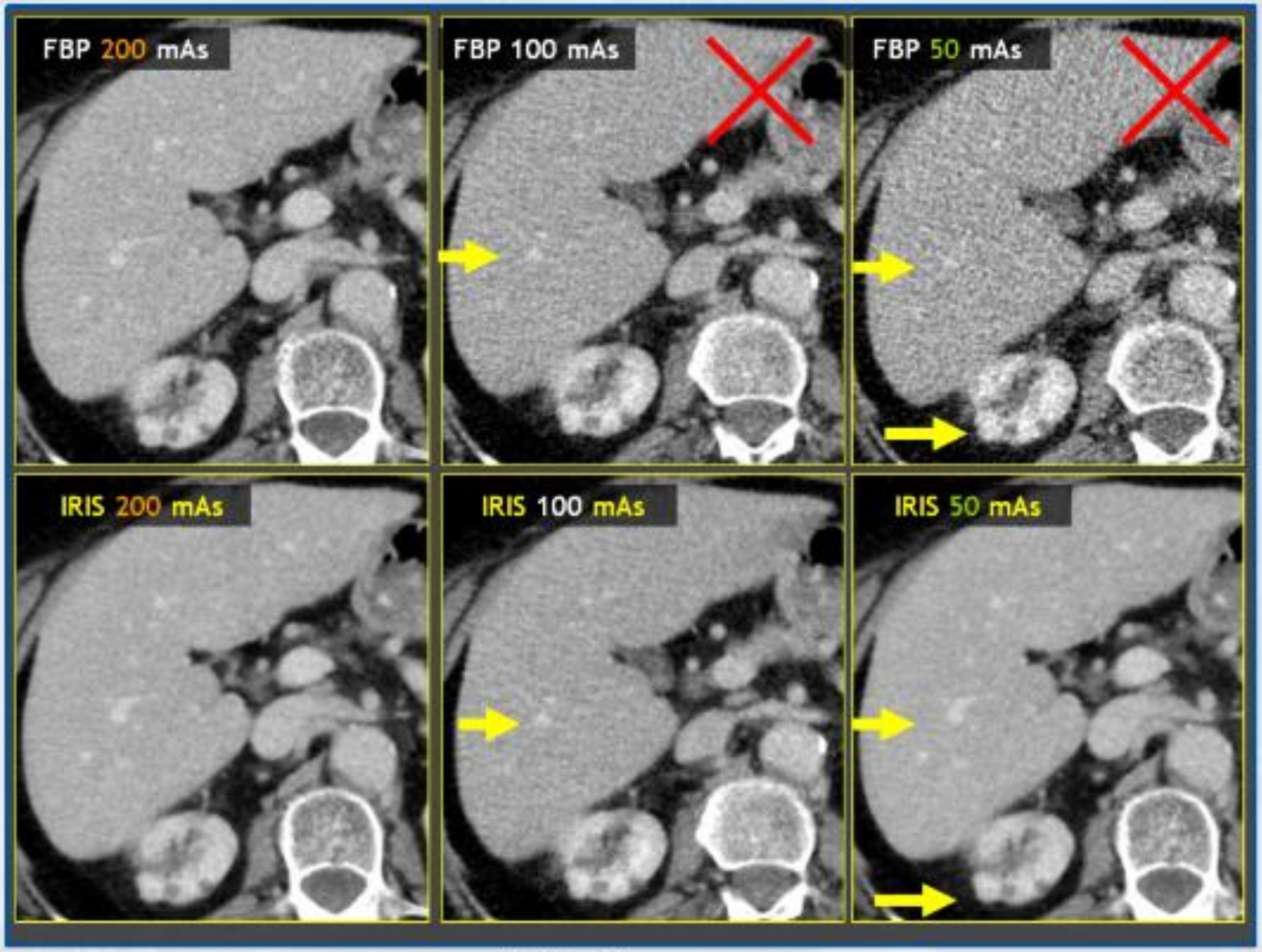


ITERATIVE RECONSTRUCTION HELP REDUCE NOISE



ASIR and VEO, GE

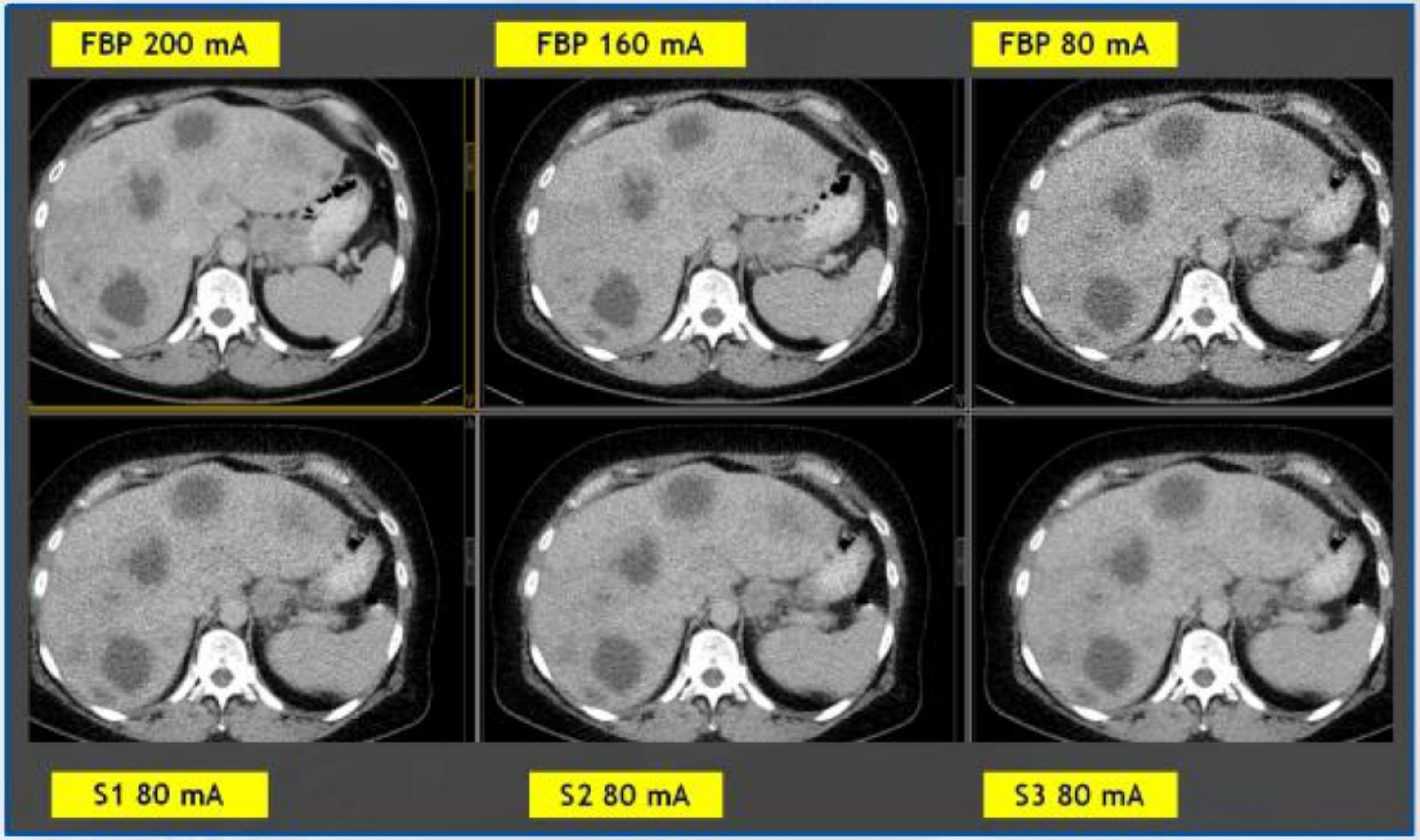
ITERATIVE RECONSTRUCTION HELP REDUCE NOISE



IRIS, Siemens

ITERATIVE RECONSTRUCTION HELP REDUCE NOISE

S1, S2, and S3 represent increasing strength of Safire for noise reduction

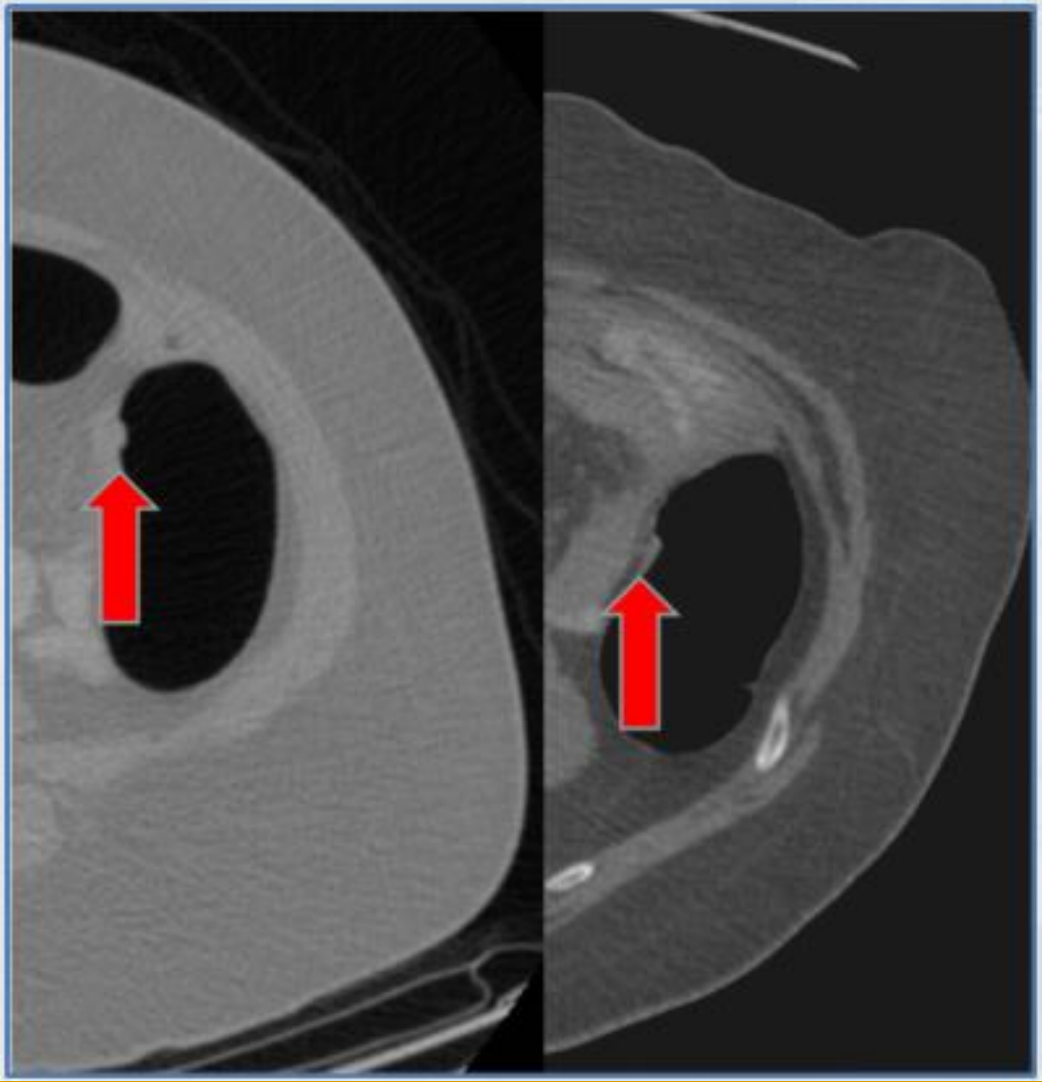


SAFIRE, Siemens

INDICATION DRIVEN ABDOMEN CT PROTOCOLS

Protocol	Clinical Reasons	Specific instructions
Routine abdomen	Masses, infections, pain, cancer staging (non-abdominal primary)	No routine non-contrast before contrast
CT urinary calculi	Suspected or known renal colic	Follow up stone CT at lower dose than initial
CT hematuria	< 40 years: non-contrast CT- Stone – No post contrast	> 40 years: non-contrast & post-contrast
CT adrenal protocol	Characterize adrenal nodule seen on chest or routine abdomen	All phases through adrenal region only
CT colonography	Screening exam, completion colonography	Lowest dose abdominal CT
CT biphasic liver	When MR can not be performed in patients with suspected liver malignancies	Arterial phase: Lower kV Arterial phase: Liver only Portal venous phase: entire abdomen

CT COLONOGRAPHY



High tissue contrast between air and colonic wall and lesions enable dose reduction

30-40 mAs: 100-120 kV
Flat polyp (8 mm)
2-4 mGy

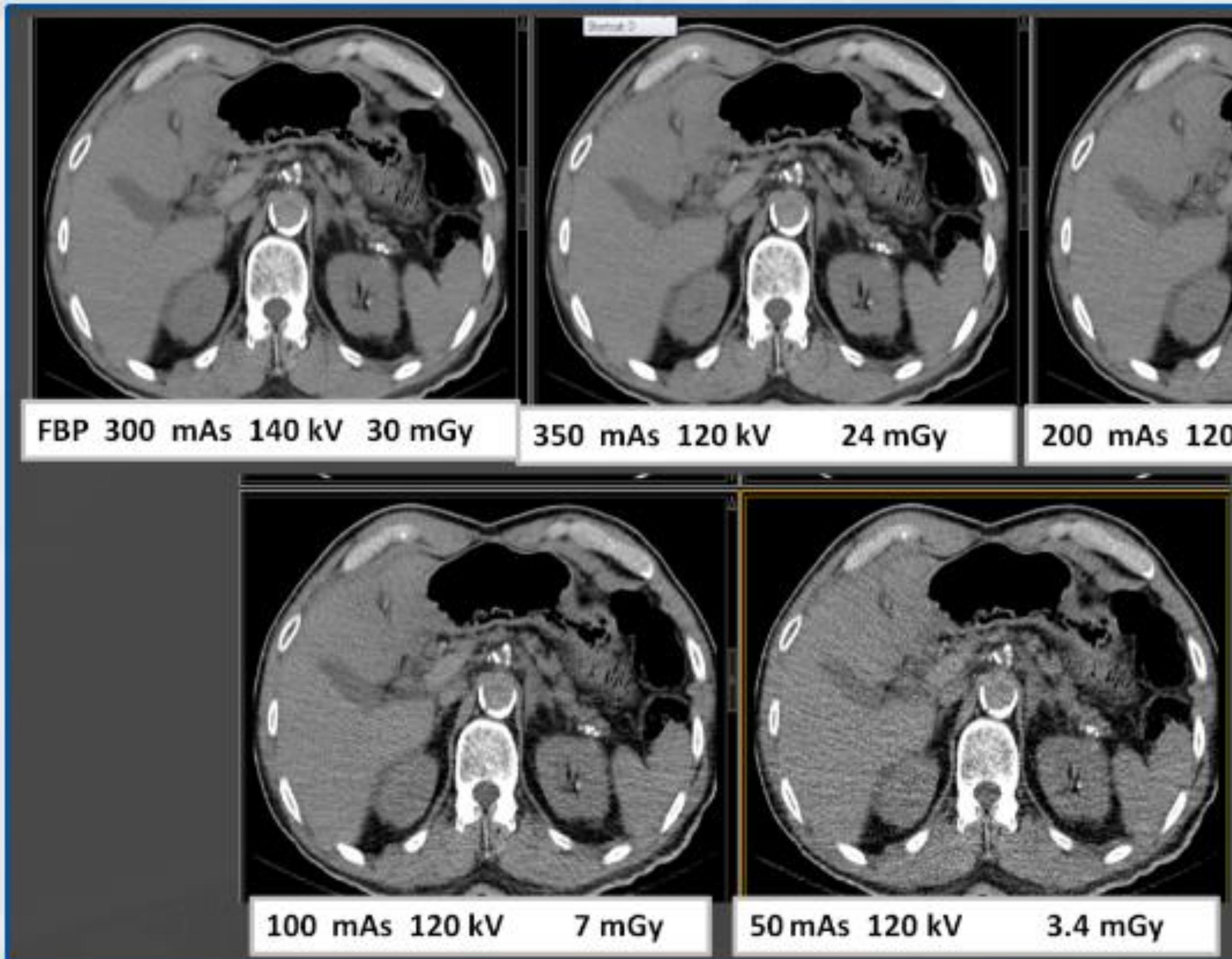
WHAT ELSE IS HIGH CONTRAST IN ABDOMEN?

High contrast = Kidney stones
Calcium vs Soft tissues

↓

Lower dose

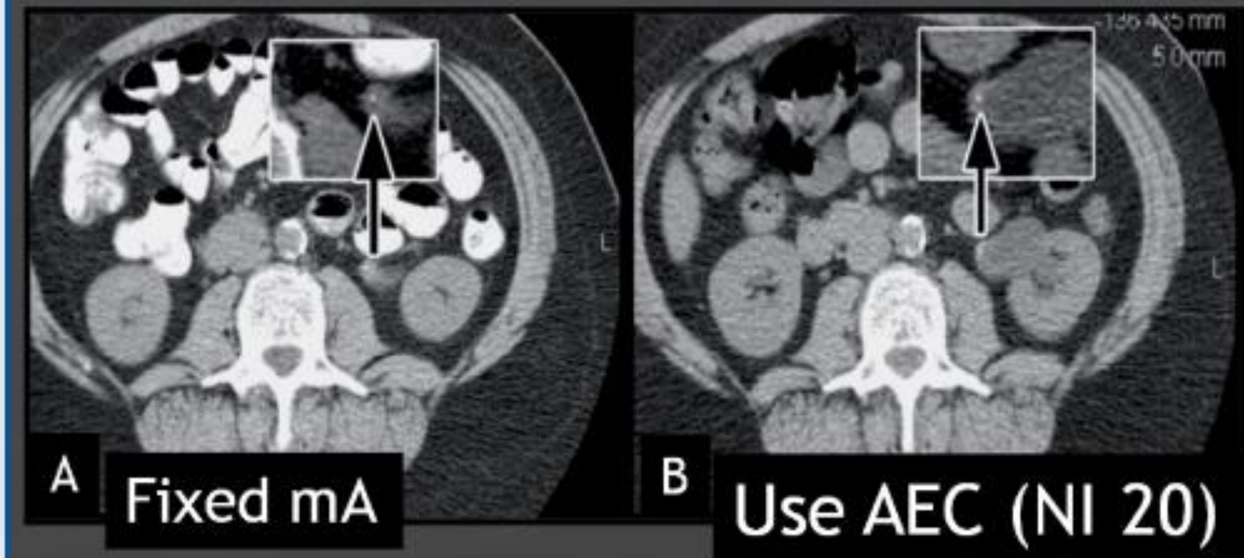
KIDNEY STONE CT: SEEN AT LOWER DOSE



65 kg
BMI 26

URINARY STONE CT

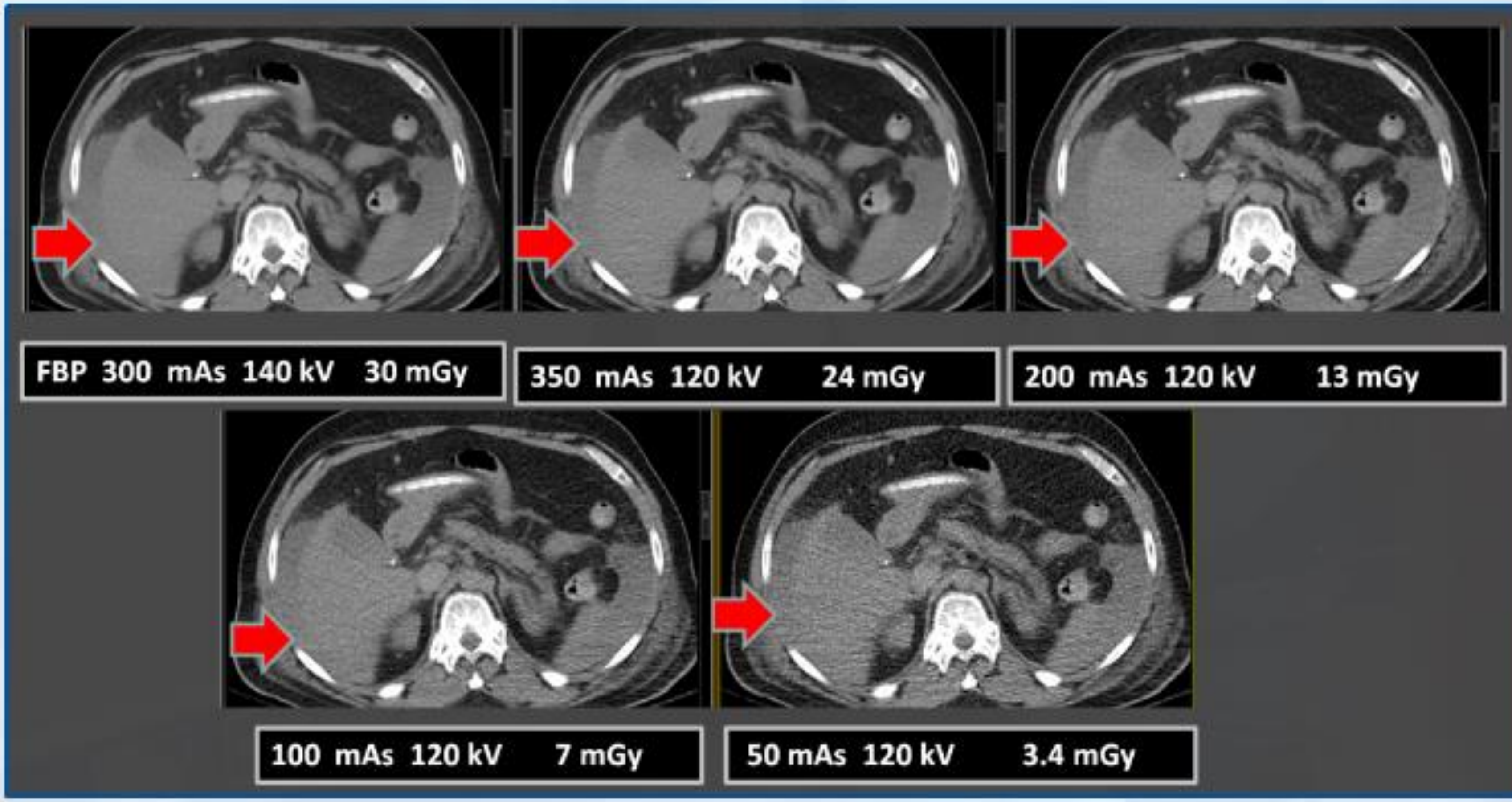
Tube Potential	120 kV commonly (100 kV for < 60 kg)
Tube current (prefer AEC)	About 30-50% lower than routine abdomen
Image thickness (mm)	2.5- 5mm
CTDIvol	2-6 mGy (size based)



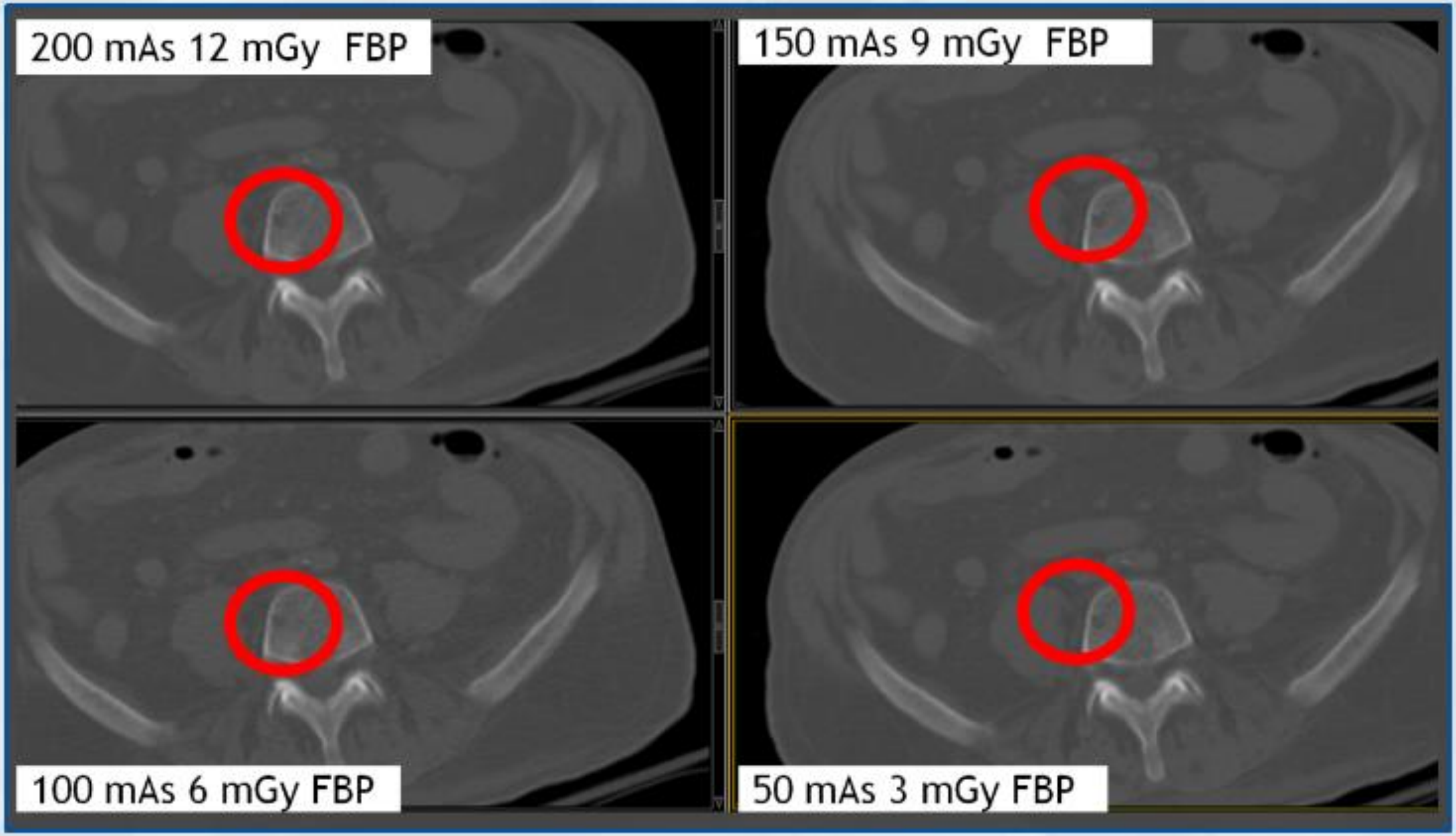
(A) CT images of 60-year-old man acquired with fixed current (A) and
(B) AEC show a tiny calculus (arrow) in left renal pelvis. AEC (B) enabled 50% dose reduction compared to fixed current technique.

CALCIUM: SEEN AT LOWER DOSE

- Radiodense stones (GB) can also be seen at low dose
- Note “fading” ascites with decreasing DOSE



BONES- CHEST OR ABDOMEN: WELL SEEN AT LOWER DOSE



WHAT ELSE IS HIGH CONTRAST IN ABDOMEN?

Vessels = CTA(abdominal aorta),
Arterial phase of liver protocol CT,
CT enterography

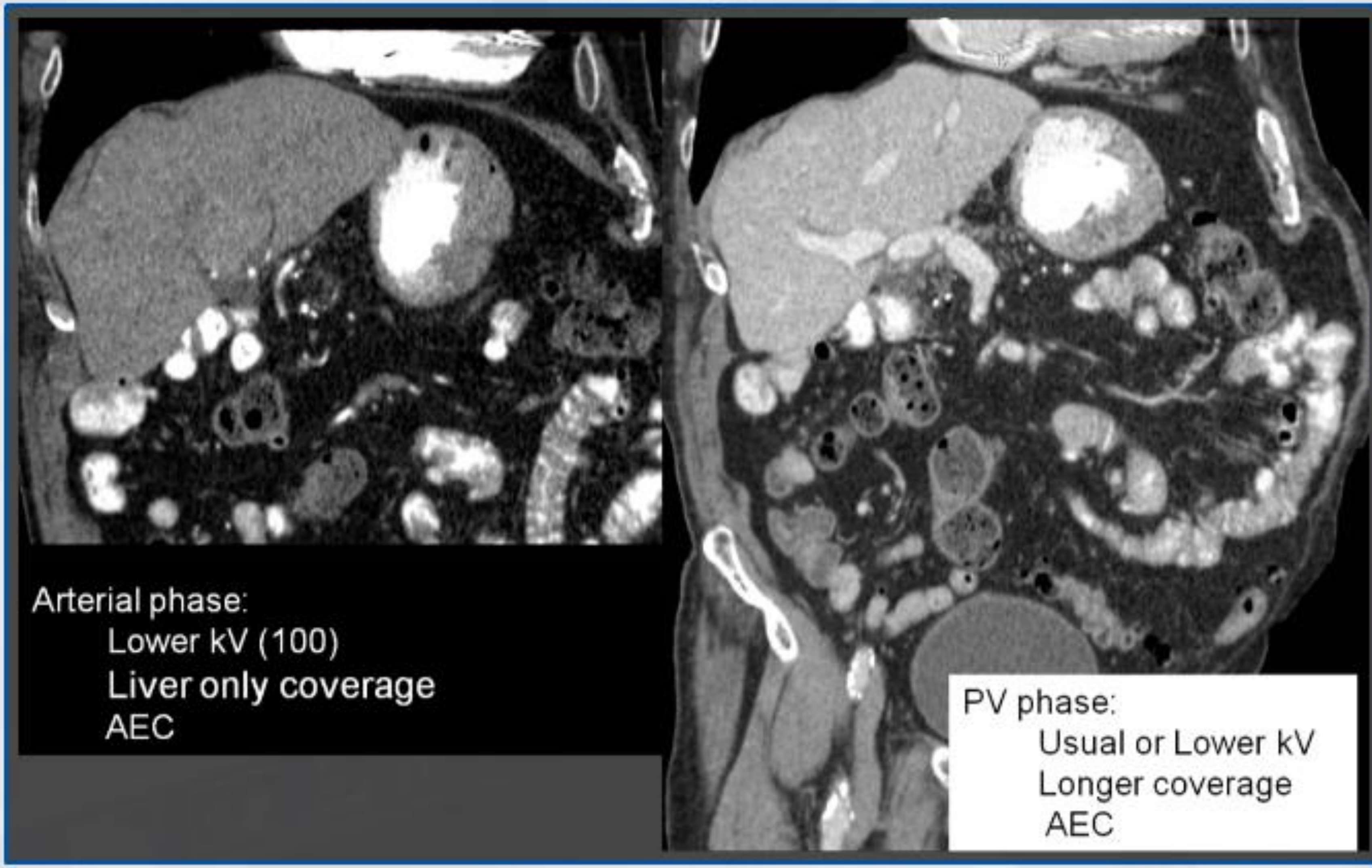
↓

Lower kV

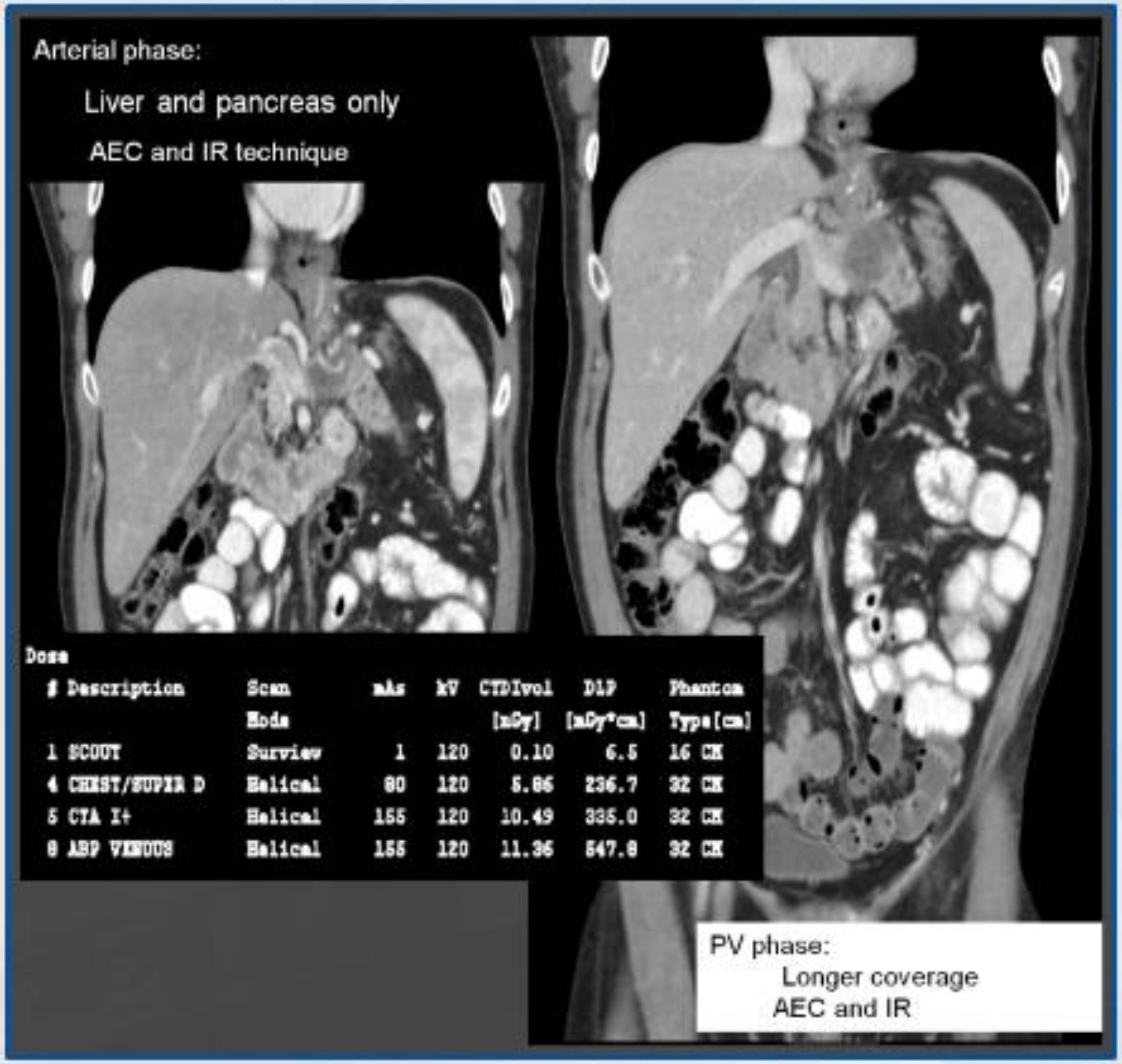
↓

Lower dose

MULTIPHASE EXAM: DOSE REDUCTION: LIVER



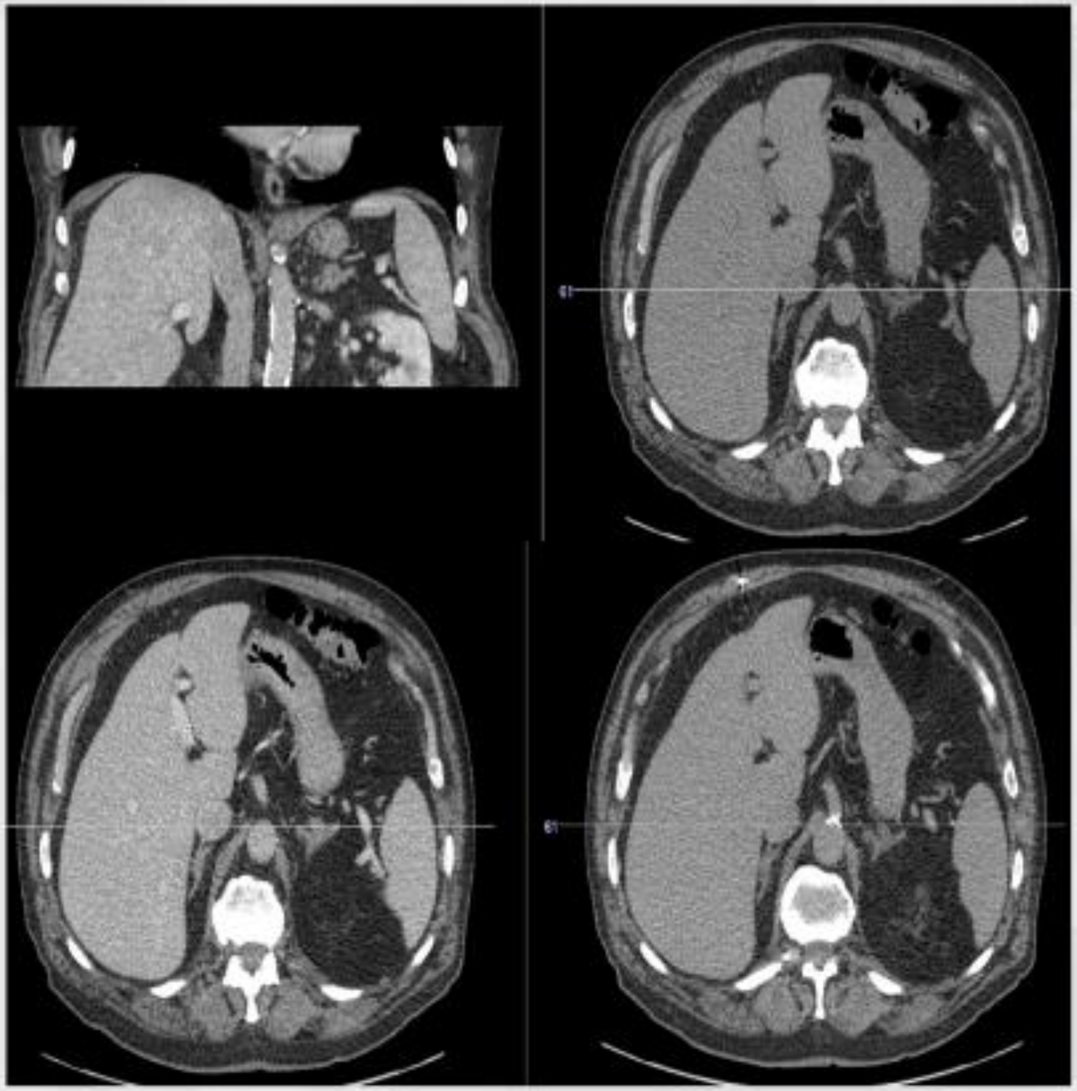
MULTIPHASE EXAM: PANCREAS



Dose

#	Description	Scan Mode	mAs	kV	CTDIvol [mGy]	DLP [mGy*cm]	Phantom Type[cm]
1	SCOUT	Surview	1	120	0.10	6.5	16 CM
4	CHEST/SUPER D	Helical	80	120	5.86	236.7	32 CM
5	CTA I+	Helical	155	120	10.49	335.0	32 CM
8	ABD VENOUS	Helical	155	120	11.36	547.8	32 CM

ADRENAL PROTOCOL



- Multiphase CT
- Scan length:
  - T11 - L2
  - Adrenals only
- 120 kV
- AEC
- IR techniques

CT FOR HEMATURIA: DECREASING SCAN PHASES

Non-contrast

limit coverage: kidneys to SP, Lower dose (- 50%, AEC and IR)

Post Contrast:
Wider coverage
AEC

Unenhanced CT

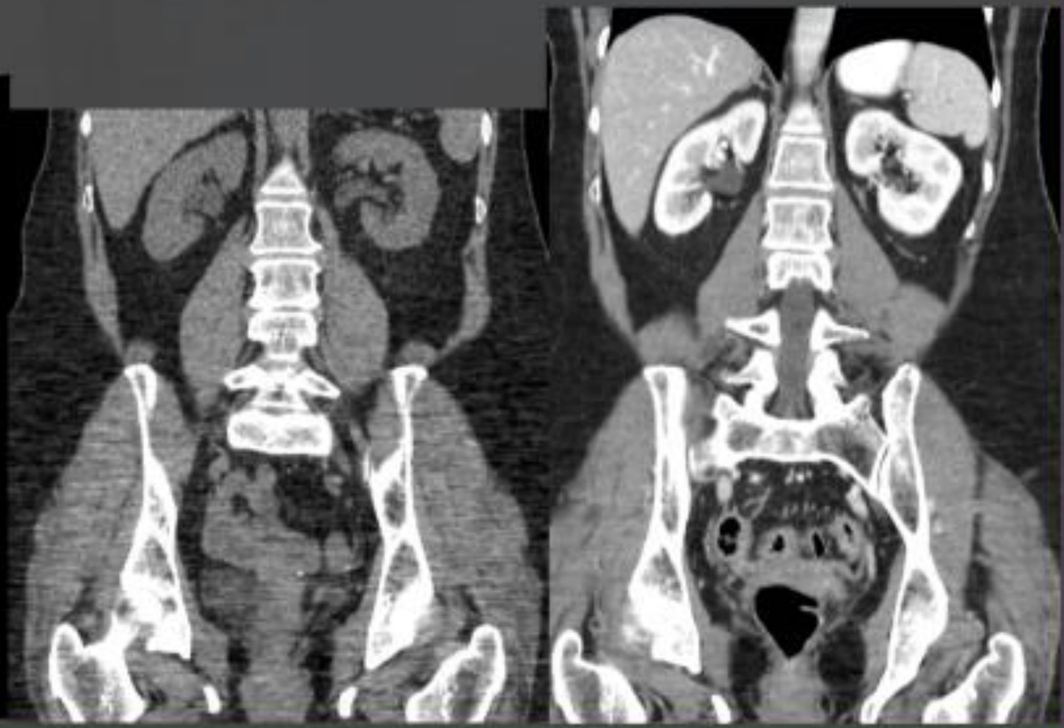
50 mL IV contrast bolus

250 mL saline drip infusion

Wait 15 minutes (Prone)

100 mL IV contrast @ 3 mL/sec

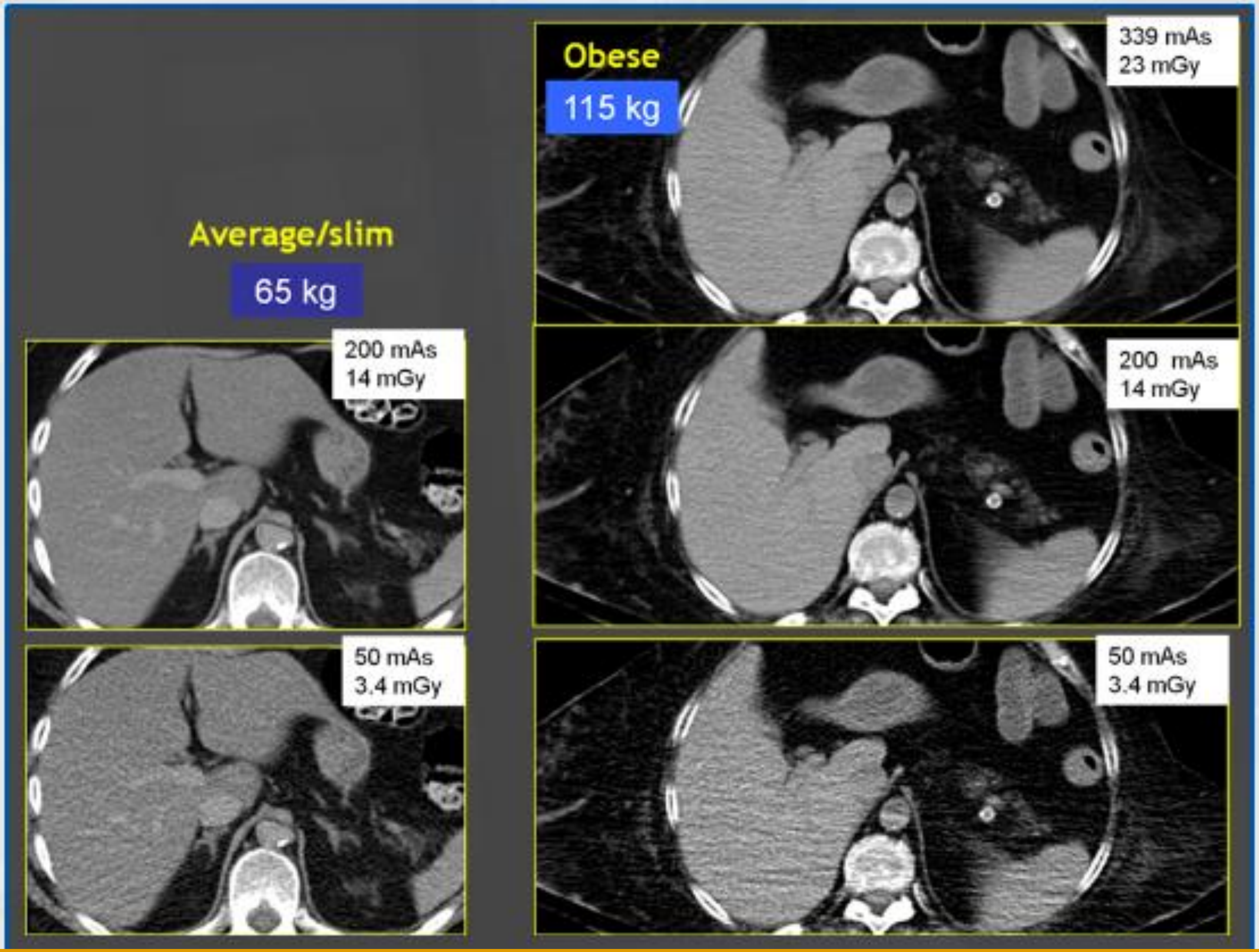
Scan at 100-sec. delay



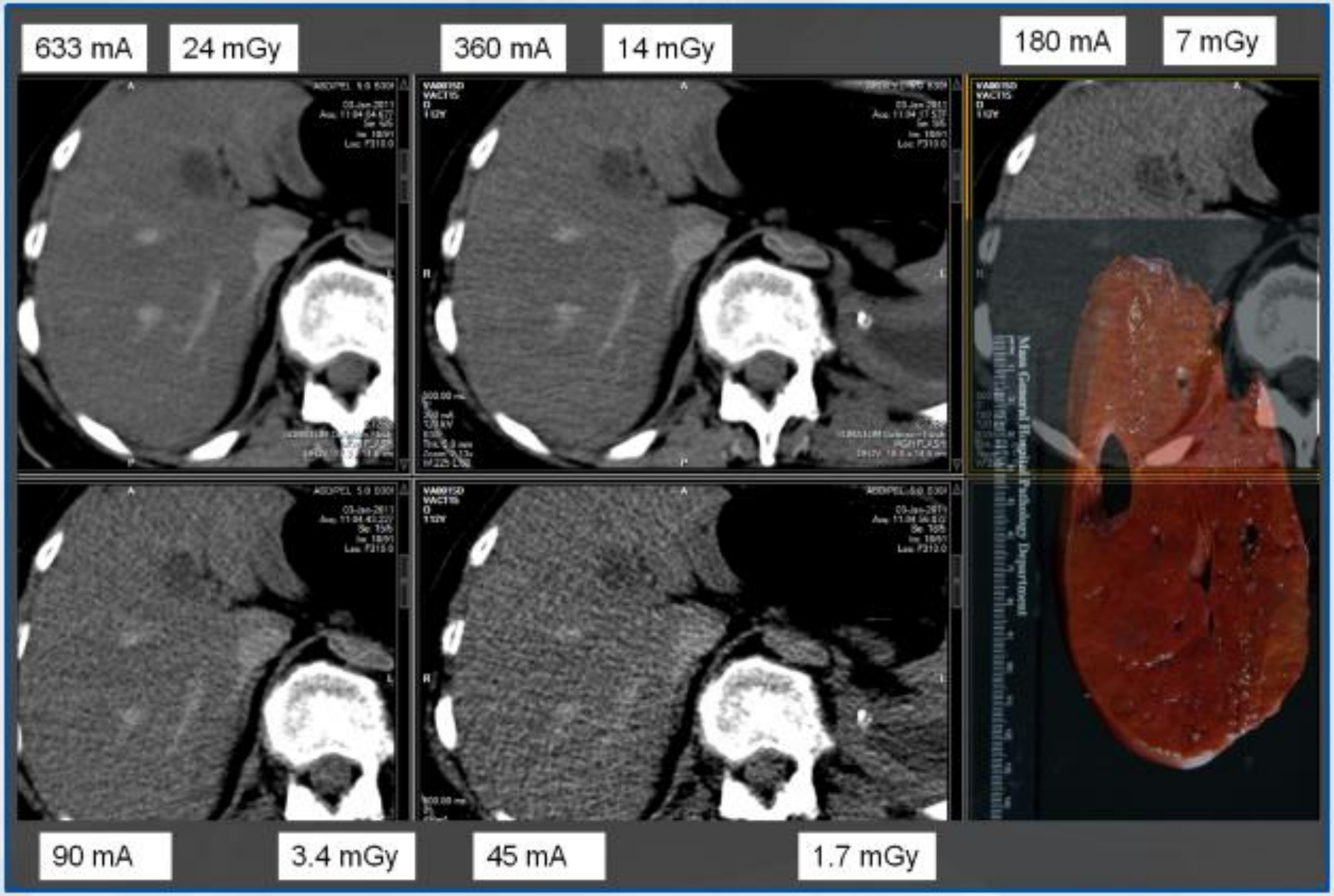
ROUTINE ABDOMEN: PATIENT FACTORS AND DOSE

- Size: Obese vs average or slim
  - Use AEC always for mA optimization
  - Lower kV in smaller patients with contrast CT helps cut dose
- Arms by the side of the patient
  - Keep out or Keep above the abdomen with pad not besides
- Patient motion (voluntary or involuntary)
  - Pitch > 1; Rotation time < 0.8 second
- Contrast or non contrast scan
- Prefer contrast when ok… Higher contrast helps lower dose

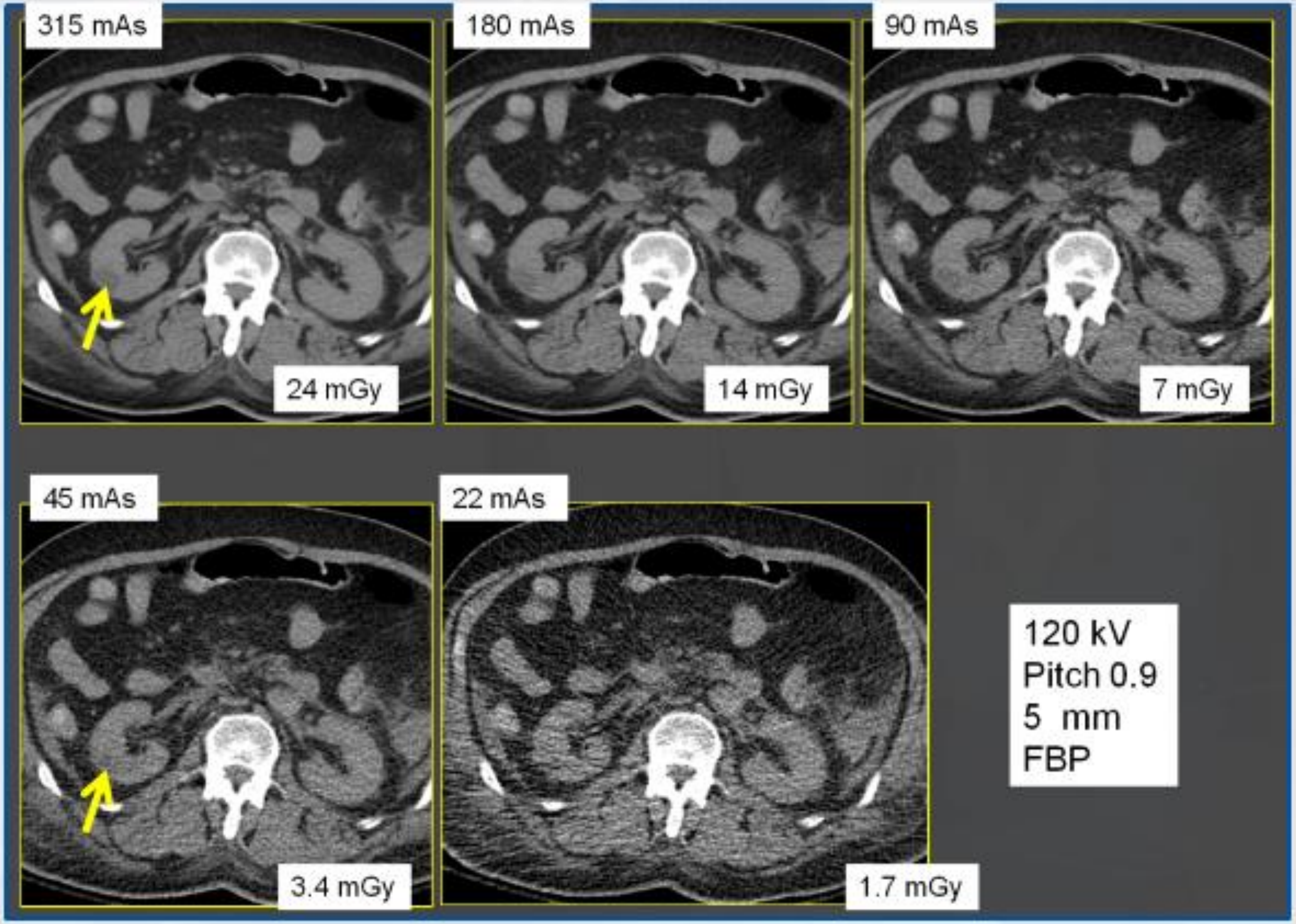
ROUTINE ABDOMEN: USE AEC



LESION MARGIN MAY NOT BE AS EVIDENT ON LOW DOSE CT



ROUTINE ABDOMINAL CT SHOW RIGHT RENAL ADENOMA

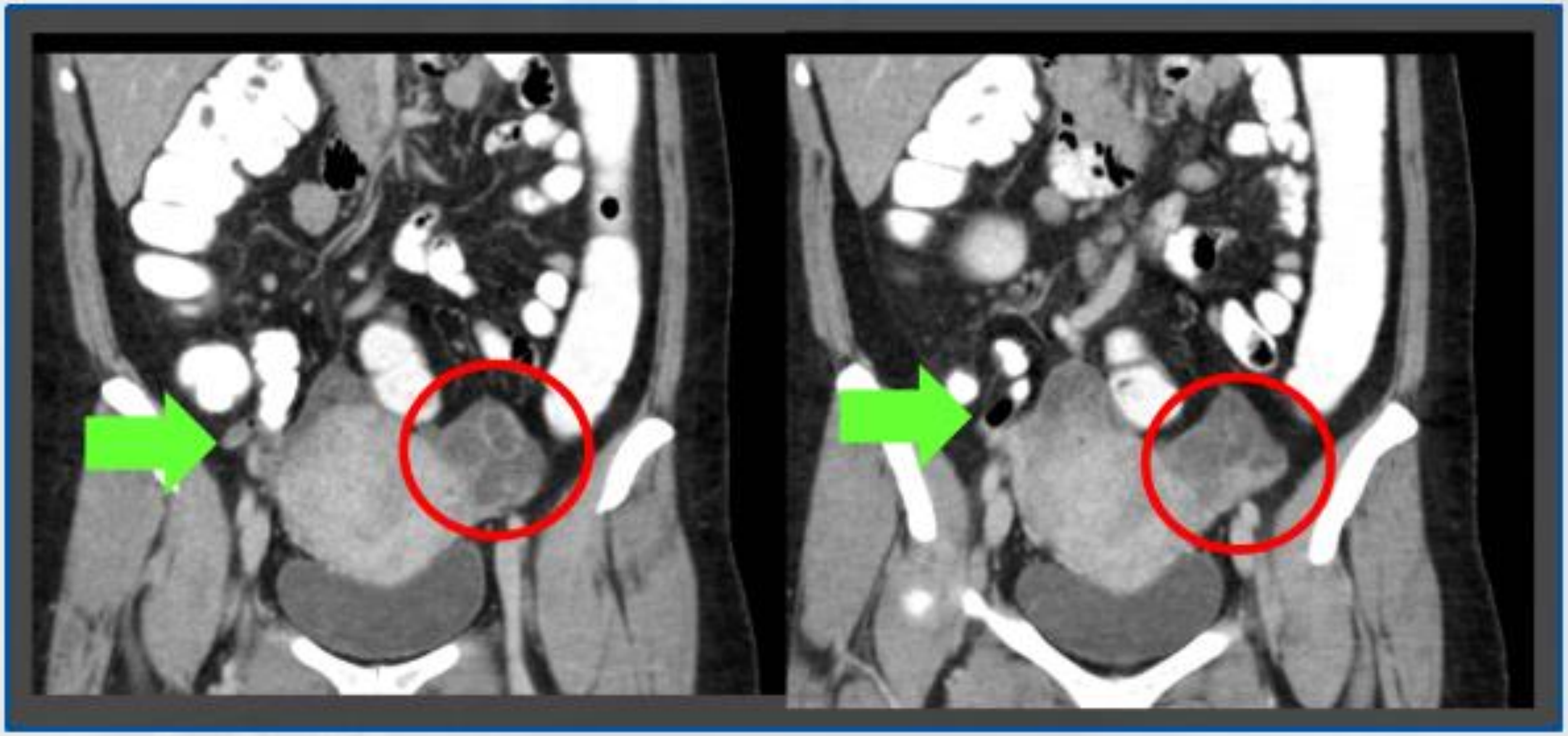


BENIGN DISEASE: YOUNG PATIENTS

Ex: Appendicitis

Limited coverage: L3 to SP

AEC for size adapted dose



ABDOMINAL CT DOSE MANAGEMENT

Lower noise: Higher dose

Lesion Detection – high confidence

Higher noise = Lower dose

Rule out Abdo CT

Low contrast lesions

Use AEC to optimize

CT colonography

CT angiography

Kidney stones

Hypervascular lesions

Use AEC &/ low kV

SUMMARY

- Understand clinical indication based CT protocols
- Avoid routine multiphase CT protocols
- Reduce scan length when possible for multiphase CT
- Use AEC
- Use lower kV for smaller patients as well as with iterative reconstruction techniques

HOW IS HEAD UNIQUE FOR CT?

OBJECTIVES

- Understand key protocols based on clinical indications for head CT
- Understand scan parameters used for head CT
- Addressing unique issues with head CT

HOW IS HEAD UNIQUE FOR CT?

- Head CT is one of the most frequently performed CT
- Remember that MRI has replaced head CT for several clinical indications
- Skull base (densest bone in body) has propensity to cause beam hardening artifacts
- Head anatomy changes rapidly from base to vault
- Differences between grey and white matter in the brain represent extremely low contrast for CT

HOW IS HEAD UNIQUE FOR CT?

- Head size does not change much with patient size unlike chest and abdomen

- Certain clinical indications allow substantial dose reduction due to high inherent contrast
  - Paranasal sinuses
  - Facial and skull bones
  - Craniostenosis
  - Patency of ventricular shunts

- Certain clinical indications have higher dose
  - Stroke work up with CT
  - CT angiography/venography of head and neck

DEVELOPING CT PROTOCOLS

Always pre-save scan protocols on the scanner

- Head CT is often an urgent, time-sensitive exam
  - Stroke work up with CT
  - Head trauma

- Time means brain parenchyma for stroke work up so fiddling with scan parameters and errors can delay CT scanning

BASIC OF CT DOSE

Justified: Ensuring that CT is the right test

↓

Interpretable: Tailoring CT for specific indications

↓

ALARA: Adapting Dose to patient size or age

PROTOCOLS: MEETING BASIC STANDARDS

Diagnostic Reference Levels and Achievable Doses for Adult and Pediatric CT ($CTDI_{vol}$)

	Patient Lateral (LAT) Dimension	CTDI Phantom Diameter (cm)	DRL (mGy)	AD (mGy)
Adult head [6,9]	16	16	75	57
Adult abdomen-pelvis [6,9]	38	32	25	17
Adult Chest [6]	35	32	21	14
Pediatric 5 year old head [6]	15	16	40	31
Pediatric 5 year old abdomen-pelvis [9]	20	16	20	14

Revised 2013 (Resolution 47)*

ACR–AAPM PRACTICE GUIDELINE FOR DIAGNOSTIC REFERENCE LEVELS AND ACHIEVABLE DOSES IN MEDICAL X-RAY IMAGING

MAKE INDICATION DRIVEN PROTOCOLS

Indication based protocols are a must for dose optimization.

- Routine head
- CT angiography head with or without neck
- Perfusion CT
- Temporal bone CT
- CT orbits
- Paranasal sinuses CT
- Shunt patency

HEAD CT: MINIMIZE MOVEMENT DURING SCANNING

- Give instructions to minimize voluntary movements
- Place in head rest to decrease motion
- Coax children properly or use sedation
- Uncooperative patients: Use faster scanning (helical scanning is a viable option in head)
- Never perform more than one repeat acquisition CT if initial scan had motion
- ONLY REPEAT ONCE if and when additional surety, sedation, or added legal restrain to decrease motion
  - Faster scanning with faster gantry rotation, helical mode, higher pitch, and/or thicker beam collimation can help

HEAD CT: CONTRAST INJECTION

Avoid suboptimal or non-diagnostic head CT from poor contrast injection technique

- Make sure there is good intravenous (IV) access
- Always flush to minimize risk of contrast extravasation
- Inject at reasonable rate based on IV access
- Always time the bolus for CT angiography
- Avoid guessed delays or fixed delays
  - Circulation times differ between patients
  - Heart functions differ between patients

HEAD CT: GOOD POINTS

- Localizer radiographs
  - Make sure that head is well positioned
  - Make sure that the head centering is good
  - When possible head should be in head rest
  - Use lower dose for localizer radiographs

- For transverse CT images, specify
  - Scan range
  - Scan parameters for each series
  - Number of scan series

AXIAL VERSUS HELICAL CT

- Some hospitals perform head CT with helical mode:
  - Advantage: Quick, MPR, no difference in quality
  - Average CTDIvol = 45-60 mGy
  - Disadvantage: No gantry tilt and higher eye dose

- Many prefer – Axial scanning mode
  - Advantage: lower dose (??), gantry tilt possible
  - Disadvantage: Slower acquisition, motion artifacts

AXIAL VERSUS HELICAL MODE

- Studies suggest that thinly collimated helical brain CT is at least as good as thickly collimated axial CT
- Some studies report eye dose from helical CT is greater than eye dose from titled axial scanning of the head
- Other publications report no increase in eye dose with helical scanning in children as compared to axial mode

HELICAL MODE FOR HEAD CT

There are special considerations to head CT performed in helical scanning mode

- Overlapping pitch (~0.5): to decrease artifacts from rapidly changing anatomy
- Thin beam collimation: To decrease radiation dose from over-ranging at the beginning and end of the helical acquisition
- No gantry tilt allowed
- Faster scanning compared to axial mode

HEAD CT: TUBE CURRENT

- Head CT can be performed with fixed mA or AEC
- Prior studies have reported potential for reducing the fixed mA substantially for head CT
- Substantial dose reductions have been reported with AEC
  - % decrease depends on baseline protocol
- AEC is also useful for neck CT
  - Variations in size of shoulders
  - Dramatic change in thickness from neck to shoulders requires benefit from change in mA with AEC

OPTIMIZING DOSE: TUBE POTENTIAL

- Traditionally routine adult head CT is performed at 120 kV
- kV can also be selected as a fixed value or automatic kV selection technique.
- CT angiography protocols benefit from lower kV (80-100kV)
  - Smaller vessels are better seen
  - Lower contrast volume or injection rate possible
  - Lower radiation dose compared to higher kV
- CT perfusion: Should be performed at 80 kV
  - Maximizes sensitivity to detect iodine in the brain.
  - Helps reduce the dose dramatically compared to higher dose at 120 kV

GOOD CT EXAM: OTHER PARAMETERS

- Scan series
  - Must be minimum required
  - When multiple- dose should not be multiple folds higher
- Avoid rescanning same region
  - E.g., head and temporal bone, face and sinuses
- Scan length: Targeted and focused
- Beam collimation: Lower is better to decrease dose for head
- Remove extraneous hardware

GOOD CT EXAM: EYE SHIELDING?

- Lead shield help reduce eye dose by 44% for head CT
  - Can cause severe artifacts over the orbits
- Bismuth in plane shields also reduce radiation dose to eyes with less severe artifacts
  - 40-53% dose reduction to lens with Bismuth shields
  - Controversial due to effect on image quality

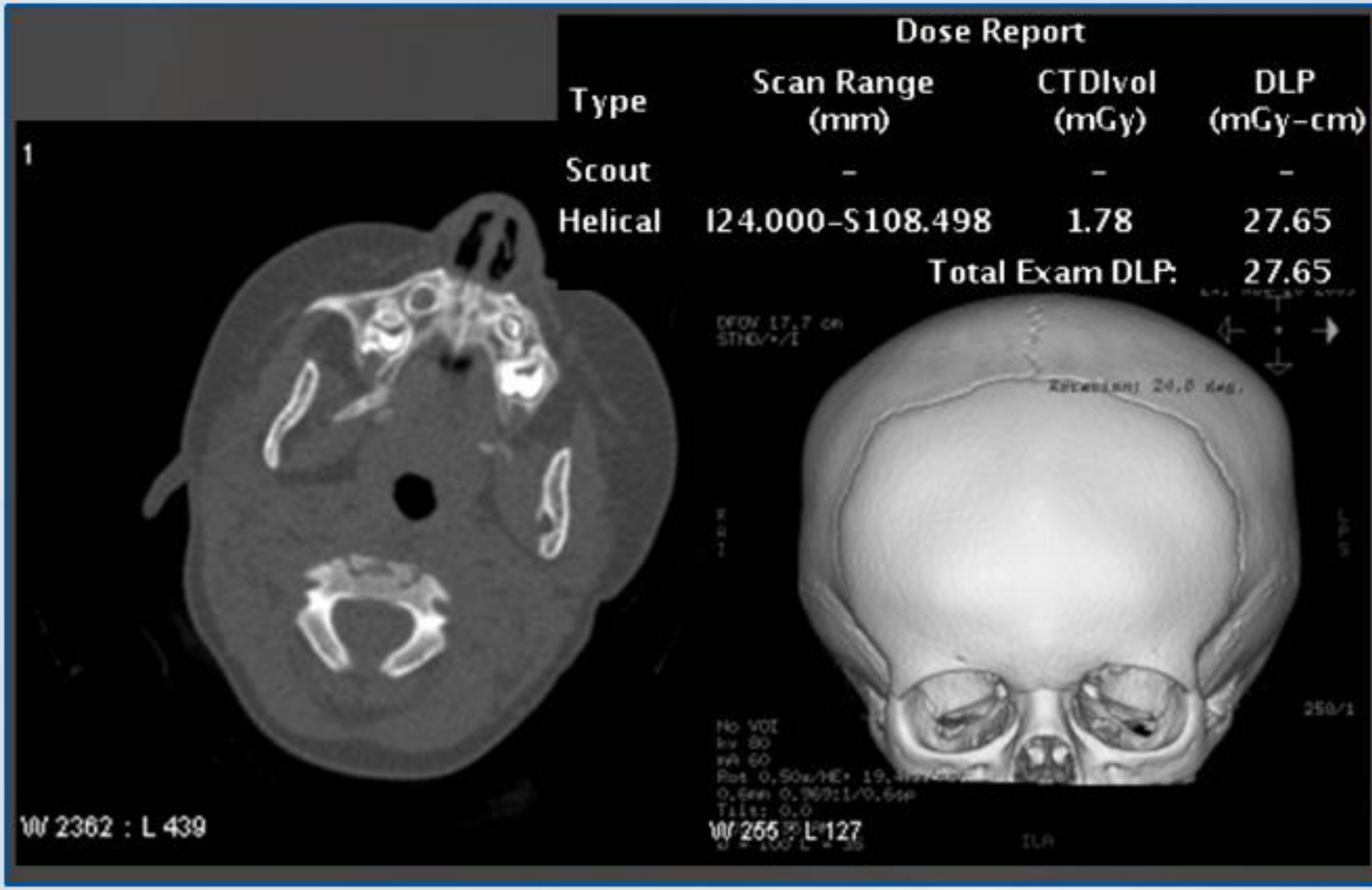
POINTS AGAINST SHIELDING

- Heany et al. Australas Phys Eng Sci Med. 2006
  - Angulation is superior to Bismuth eye shields
    - 88% reduction versus 48% reduction
- Leswick et al. Radiology 2008
  - AEC is better than Bismuth thyroid shields
    - 78% dose reduction versus 42%
- Other publications support use of Bismuth

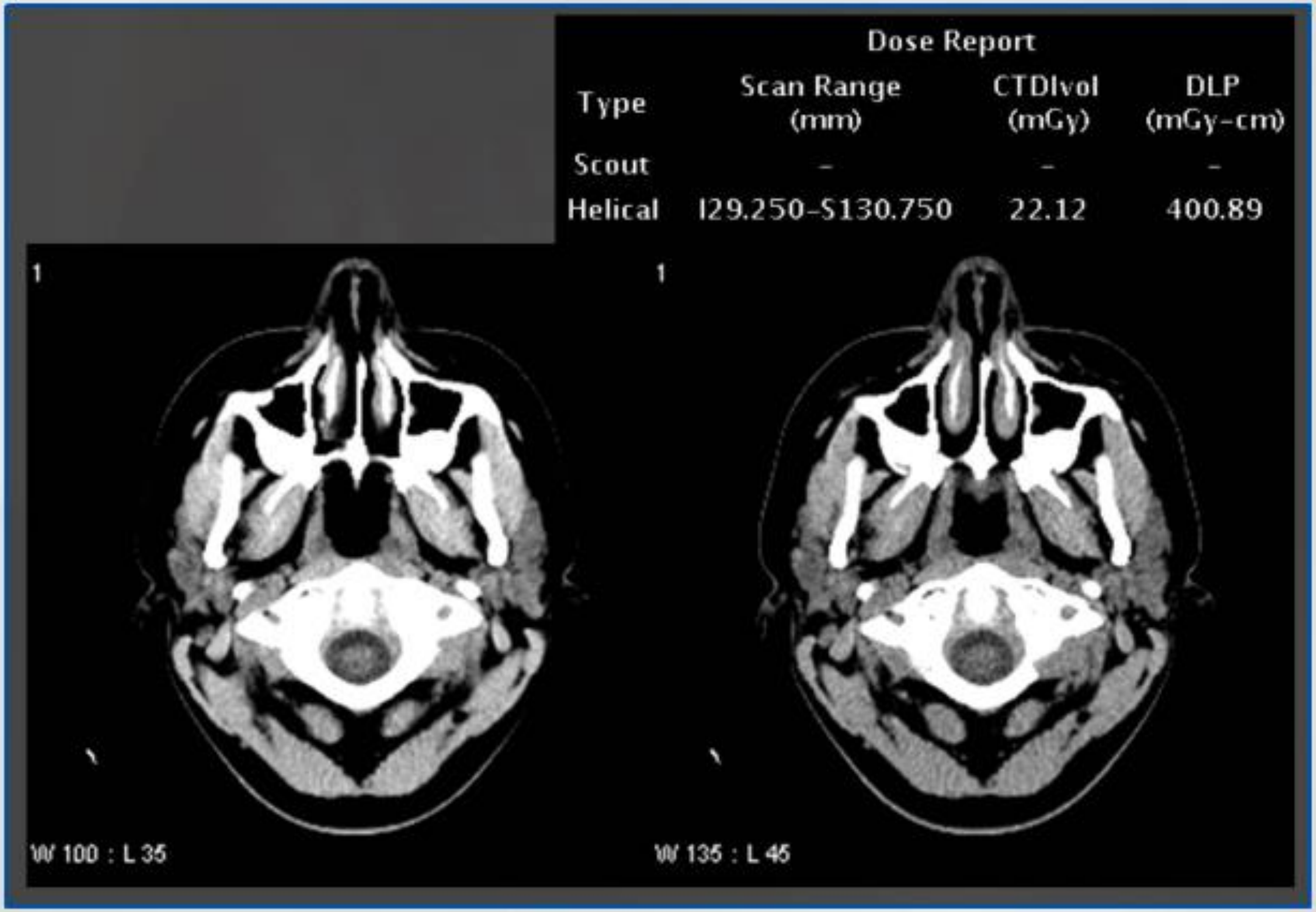
PEDIATRIC HEAD CT

- Perform only when appropriate, use brain MRI to avoid need for head CT when possible
- Lower dose head CT should be used in children compared to adult head CT
- Create specific protocol for ventricular shunt patency: low kV and fixed low mA
- Create separate protocol for craniostenosis: Low kV (80 kV) and low mAs (ex. 50 mAs)

CRANIOSTENOSIS: 80 kV, 60 mA, p = 1.4, 0.04 mSv



POST TRAUMA: 120 kV, 90-140 mA, p = 0.984, 5 NI, 5 mm - 2.5 mm



Dose Report

Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)
Scout	-	-	-
Helical	I29.250-S130.750	22.12	400.89

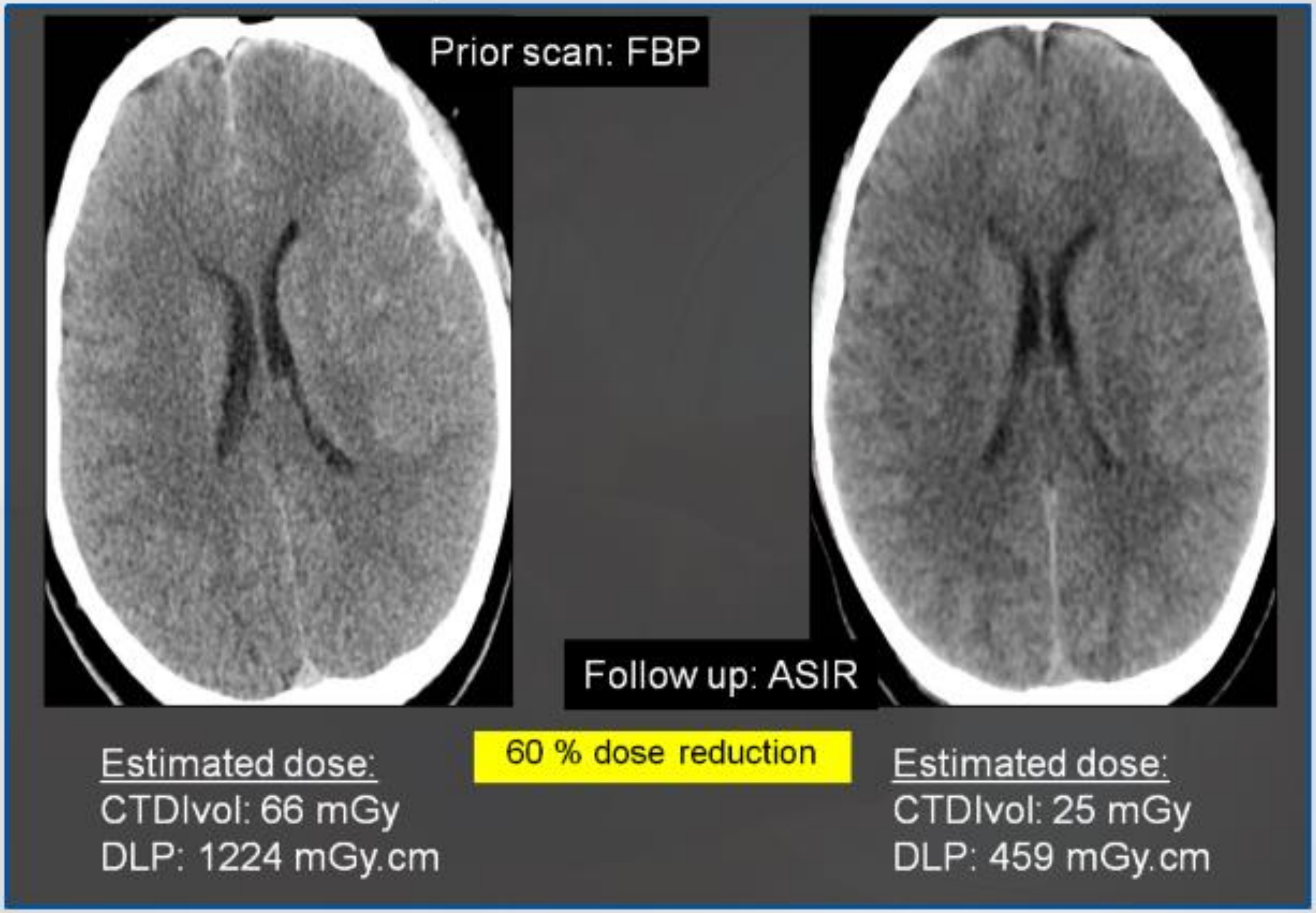
SINUS AND ORBITS

- Facial bones and sinuses can be scanned at extremely low radiation dose
  - High tissue contrast between bones and air offers scope for reduced radiation dose CT
  - 100-120 kV and 40-50 mAs generally sufficient for sinuses
  - Helical scanning allows isotropic image reconstruction in other planes without need to acquire additional series in coronal plane

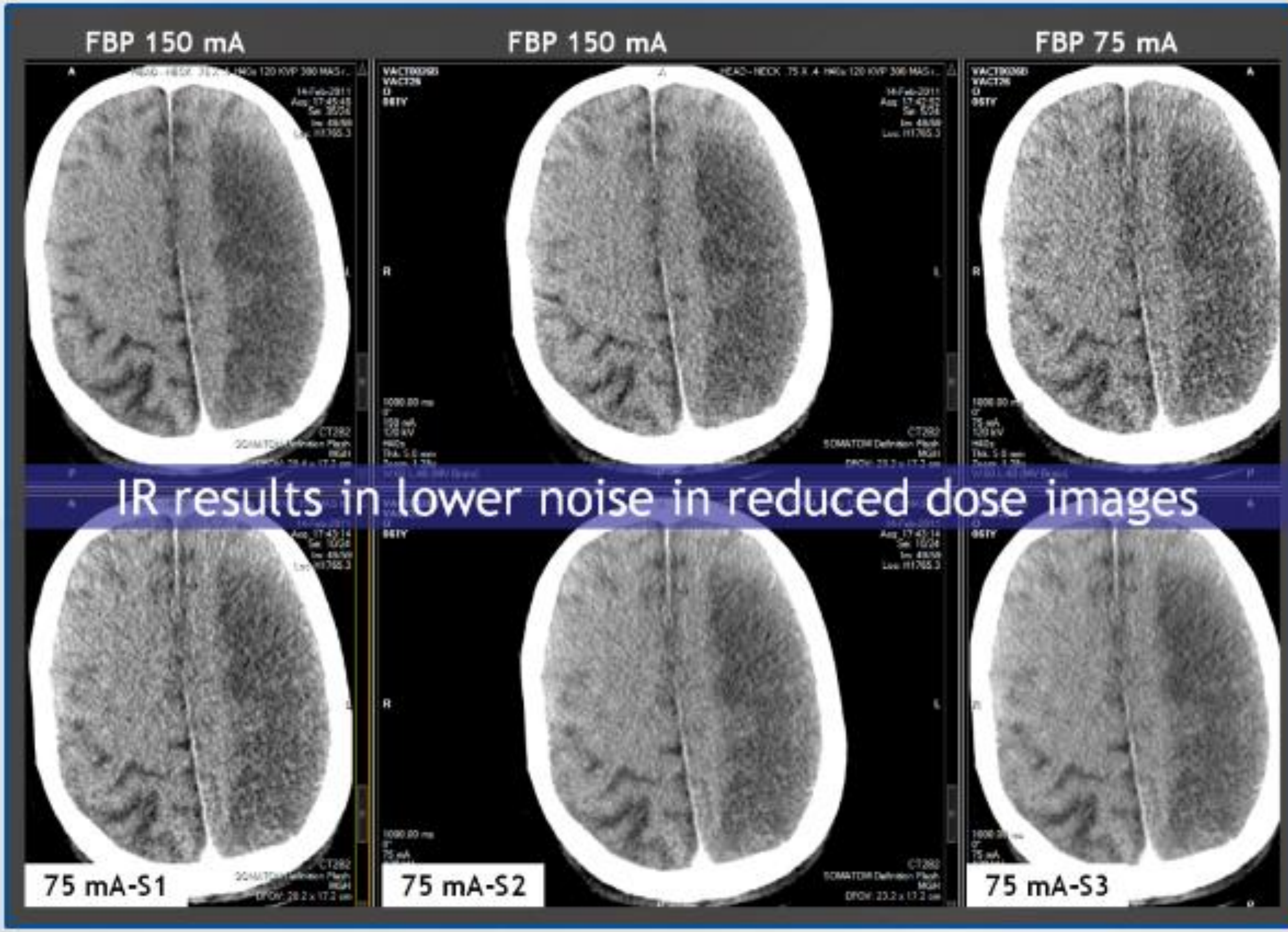
STROKE WORK UP CT

- Doses with comprehensive stroke protocol CT can be as high as 16-20 mSv
  - Non-contrast CT
  - CT angiography (CTA)
  - CT perfusion
  - Post contrast images of brain
- For CTA: Use lower kV (≤ 100 kV)
- For CT perfusion: use 80 kV

ITERATIVE RECONSTRUCTION AND DOSE REDUCTION FOR HEAD CT



ITERATIVE RECONSTRUCTION (IR) IN HEAD CT



RADIATION DOSE MANAGEMENT IN CT

MODULE 10: KEY ASPECTS FOR PEDIATRIC CT PROTOCOLS

WHY CHILDREN ARE SO SPECIAL FOR CT?

Well… because they are just special!

Seriously: Every patient is special but children are more special… For CT

- Children are at higher risk for radiation induced stochastic effect (radiation induced cancer)
  - Biology: Children have more dividing cells which are more vulnerable to radiation induced effects
  - Expectancy: Children are likely to live longer than adults, so they have more chances to have cancer over their lifetime

WHY CHILDREN ARE SO SPECIAL FOR CT?

- Children range widely in size from less than 1 kg to adult body habitus and larger
  - Smaller children can be and should be scanned with smaller doses
- Young children often need faster scan time or sedation or anesthesia or immobilization for CT
- Gamut of pathology for CT in children are different
  - Triage to other tests (radiography, ultrasound or MRI)
  - Seldom need repeat scanning or multiphase CT
  - Benign indications are commoner in children

DEVELOPING CT PROTOCOLS IN CHILDREN

- Children should not be scanned with "on the fly" protocols
- Protocols should be pre-defined, and archived on CT
- Demands from a pediatric CT are much higher
  - Errors can happen
  - Children can move during scanning
  - Children can get anxious while waiting
  - Children may need longer sedation
  - Contrast injection can go wrong!
  - More time will be wasted!!
  - Not all radiographs and radiologists are equal in expertise

BEST ALL TIME WINNER FOR CT DOSE REDUCTION

… Good mechanism to guide appropriateness of CT!

SPECIFIC PEDIATRIC CT PROTOCOLS

- Never…ever use adult protocols in children.
- Like all adult protocols, pediatric CT protocols should also begin with clinical indications.
- Each scan protocol should address
  - Clinical question to be answered
  - Dose adjustment for patient size
  - Specific adjustments for uncooperative children
  - Special attention to contrast injection

GUIDING PRINCIPLES FOR PEDIATRIC CT

- Perform only necessary CT
  - Triage to other safer tests when appropriate
  - Do not delay or hesitate in emergent valid clinical need
  - Avoid unnecessary repeat studies
- Scan only the organ or anatomy indicated
- Properly center all children in the CT gantry
- Adjust scan parameters to size, body region and indication
- Use pediatric positioning accessories
- Minimize multi-phase contrast CT

WHY INDICATION DRIVEN PROTOCOLS?

- Certain indications can be scanned at substantially reduced dose in children
- Some of these indications can be scanned at extremely low doses compared to others

Low dose head CT	Low dose chest CT	Low dose abdomen CT
Craniosynostosis Ventricular shunt patency Paranasal sinuses Facial trauma Follow up head CT	Lung abnormalities Airway evaluation Pleural effusion/empyema Chest wall deformities Scoliosis Chest trauma Follow up chest CT	Kidney stones CT enterography Follow up abdominal CT Bony deformities

PEDIATRIC CT: PATIENT PREPARATION

- Address nervousness
  - Be calm and professional
  - Inform steps of CT to patient and accompanying person
  - Do not over-crowd
  - Decide if someone needs to stay in the room (when appropriate)

- Minimize pain
  - Take intravenous access if needed outside the room and in advance

- Instruct, demonstrate and practice
  - Tell what should be done (breath-hold), when appropriate
  - Demonstrate how it will be done (when appropriate)
  - Practice what has to be done (breath-hold, when appropriate)

- Ensure contrast injection is well planned: Do not botch!!

- Avoid artifacts from external and internal sources

PEDIATRIC CT: SCANNER PREPARATION

- Choice of CT scanner
  - If you can, choose the CT which is faster
    - Dual source CT are faster than single source CT
    - Wider area detector CT are faster than others
  - If you can, choose the scanner with AEC, automatic kV selection and/or iterative reconstruction techniques
  - If you can, choose an experienced or expert radiographer
  - When appropriate and possible, discuss the CT protocol with a radiologist (so s/he can triage too!!)

PEDIATRIC CT PROTOCOLS: GOOD PRACTICE

- Centering is extremely important in children
- Offcentering or miscentering can
  - Mess up estimation of mA for AEC
  - Mess up beam shaping filters' functions
    - Asymmetric distribution of noise and artifacts
  - Increase surface to vital organs (thyroid/breasts)
  - Effect can be require repeat scanning especially for very low dose protocols with severe artifacts

PEDIATRIC CT PROTOCOLS: GOOD PRACTICE

- Indication and size specific scan parameters
  - Tube current:
    - Prefer AEC over fixed mA
    - You can use fixed mA for very low dose CT protocols
    - Minimized mAs for
      - Craniostenosis, chest wall deformities, scoliosis
    - Reduced mAs
      - Follow up CT, lung/airway abnormalities, kidney stones
    - Lower mAs &/or kV for iterative reconstruction than FBP

PEDIATRIC CT PROTOCOLS: GOOD PRACTICE

- kV selection:
  - Automatic kV selection should be used when available
    - Use appropriate settings based on clinical indication
    - Use lower reference kV for its application
  - Manual kV selection
    - Do not underuse low kV in small children
    - Lowest kV should be used for very small children
      - Infants can be scanned adequately at 70-80 kV
    - Lowest kV should be used for CT angiography
      - Most children up to 80 kg can be scanned at 80 kV
      - Heavier children can be scanned at 100 kV
  - Iterative reconstruction enables lower kV more often

PEDIATRIC CT PROTOCOLS: GOOD PRACTICE

- Select non-overlapping pitch
  - Non-overlapping pitch should be preferred to minimize scan duration and motion artifacts
  - On certain scanners, lower pitch means higher dose
- Beam collimation: Minimize scan duration
  - For longer scans (chest, abdomen, spine), choose wider beam
  - For variable detector array systems: Choice depends on required need for specific slice thickness
  - Ex: 16 x 0.75 mm if < 1 mm slice are required
  - Ex: 16 x 1.5 mm when >1.5 mm slices required
- Fast gantry rotation speed: minimize motion artifacts

PEDIATRIC CT PROTOCOLS: GOOD PRACTICE

- Minimize repeat scanning or multiple phase CT
  - Generally are not needed in children and increase radiation dose
  - Generally a single acquired series is enough
  - Routine pre- & post-contrast CT should be avoided

- Scan length: Must be limited to what is needed
  - Chest: Lung apices to base (no need to go for adrenals)

- Single run CT: if scanning two contiguous regions
  - Whenever appropriate, go for a single run helical: It avoids overlapping dose, it is more dose efficient (remember over-ranging), and it is faster!

PEDIATRIC CT PROTOCOLS: GOOD PRACTICE

- Slice thickness
  - Thick slices have lower noise: Use these for low contrast
  - High contrast organs can be seen at greater noise
    - Lungs and vessels can tolerate higher noise
- Reconstruction kernels
  - Softer kernels have lower noise: use for abdomen
  - Avoid too sharp kernels: they increase noise and may necessitate you to increase dose for future exams
- Reconstruction techniques
  - Use iterative reconstruction techniques when available to enable further dose reduction

DOSE ADJUSTED TO CLINICAL INDICATIONS IN CHEST CT

Indications	Result	Author (journal year)
Bronchiectasis	Dose reduction with low mAs	Yi et al. (AJR 2003)
Pulmonary nodule	Dose reduction with use of low mAs	Diederich et al. (Radiology 1999)
Pneumonia	Dose reduction with low kV and low mA	Rizzi et al (Clinical imaging 2007)
Pulmonary embolism	Dose reduction with low kV and low mA	Doshi et al. (BJR 2008)

Radiation dose should be adjusted according to the clinical indications

DOSE ADAPTED TO THE CLINICAL INDICATIONS FOR ABDOMEN

Indications	Results	Authors (journal year)
Appendicitis	Tube current can be reduced substantially to achieve lower dose	Fefferman et al. (Radiology 2005) Keyzer et al. (Radiology 2004)
Colon polyps	Use of lower mA and AEC help reduce dose	Graser et al. (AJR 2006)
Renal calculi	Use of lower mAs and AEC help reduce dose versus routine abdomen	Kalra et al. (Radiology 2005) Heneghan et al (Radiology 2003)

Radiation dose should be adjusted according to the clinical indications

DOSE ADAPTED TO NUMBER OF PRIOR CT SCANS

Follow up of :	Results	Authors (journal year)
Cystic fibrosis	Low mAs and skipped acquisition (axial scanning)	Jimenez et al (Arch. dis. Child. 2006)
Ventriculoperitoneal shunt	Low dose from use of low mAs and KV	Udayashankar et al (AJNR 2008)
Craniosynostosis	Use of low kV and low mA	Trattner et al. JACR 2014

SIZE BASED CT DOSE OPTIMIZATION IN CHILDREN

- Frush et al described use of Broselow-Luten System* for color coded system for optimizing radiation dose in children in a seminal paper in AJR 2002.
- The system outlined an outstanding way of using height and weight of children to optmize kV and mA.

*This system relates the height of the child to the weight to provide important information on drug doses, and most suitable equipment sizes

COLOR CODED DOSE OPTIMIZATION IN CHILDREN

Other authors have described color coded system in children to adapt radiation dose to

- Patient weight
- Body region
- Clinical indication
- Number of prior exams
- Automatic exposure control (AEC)

COLOR CODING OF INDICATIONS, BODY REGION & PRIOR CT

Indications	Zone number	Color zone	Radiation dose
Routine or "rule out" abdomen situations	1	Pink	Standard
Follow up abdomen CT, first chest CT	2	Green	
Multiple prior chest & abdomen CT scans, Index CT for bone indications	3	Red	
CT angiography	4	Grey	

Color codes help remember the different zones based on body regions, clinical indication & number of prior CT

SPLIT INDICATION BASED PROTOCOL INTO WEIGHT GROUPS

zone / numeric code
Pink /1

→

Weight (lbs)	Subcodes / Subzones
< 20	Babies
21-60	Cuties
61-100	Kiddies
101-200	Teenies
>201	Biggies

While some AEC techniques do not require specific spliting of indication groups into weight groups, each weight group also had different kV to optimize dose.

ADJUST PARAMETERS TO PATIENT SIZE FOR EACH COLOR ZONE

Weight (kg)	Pink zone	Noise index	Min- max mA	kV
< 9	Babies	5	65-130	80
10-26	Cuties	7	80-160	100
27-45	Kiddies	10	95-190	120
46-100	Teenies	12	110-220	120
>101	Biggies	15	125-300	120

Routine abdomen indications

Weight (kg)	Green zone	Noise index	Min- max mA	kV
< 9	Babies	7	50-100	80
10-26	Cuties	9	60-120	100
27-45	Kiddies	11	70-140	120
46-100	Teenies	13	80-160	120
>101	Biggies	16	90-240	120

Follow up abdomen
First chest CT

While some AEC techniques do not require specific spliting of indication groups into weight groups, each weight group also had different kV to optimize dose.

CLASSIFICATION OF INDICATION CATEGORY: RADIOLOGIST'S JOB!

- Offers opportunity to triage patient to other modality

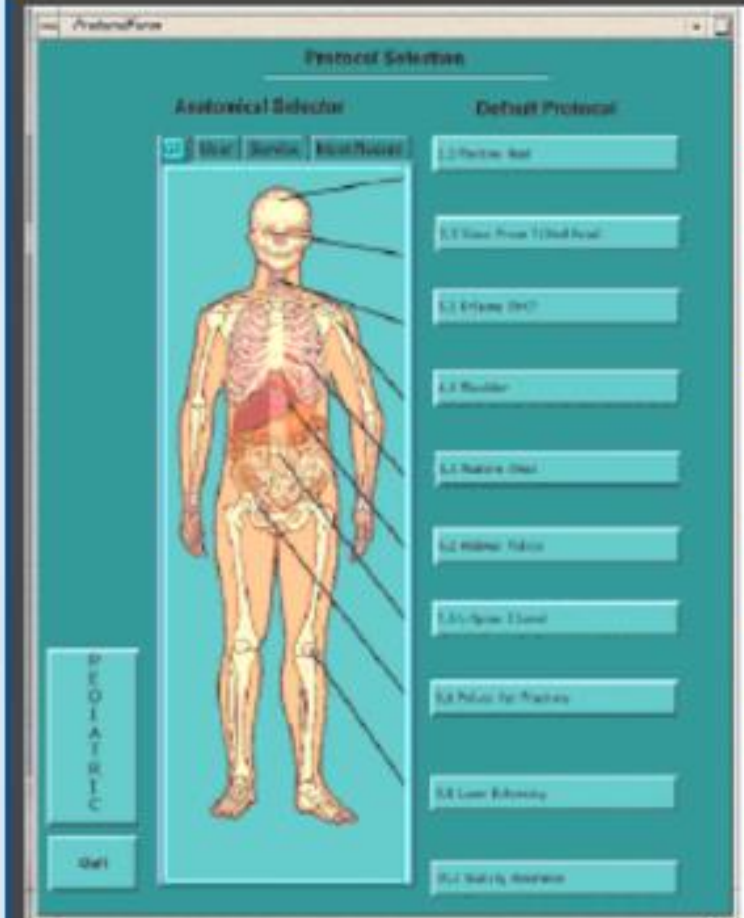
- Radiologist should look at CT requests for
  - Clinical indication
  - Presence of prior CT
  - Body region

- Based on indications need for CT should be decided
  - CT not needed - No CT, No additional dose - Call physician to triage appropriately
  - CT needed - specify

RAISING AWARENESS AMONGST RADIOGRAPHERS

- Imbibe need for dose reduction especially in children
- Understand the color zones specified by the radiologists
- Weigh all children, avoid guessing
- Only guess, if weight cannot be measured
- Pick exact scan length, do not under or over "scan"
- Center patients in CT for good dose reduction with AEC
- Select radiologist specified protocol & weight determined subzone
- Do not make any changes to parameters unless specified

SAVE PROTOCOLS ON THE SCANNER (LOCK DOWN)



Color zone	Weight subzone
Pink	<9 kg
Green	10-26 kg
Red	27-45 kg
Yellow	46-100 kg
Blue	>101 kg
Grey	

Weight (kg)	Green zone	Noise index	Min- max mA	kV
< 9	Babies	7	50-100	80
10-26	Cuties	9	60-120	100
27-45	Kiddies	11	70-140	120
46-100	Teenies	13	80-160	120
>101	Biggies	16	90-240	120

CT scanner user interface

CT WORKFLOW


We need CT!
1
Red Zone!
4.4.32 Monday Apr 23, 2007 1:36 PM
Select pt
Some, Child CT
Orders
Results
FEPL
Electronic Medical Records
Indications
Number of prior CT exams
2
Oh, Baby!
RADIOLOGIC TECHNOLOGIST
3
Weigh or guess
4

ATTEMPT GRADUAL DOSE REDUCTION IN SMALL STEPS

Step 1

Pink zone	Weight (kg)	Noise index	Min- max mA	kV
Babies	< 9	4	65-130	80
Cuties	10-26	6	80-160	100
Kiddies	27-45	8	95-190	120
Teenies	46-100	10	110-220	120

Step 2

Pink zone	Weight (kg)	Noise index	Min- max mA	kV
Babies	< 9	5	65-130	80
Cuties	10-26	7	80-160	100
Kiddies	27-45	10	95-190	120
Teenies	46-100	12	110-220	120

Step 3

Pink zone	Weight (kg)	Noise index	Min- max mA	kV
Babies	< 9	5	65-130	80
Cuties	10-26	7	80-160	100
Kiddies	27-45	10	95-190	120
Teenies	46-100	12	110-220	120
Biggies	>101	15	125-300	120

In our department, doses for each indication was reduced in 3 steps over a period of one year

ASSESS DOSE REDUCTION

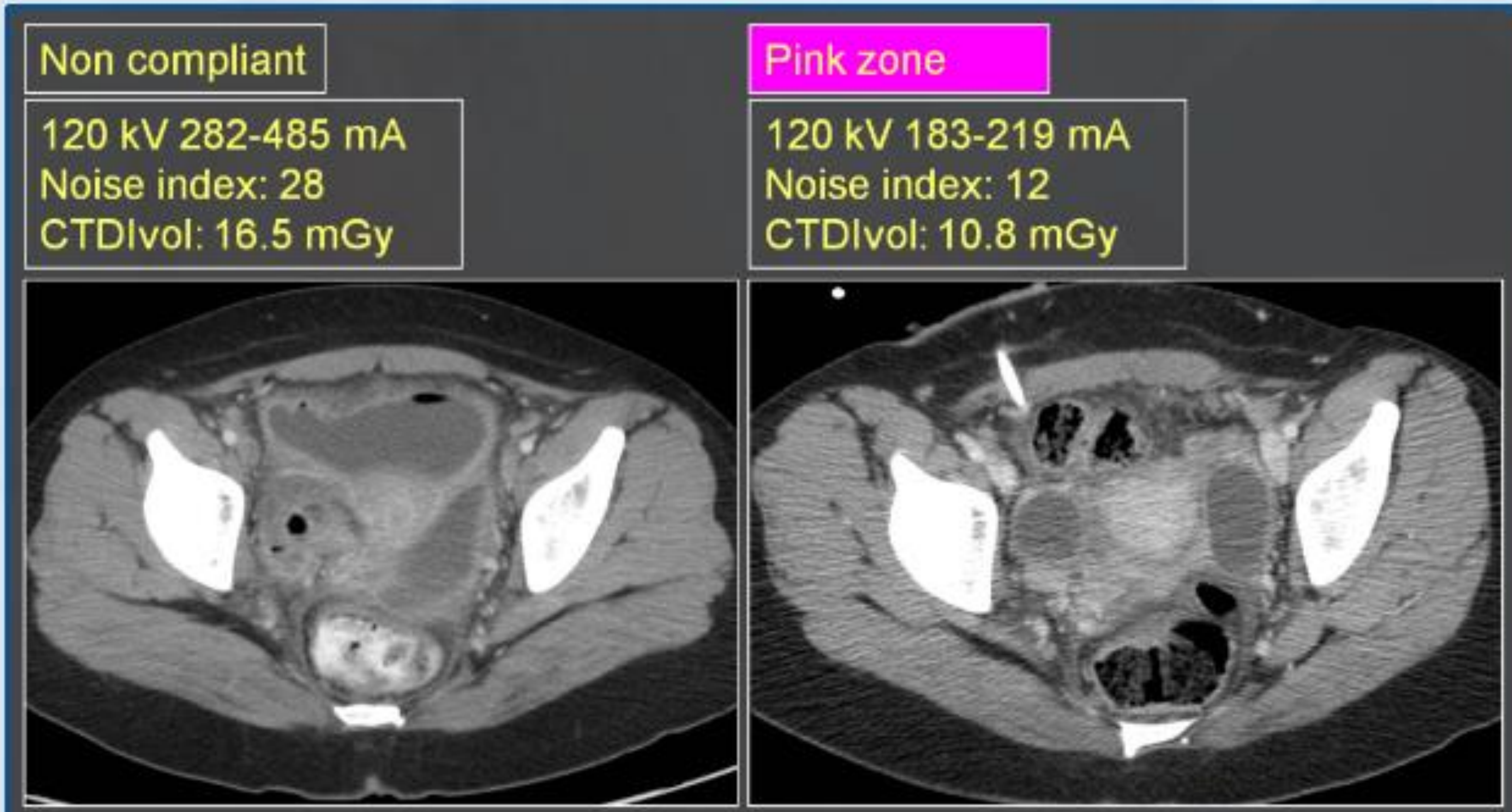
Following implementation of CT protocol: Compare radiation dose with old protocols, compliant & non compliant with composite color coded protocols.

	Step 1		Step 2		Step 3	
	CTDI vol (mGy)	Dose reduction	CTDI vol (mGy)	Dose reduction	CTDI vol (mGy)	Dose reduction
Compliant	6.6	**65%**	6.7	**61%**	4.6	**75%**
Non compliant	19.1		17.4		18.5	

*Results of color coded protocol implemented at MGH

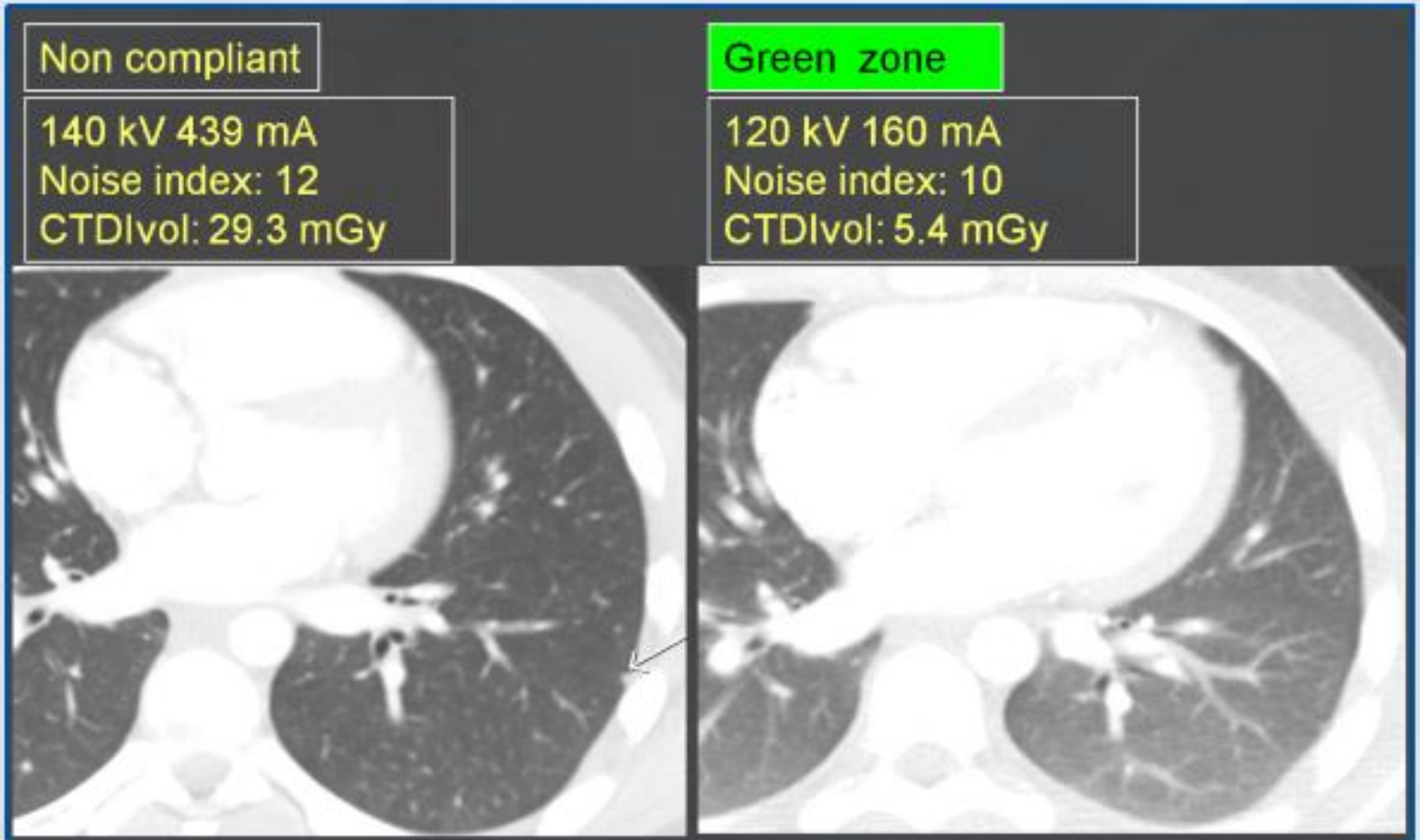
PINK ZONE ABDOMINAL CT

13 yr old female weighing 67 kg (transverse diameter 33.2 cm) underwent CTABP+ for abdominal pain.



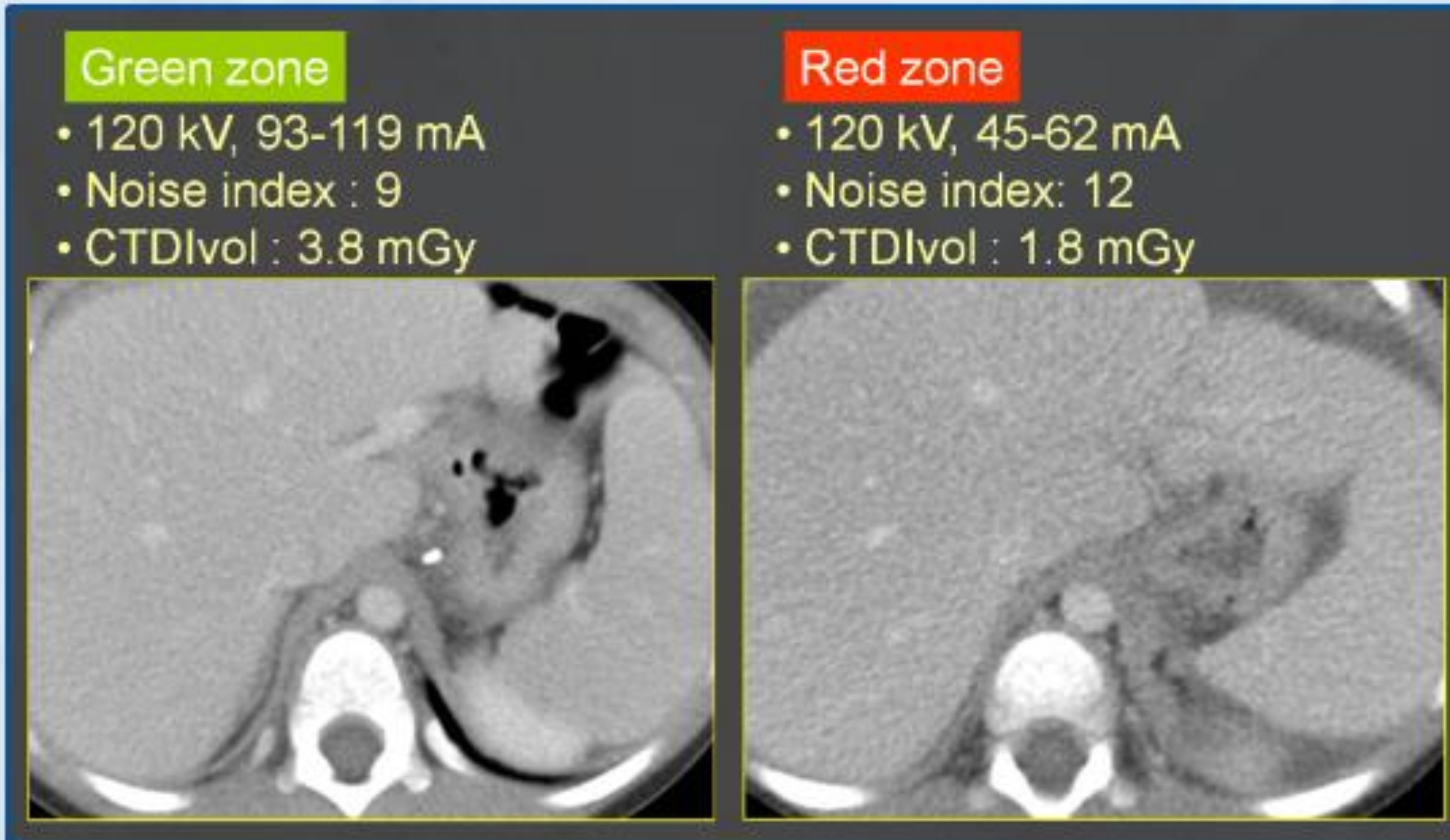
GREEN ZONE CHEST CT

16 yr old male weighing 76 kg (transverse diameter 31.4 cm) underwent CTCH+ for follow up of pulmonary nodule



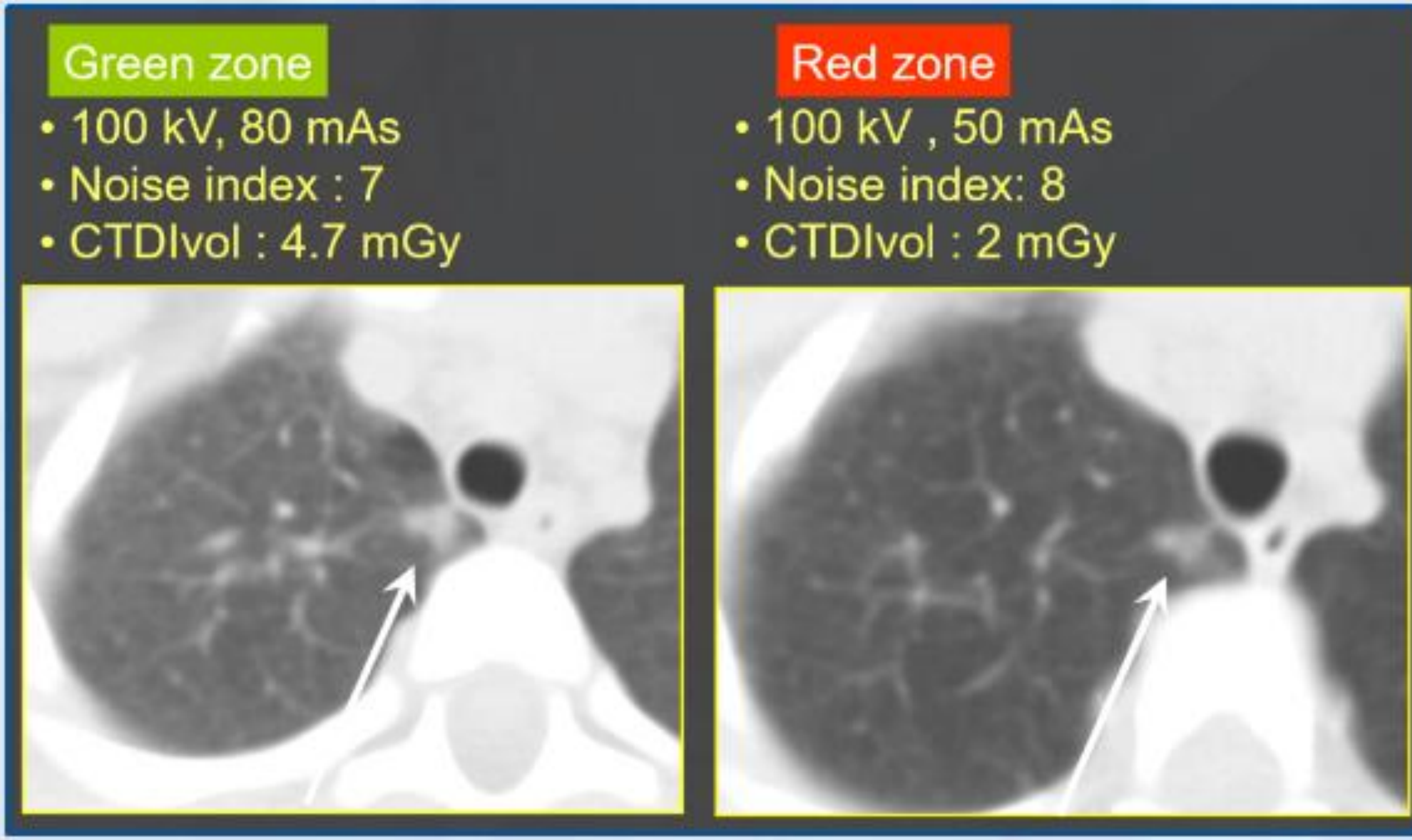
RED ZONE ABDOMEN CT

2 yr old male with transverse diameter 17.8 cm underwent CTABP+ for post left adrenal neuroblastoma resection



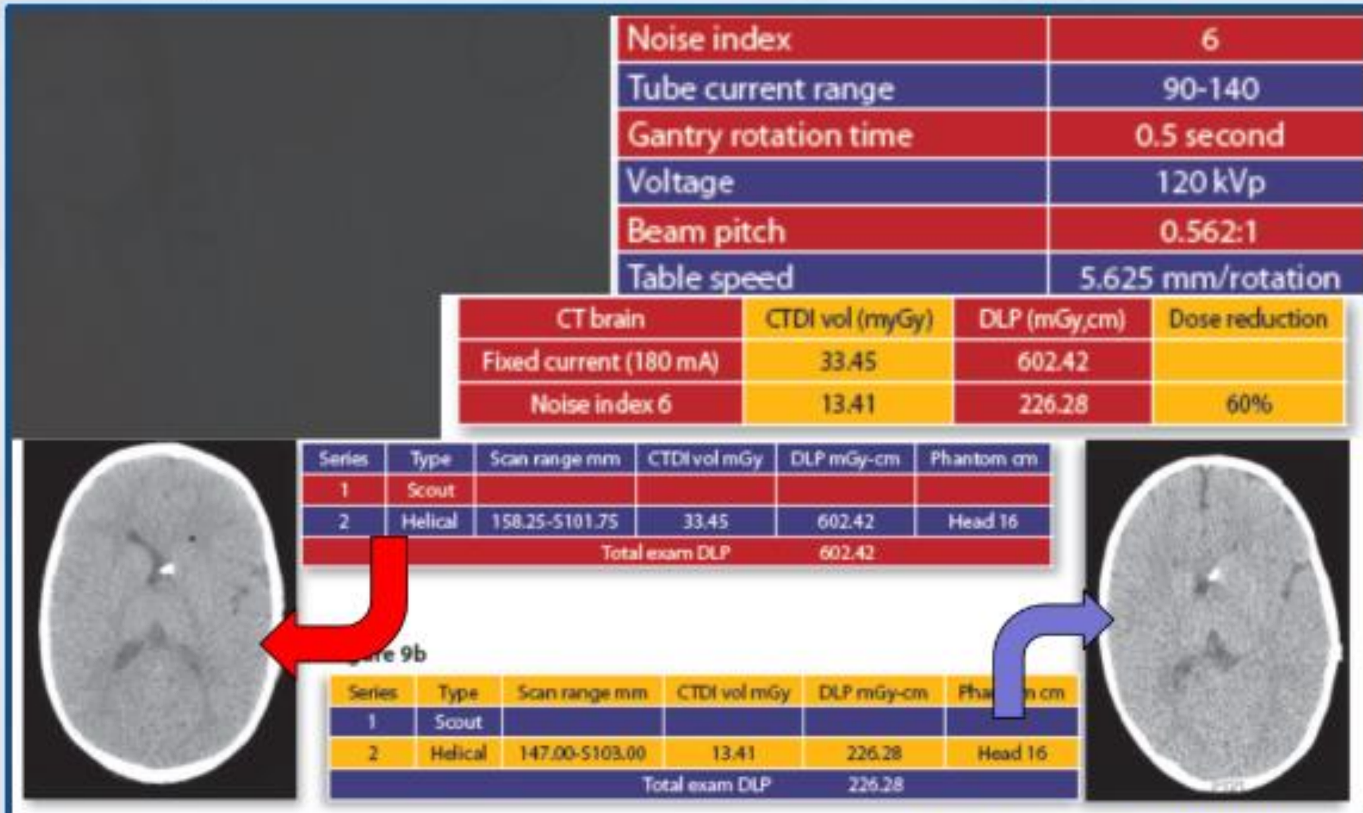
RED ZONE CHEST CT

5 yr old male with transverse diameter 17.4 cm underwent CTCH+ for chronic cough



PEDI NEURO CT

- Trauma
- VP shunt patency
- Post operative



Noise index	6
Tube current range	90-140
Gantry rotation time	0.5 second
Voltage	120 kVp
Beam pitch	0.562:1
Table speed	5.625 mm/rotation

CT brain	CTDI vol (myGy)	DLP (mGy,cm)	Dose reduction
Fixed current (180 mA)	33.45	602.42	
Noise index 6	13.41	226.28	60%

Series	Type	Scan range mm	CTDIvol mGy	DLP mGy-cm	Phantom cm
1	Scout				
2	Helical	158.25-S101.75	33.45	602.42	Head 16
		Total exam DLP		602.42	

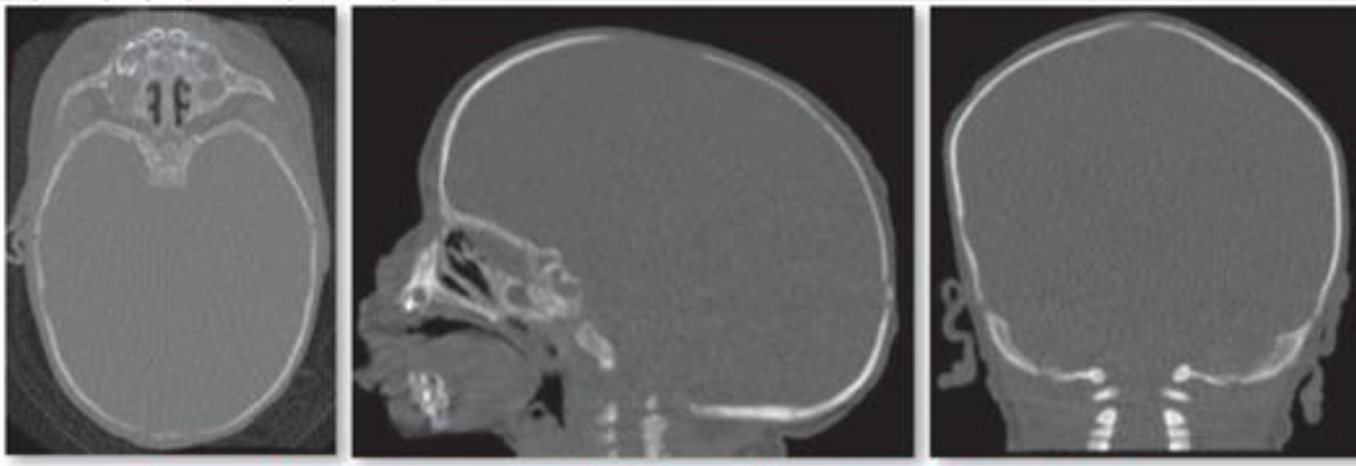
Series	Type	Scan range mm	CTDI vol mGy	DLP mGy-cm	Pha[illegible]n cm
1	Scout				
2	Helical	147.00-S103.00	13.41	226.28	Head 16
		Total exam DLP		226.28	

Setty, kalra, et al. SPR 2008

PEDI SKULL

Tube current range	100
Gantry rotation time	0.5 second
Voltage	80 kVp
Beam pitch	0.562:1
Table speed	5.625 mm/rotation
Detector configuration	16 X 1.25 mm
Reconstructed slice thickness	0.625 mm @ 0.625 mm interval

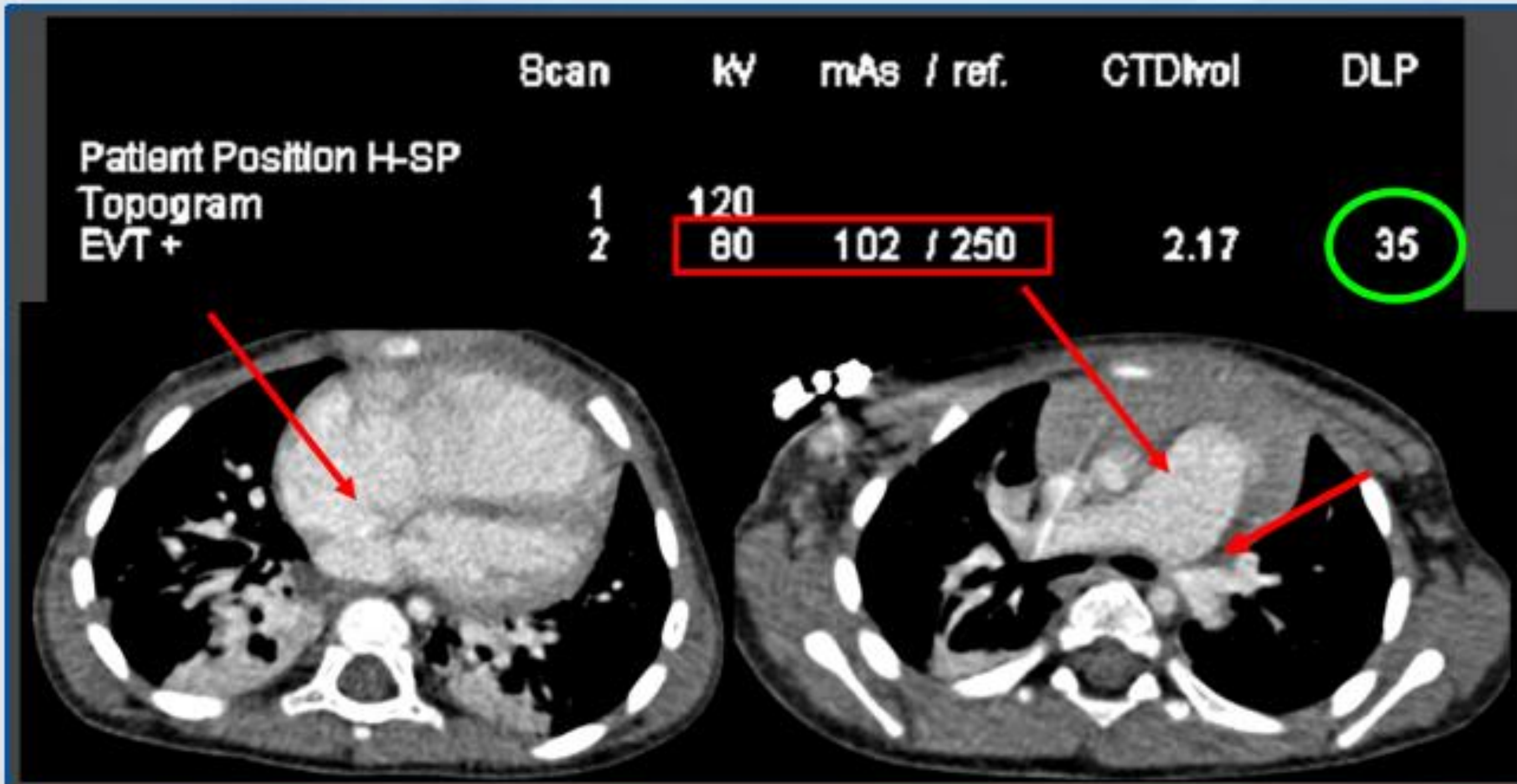
Craniosynostosis



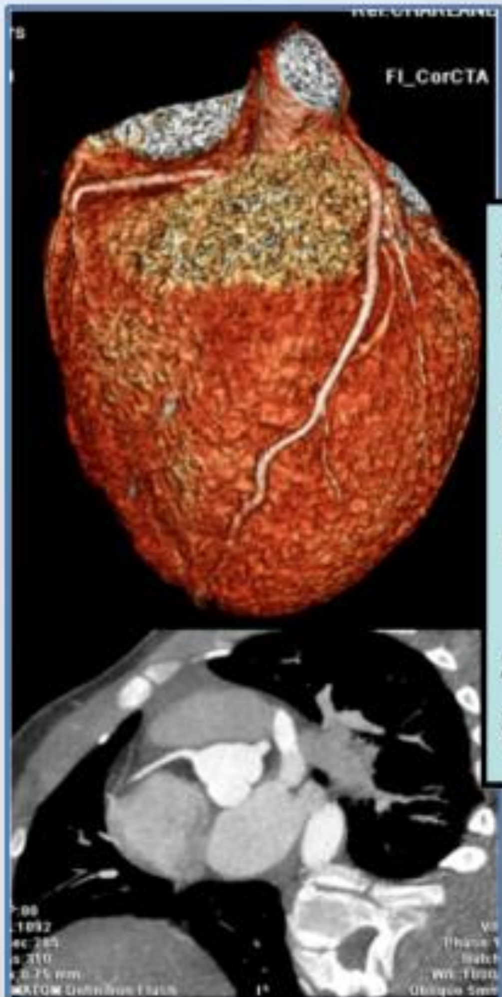
Series	Type	Scan range mm	CTDI vol mGy	DLP mGy-cm	Phantom cm
1	Scout				
2	Helical	166.25-556.25	1.48	20.31	Head 16
		Total exam DLP		20.31	

CHEST CT FOR AORTA & PULMONARY ARTERIES

13 month old girl with pulmonary artery stenosis scanned at 80 kV, low mA (AEC) and without EC gating



CARDIAC CT WITH HIGH PITCH AND LOW kV



Age **14 years** Weight **59 kg**	Age **65 years** Weight **135 kg**
EKG gated heart	**Non gated pulm. veins**
Pitch 3.4	**Pitch 3**
80 kV CTDIvol = **2.5 mGy**	**100 kV** Dose **3 mSv**

SUMMARY

- Pediatric CT should be performed once it is clear that other safer modalities can not give accurate and timely informatio
- Adult CT protocols and radiation doses should not be used for pediatric CT
- Use of multiphase CT must be avoided in children
- Iterative reconstruction, AEC, and automatic kV selection techniques must be used in children when available.

QUANTITATIVE MEASURES

OBJECTIVES

- Understanding risk of CT radiation exposure in pregnancy
- Steps to cut unnecessary radiation dose from CT:
  - Appropriate indications
  - Reduce scan length
  - Optimize scan parameters
  - Use of shielding

QUANTITATIVE MEASURES

- X-rays ionize atoms and molecules in human tissues by deposition of energy
  - Absorbed dose: Quantity of energy deposited locally in an organ per unit mass
  - Equivalent dose: Product of averaged absorbed dose in an organ and radiation weighting factor
  - Effective dose: Sum of products of equivalent doses for irradiated tissues/organs and suitable tissue-weighting factor (risk estimate)

QUANTITATIVE MEASURES OF RADIATION

	Absorbed Dose	Effective Dose
Current SI Units	1 grey (Gy)	1 Sievert (Sv)
Old Units	100 rad	100 rem
"Loose change"	1 rad = 10 mGy	1 rem = 10 mSv

AVERAGE FETAL DOSES FROM MATERNAL CT EXAMS

Extra-abdominal	Mean fetal dose (mGy)
CT head	< 0.01 (max. dose <0.01)
CT chest	
Routine	0.2 (max. dose= 1)
Pulmonary Emboli	0.2 (max. dose= 1)
Coronary arteries	0.1
Abdominal CT	
Routine abdomen	4
Routine abdo-pelvis	25.0 (max. dose= 79.0)
Routine pelvis	25.0 (max. dose= 79.0)
Abdominal aorta CTA	34
Stone protocol	10

IONIZING RADIATION: EFFECTS

- Effects of ionizing radiation can occur from either direct or scattered external beams
- Direct cellular (molecule in path of X-ray) or indirect (free radical production) effects
- Embryonic and fetal effects include
  - Mutagenesis
  - Teratogenesis
  - Carcinogenesis

IONIZING RADIATIONS: THRESHOLD FOR FETAL EFFECTS

- Fetal dose < 100-200 mGy is not associated with measurable increase in non cancer fetal risks
- Most radiological investigations are associated with doses much less than 100 mGy

RADIATION MUTAGENESIS

- Include germ-line genes alteration and mutations, which can affect future generations
- Biological filtration: Affected cells are often filtered out of existence by the body
- Mutagenesis in offspring of radiated patients has not been demonstrated in humans, although these effects have been seen in plants and animals at high doses

PREVALENCE OF MALFORMATIONS

	Rate per 1000 live births
Any malformation	45.3
Major malformation	27.7
Minor malformation	17.9
Malformations of:	
MSK	14.3
Genitourinary	9.2
cardiovascular	8.0
Central nervous	5.3

RADIATION TERATOGENESIS

Gestation weeks	Embryonic and Fetal Effects
First week	Most sensitive period for prenatal death Failure to implant and conceptus death
2-8 weeks	Most sensitive period for IUGR Embryo is also predisposed to teratogenesis
2-15 weeks	Most sensitive period for small head size Low Dose: Small head size Higher doses: small head with severe MR
8-15 weeks	No severe teratogenesis except GU and organ hypoplasia (brain and testis) Most sensitive period for severe MR
15 weeks- term	No documented risk for teratogenesis

In most sensitive period of teratogenesis, no evidence of adverse effects <100- 200 mGy.

RADIATION AND BIRTH DEFECTS

Conceptus radiation dose	Child without malformations	Child will not develop cancer	Child without malformations and cancer
0 mGy	96.00%	99.93%	95.93%
50 mGy	95.90%	99.51%	95.43%
100 mGy	95.80%	99.07%	94.91%

Data from Wagner LK, Lester RG, Saldana LR. Exposure of the pregnant patient to diagnostic radiations: a guide to medical management. Madison (WI): Medical Physics Publishing; 1997; with permission; and Wagner LK, Hayman LA. Pregnancy and women radiologists. Radiology 1982;145(2):559–62.

RADIATION AND BIRTH DEFECTS

Question: My patient had abdominal CT in first trimester of pregnancy. Will the child have malformations?

First estimate the radiation dose to conceptus
(Generally << 50 mGy: Let us say 10 mGy)

Answer: About 4-6% children have malformations in absence of radiation exposure (baseline risk). Radiation dose (when < 100 mGy) to conceptus has not been shown to significantly increase the risk of malformations above the baseline risk.

RADIATION CARCINOGENESIS

- Slight rise in background leukemia rate from 3.6/ 10000 to 5/10000 after in utero dose to 1-2 mGy
- While an association between risk for cancer and prenatal radiation exposure is not questioned, etiologic significance of radiation remains unresolved

WHEN TO DO CT?

- CT must be performed only if information is important for care and not obtainable by other means
- Informed decision: Radiologist, Physician, Patient
- Life threatening conditions: image without delay
- Non-emergent: pregnancy testing - if uterus will get irradiated

USE OF CT IN PREGNANCY

- Golden Rule 1:
Use of CT for appropriate indications in pregnancy must NOT be restricted

- Golden rule 2:
When possible and timely, try non-ionizing radiation or lower dose imaging tests in pregnancy

- Golden rule 3:
While more than necessary radiation should be avoided, use of less than necessary radiation resulting in suboptimal information content should be strongly discouraged!

COMMON INDICATIONS FOR CT IN PREGNANCY

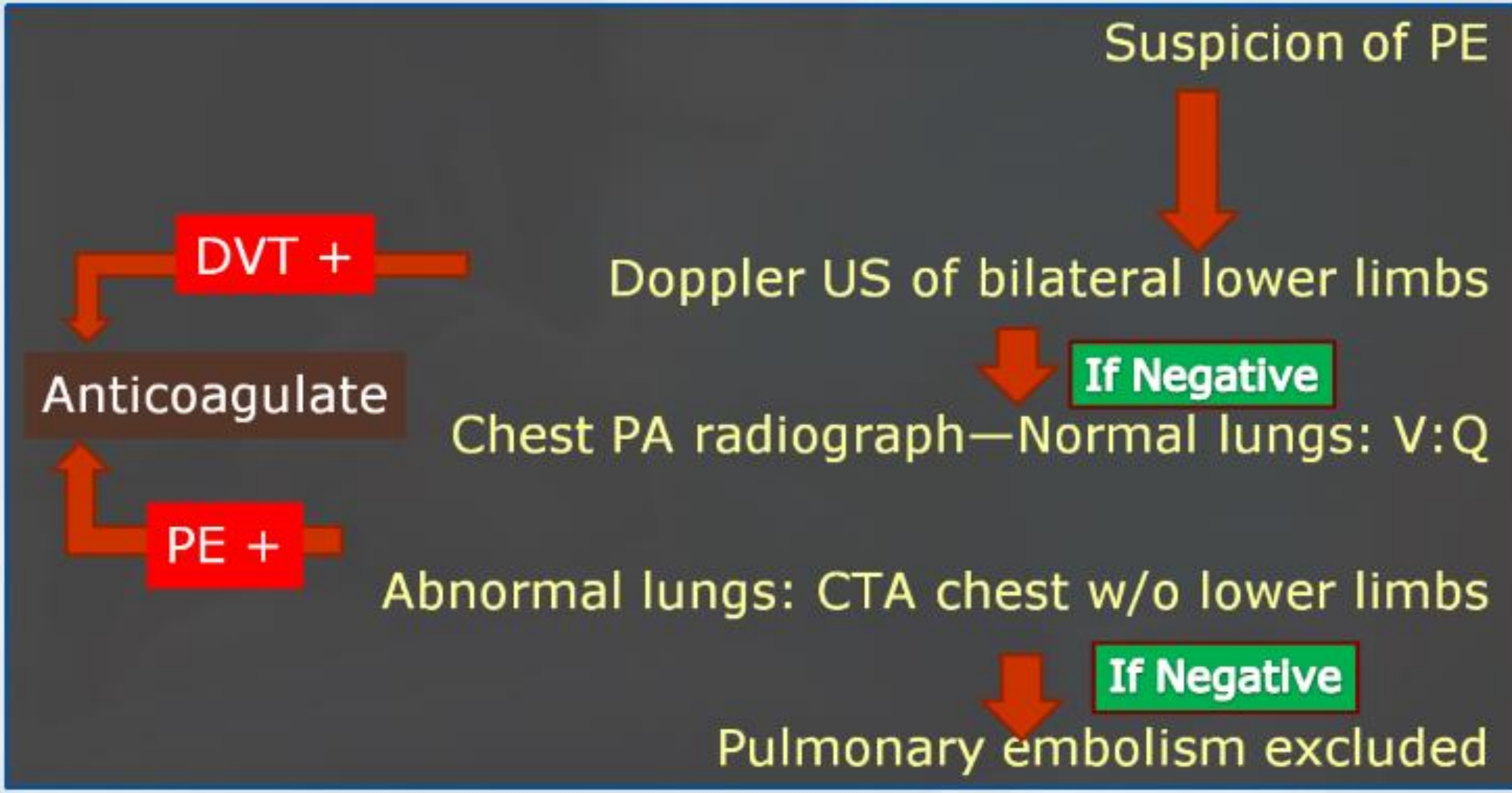
Chest CT:
- Pulmonary embolism

Abdominal CT:
- Renal colic
- Appendicitis

STRATEGIES FOR CT DOSE OPTIMIZATION IN PREGNANCY

- Use AEC to adapt mAs to patient size
- Use appropriate kV based on clinical indication
  - Lower kV for CT pulmonary embolism than for kidney stones
- Prefer wider beam collimation to improve dose efficiency
- Use non-overlapping pitch ($\leqslant$ 1 but not 0.5) to minimize motion artifacts
- Restrict scan range to what is absolutely necessary
- Use lead shielding (External scatter - decrease anxiety)
- Give oral contrast agent for internal shielding- better!

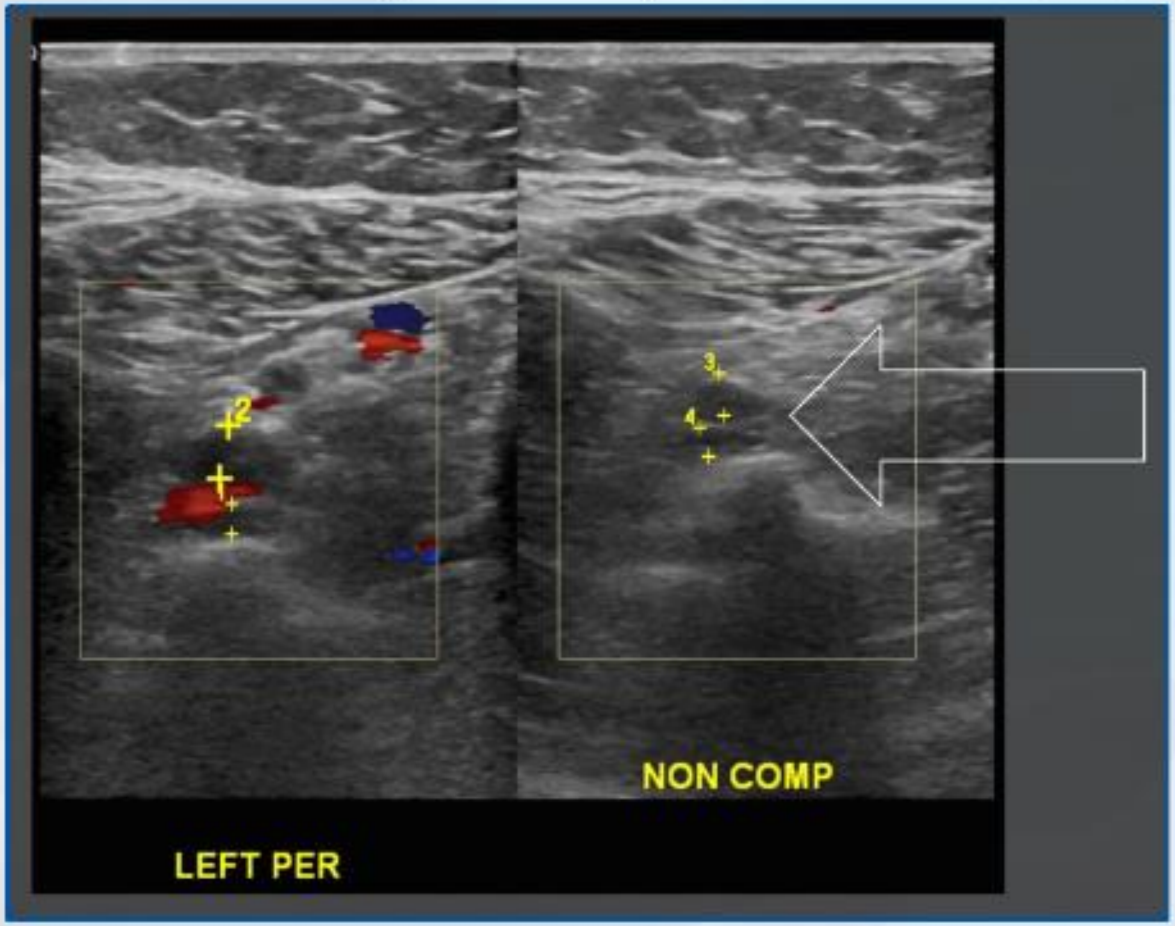
CT PULMONARY EMBOLISM IN PREGNANCY: THE ALGORITHM



Patel et al. Radiographics 2007

CT PULMONARY EMBOLISM

First Consider Doppler for Deep Vein Thrombosis (DVT)



Positive Doppler for DVT implies anticoagulation. No CT is needed in this case

CT PULMONARY EMBOLISM IN PREGNANCY: THE APPROACH

Localizer radiographs

- Ensure good patient centering before acquiring localizer radiographs
- Low kV and low mA for localizer radiograph
- Do not acquire extra-long localizer into abdomen
- Prefer two localizers for adequate centering

Patel et al. Radiographics 2007

CT PULMONARY EMBOLISM IN PREGNANCY: THE APPROACH

Minimize motion artifacts in CT images

- Demonstrate breath-holding
- Practice breath-hold with patient
- Use fast gantry rotation time
- Use non-overlapping pitch
- Prefer wide beam collimation when slice thickness is not limited
- Shorten scan range:
  - Exclude upper abdomen: Inferior limit to just below xiphoid process
  - No pelvis or lower limb scanning

Avoid suboptimal contrast enhancement in pulmonary arteries

- Instruct patients to avoid Valsalva maneuver
- Use good contrast bolus timing technique
- Make sure risk of contrast extravasation is minimized with saline flush
- Make sure there is good intravenous access for contrast

CT PULMONARY EMBOLISM IN PREGNANCY: THE APPROACH

- Use 80-100 kV for patients who have body mass index of less than 30 kg/m2
- Prefer AEC technique over fixed mA
- Use iterative reconstruction (when available)
  - To enable additional radiation dose reduction over FBP technique

Prakash, Kalra et al. Investigative Radiology 2010

On use of lead shielding

- Remember external scatter does not cause much radiation in CT
- Most radiation to conceptus results from direct radiation or from internal scattering from chest to abdomen
- External shielding does not protect against internal scatter but does decrease anxiety
- When using external shield make sure to wrap the shield all around the patient

INTERNAL SHIELDING: PREGNANCY

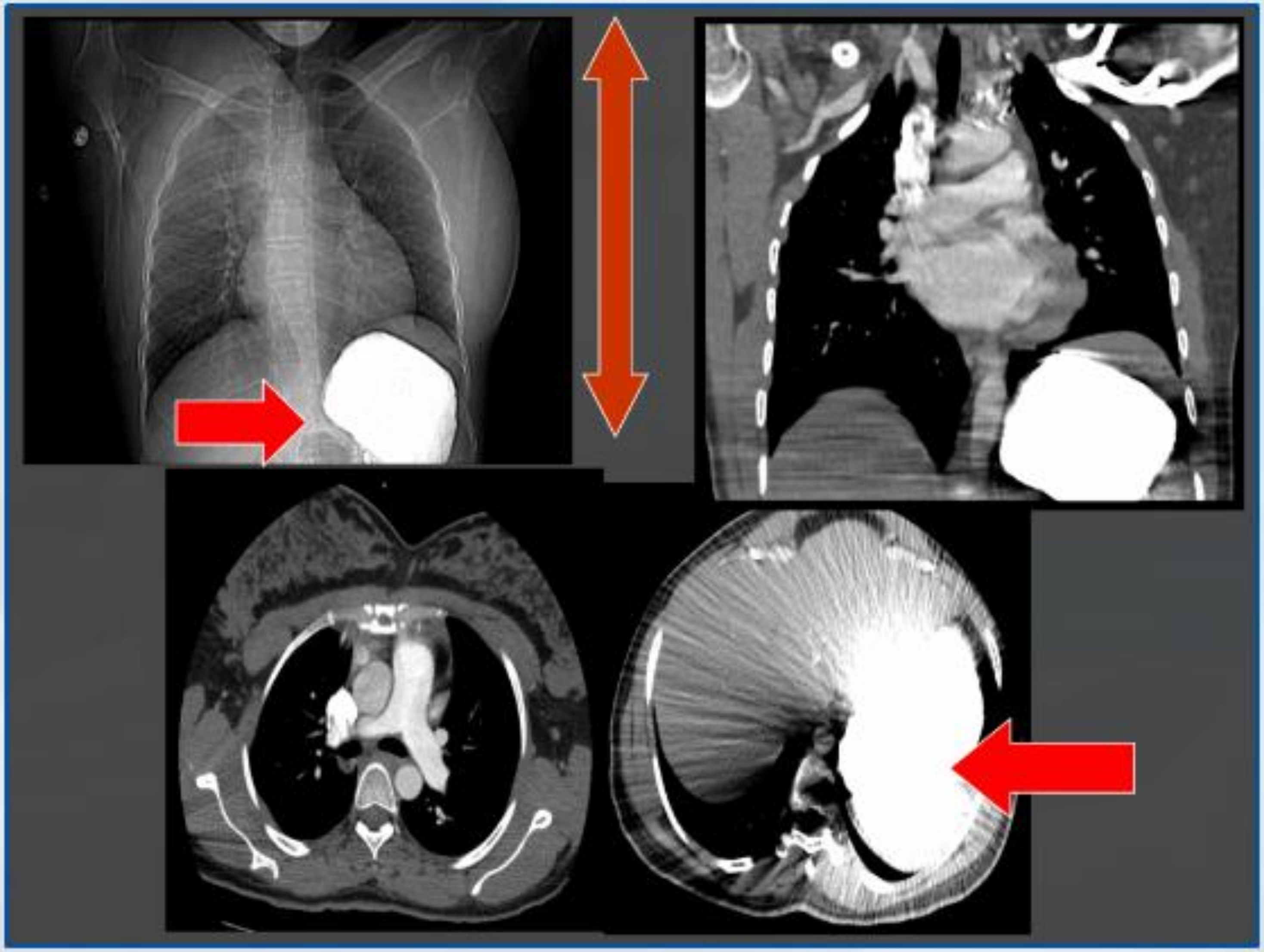
Use of barium based oral contrast agents for internal shielding of conceptus during CT pulmonary embolism.

- Barium sulphate up to 30% (3-400 ml) reduces internal scatter by about 91% which is equal to 1mm lead shield.
- Internal shield is more effective than external shield in reducing radiation dose to the conceptus from chest CT.
- Slowly administer 1-2 glasses of Ba Sulphate on CT table.
- Always give water after barium to wash out barium from esophagus to avoid artifacts.

Yousefzadeh et al. Radiology 2006

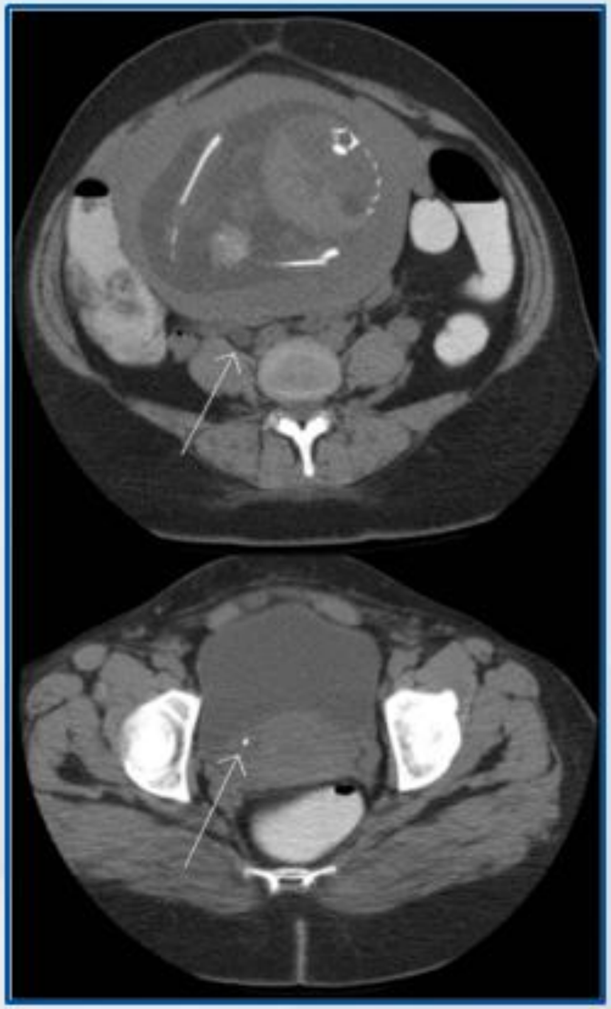
Although innovative and seemingly straightforward, this approach has only been validated in phantom study and not in live human subjects. Should site choose to implement this approach, they should exercise caution. It is important to remember that in pregnant patients undergoing chest CT, it is far more important to apply suitable scan parameters including appropriately short scan length in the first place.

ADMINISTRATION OF BARIUM TO PREGNANT PATIENT



KIDNEY STONES AND PREGNANCY: USE AND RADIATION DOSE

- Low-dose CT for renal calculi is sufficient
- CT is especially helpful as urinary tract often difficult to see with US or radiographs due to pregnant uterus
- Fetal radiation doses of 4-7 mGy and of 8-12 mGy at 0 and 3 months of gestation from a renal stone CT with a relatively low tube current (160 mA)



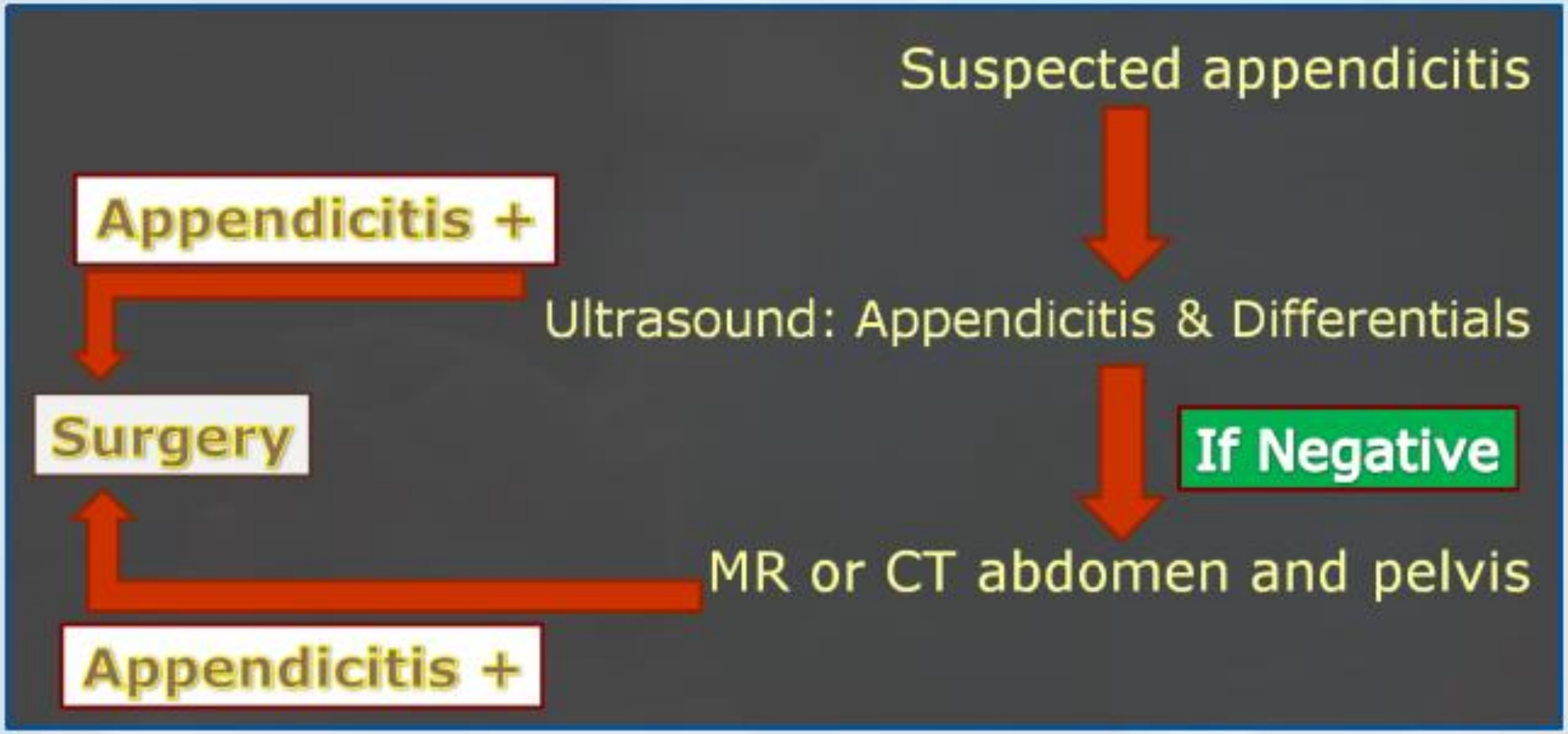
KIDNEY STONES AND PREGNANCY: USE AND RADIATION DOSE

- Localizer radiographs
  - Use low mAs to acquire the localizer
  - Ensure good patient centering prior to localizer

- Use AEC over fixed mA
  - Set image quality parameter at lower level to reduce dose compared to routine abdomen CT
  - 25-30 NI for GE, 100 reference mAs for Siemens

- Reduce scan range (strict "borders")
  - Top of kidney to pubic symphysis
- Less than or equal to 120 kV
- Pitch greater than or near to 1
- Wider beam collimation for greater dose efficiency
  - For ex: 16 slice CT: 16 x 1.25 > 16 x 0.625
- When available apply iterative reconstruction technique to enable dose reduction

CT FOR APPENDICITIS IN PREGNANCY

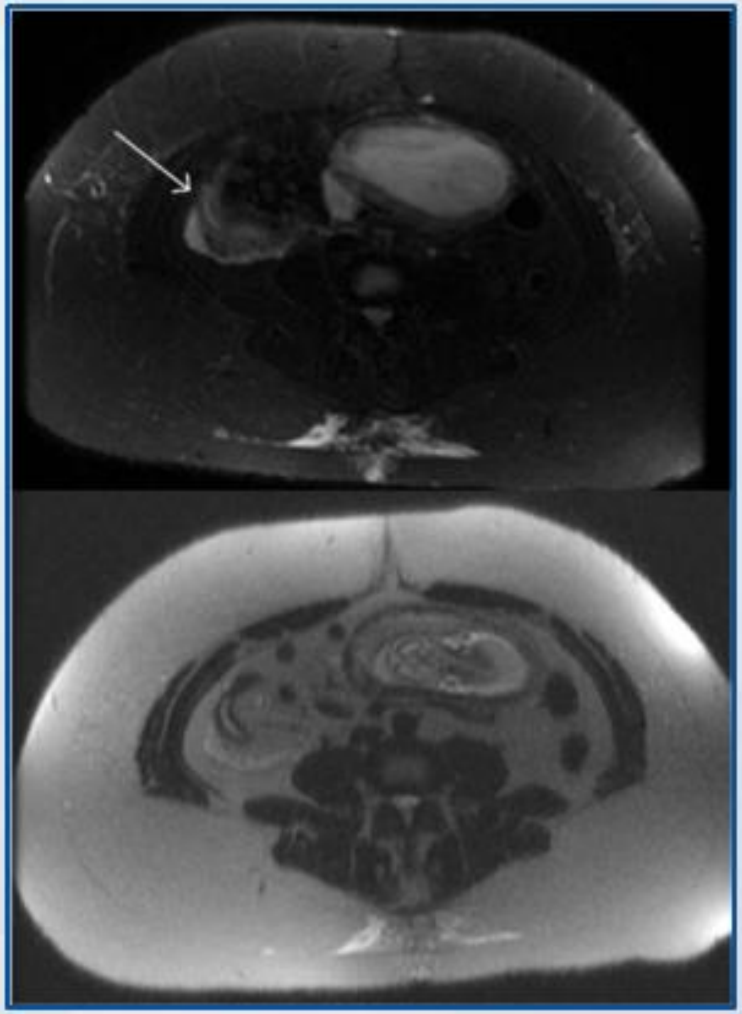


Patel et al. Radiographics 2007

CT FOR APPENDICITIS

- Same rules for localizer radiographs as for kidney stones

- Transverse CT images
- Single phase only
- NO Dual pass please
- Restrict scan coverage
- 120 kV generally
- Apply AEC
- Non-overlapping pitch
- Wider beam collimation
- When available apply iterative reconstructions to enable additional radiation dose reduction



PRECAUTIONS FOR PREGNANT PATIENTS

There should be a sign in each radiology waiting area
"Notify technologist if you think you are pregnant"

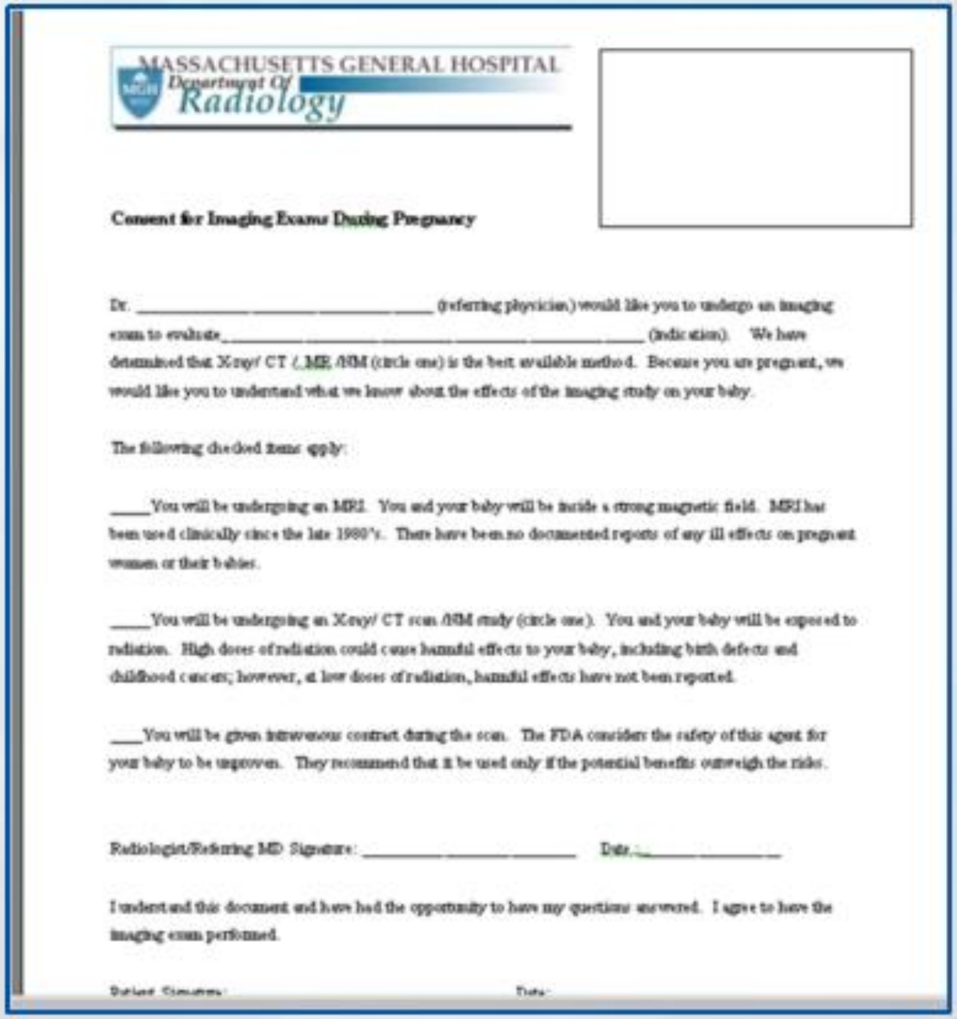
- Before CT:
  - Radiographers must ask each woman of childbearing age if she thinks she might be pregnant
- Fetal dose must be minimized without affecting diagnostic image quality

ESTIMATION AND DOCUMENTATION OF FETAL EXPOSURE

- Technologist should notify appropriate radiologist when imaging is performed on a pregnant patient
- Medical physicist should estimate and document fetal radiation dose
- Referring physician and patient must be advised about fetal exposure

ASSURANCE AND COUNSELING

- Inform patients
- Dose information must be conveyed to physician to counsel pregnant patient and to help make informed decision regarding possible impact of radiation



MASSACHUSETTS GENERAL HOSPITAL
Department Of Radiology

Consent for Imaging Exams During Pregnancy

Dr. ______________________ (referring physician) would like you to undergo an imaging exam to evaluate______________________ (indication). We have determined that X-ray/ CT / MR /NM (circle one) is the best available method. Because you are pregnant, we would like you to understand what we know about the effects of the imaging study on your baby.

The following checked items apply:

_____You will be undergoing an MRI. You and your baby will be inside a strong magnetic field. MRI has been used clinically since the late 1980's. There have been no documented reports of any ill effects on pregnant women or their babies.

_____You will be undergoing an X-ray/ CT scan /NM study (circle one). You and your baby will be exposed to radiation. High doses of radiation could cause harmful effects to your baby, including birth defects and childhood cancers; however, at low doses of radiation, harmful effects have not been reported.

____You will be given intravenous contrast during the scan. The FDA considers the safety of this agent for your baby to be unproven. They recommend that it be used only if the potential benefits outweigh the risks.

Radiologist/Referring MD Signature: ______________________ Date: ______________

I understand this document and have had the opportunity to have my questions answered. I agree to have the imaging exam performed.

Patient Signature: Date: