

Implementation of (Low Dose) CT Protocols

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The Impetus...

- In U.S., CT comprises only 11% of all exams but *generates 67% of total diagnostic dose*

• Mettler 2000

- Annual number of CT exams in US has grown from 3 million in 1980 to estimated 62 million in mid 2000s

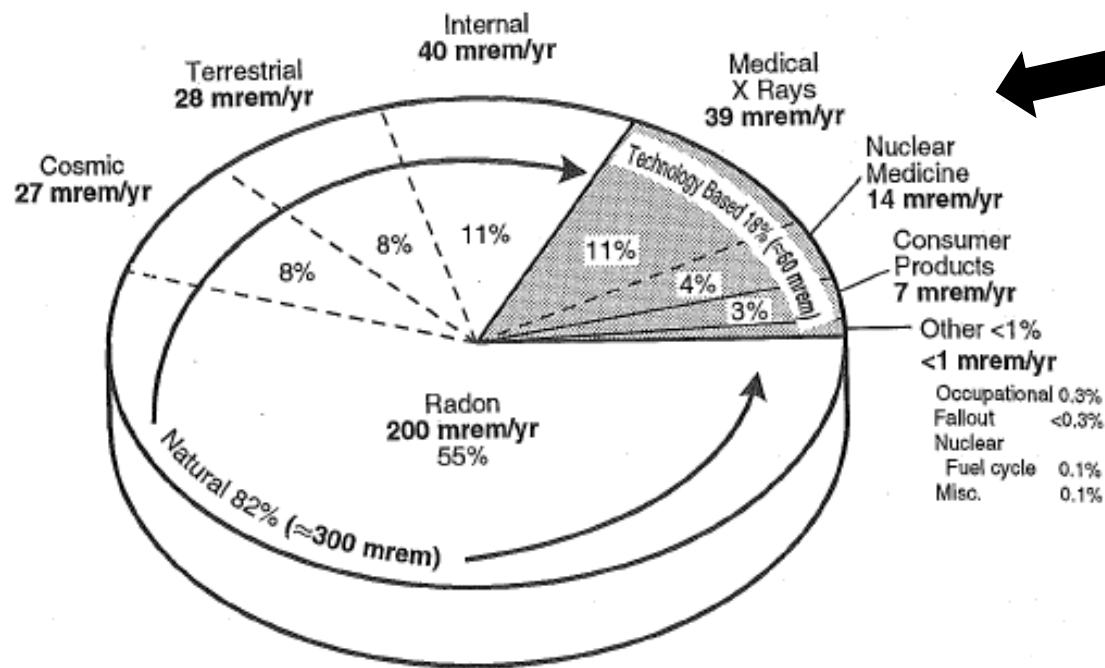
• Brenner/Hall 2007

- Number of pediatric ED visits that included a CT increased five-fold from 1995 to 2008

• Larson 2011

Radiation exposure to US population (*then ...*)

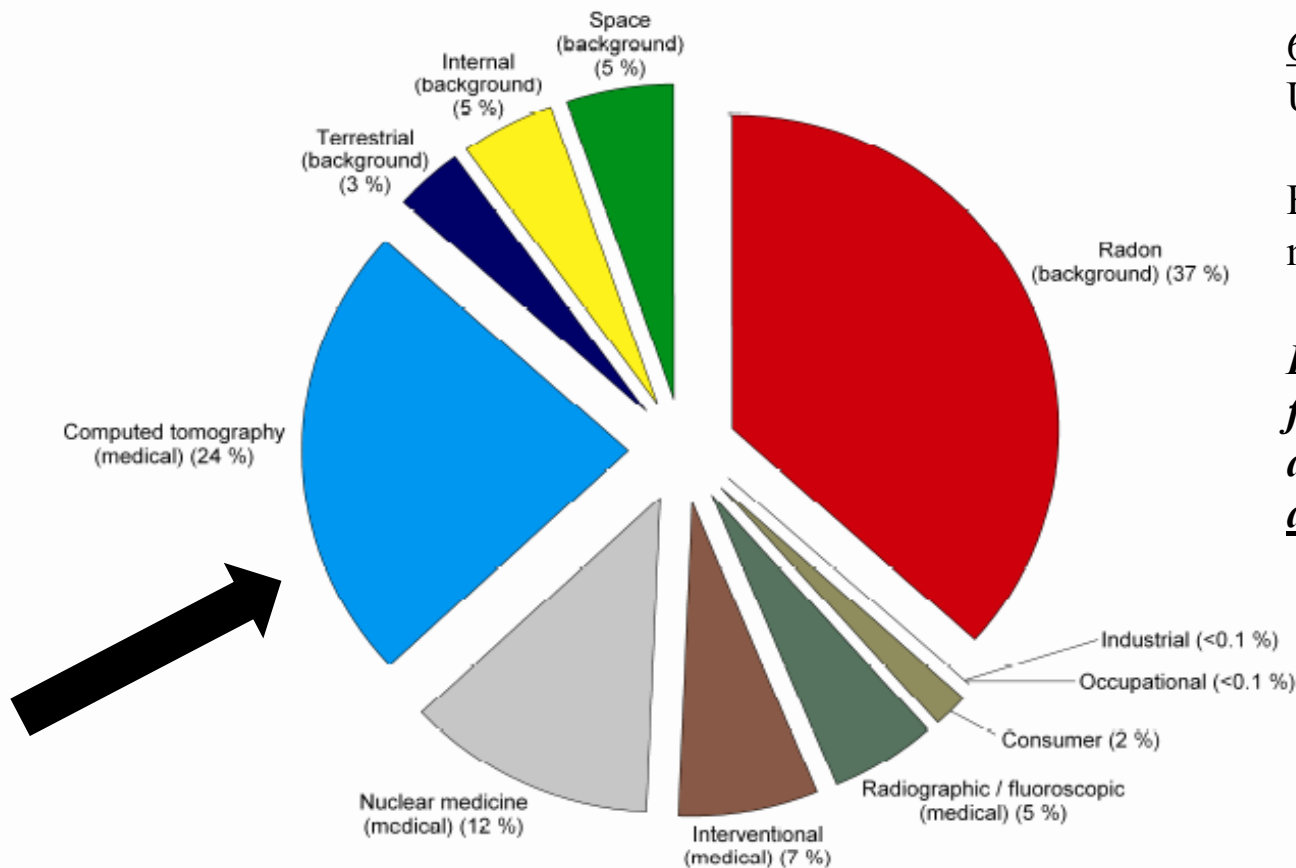
- U.S. average: about 360 mrem (3.6mSv) /year, the majority of which - 300 mrem (3 mSv) - from background
- 15% or about 55 mrem (0.55 mSv) from medical



Essential Physics of Med. Imaging, Bushberg, et al., adapted from NCRP 93, 1987

Population Radiation Exposure (*now*)

NCRP - 2008



6.2 mSv (620 mrem) ED per US citizen

Background still around 300 mrem (3 mSv)...

But now 300 mrem (3mSv) from medical (~50% of total) and half of that from CT alone.

Increased Utilization:

Technology, Speed, Reimbursement

- Sub-second, helical rotation, multi-slice technology increases throughput.
- Improved diagnostic capabilities & higher billing rates.
- Significant increase in pediatric applications brings additional concerns
 - ↑ radio-sensitivity
 - ↑ organ and effective doses, particularly when technical factors are not adjusted

Background: CT/Radiation News

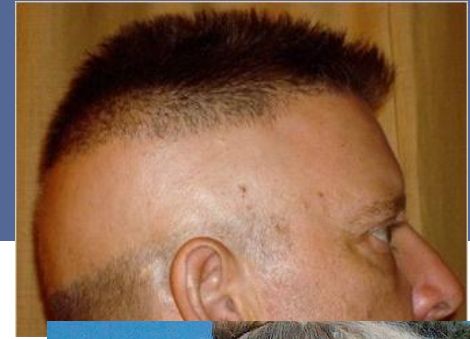
- Literature & media: “high CT utilization increases cancer risk...”
 - Dose from CT same as AB survivor 1-2 miles from ground zero
 - In 2007 70 million CT scans → 29,000 cancers (*Berrington, Arch Int Med 2009*)
 - 600,000 annual CT scans on children under 15 → 500 cancer deaths (*Brenner AJR*)
 - Children more sensitive → *Image Gently* program
- Up to 2% of all cancers in US *in the future* might be associated with radiation from diagnostic imaging (*Brenner 2010*)

How did this become an issue?

- Regardless of what *stochastic* risks may exist (cancer risks) it was the *deterministic* effects that got everyone's attention ...
 - Stochastic: probabilistic chance of occurrence that increases with dose, severity independent of dose (lottery)
 - Deterministic: requires dose threshold, severity of effect increases with dose

CT incidents & reaction

- Brain-perfusion studies in California and Alabama (2009-2010)
 - Hundreds of patients “overdosed” up to 10x “normal” dose → *hair loss, skin burns, cataractogenesis?*
- Mad River Incident: repeated scans in single location on baby
- Class action lawsuits against multiple hospitals and vendors
- Media attention & requests for CT experts/ opinions



Professional Response

ACR, ASNR, AAPM:

- Over reliance on automation
- Review/ consider dose reference levels
- Importance of accreditation
- Protocol review by lead radiologist, technologist, physicist
- Enable dose reporting functions
- CT specific training for all parties involved
- Position statements in response to media stories on increase in medical radiation utilization, cancer risk, overdoses and accidents

Government Response

- Recommendations to Health Care Providers:
 - Investigate for potential injuries
 - Review protocols & implement QC procedures
 - Adjust for appropriate dose & be familiar with dose indices
- Recommendations to Public:
 - Consult with your physician
 - Track your dose (now an i-phone app.)

Specific Responses

- *FDA: Initiative to Reduce Unnecessary Radiation from Medical Imaging (2/8/10)*
 - *Safeguards in scanner design, technology, and training*
 - *Informed clinical decision making & appropriate use criteria*
 - *Increase patient awareness.*
 - *Display, record, & report equip. settings & rad. dose*
 - *Capture & transmit rad. dose to electronic med. record & dose registries*
- *Joint Commission Sentinel Event Alert (2011)*
 - *Right test, right dose, effective processes, safe technology & culture...*
- *Medicare & Medicaid Services (CMS): Accreditation of CT facilities (non-hospital) as of January 1, 2012*

Senate Bill 1237 (California)

- SB-1237 signed into law by Governor Schwarzenegger, “paving the way for implementation of the first state law in the U.S. aimed at protecting patients from excessive radiation exposure received during CT scans and radiation therapy procedures.”
- Text of bill:
 - <http://www.acr.org/SecondaryMainMenuCategories/NewsPublications/FeaturedCategories/CurrentACRNews/California-State-Senate-Bill-1237.aspx>
 - http://www.aapm.org/government_affairs/documents/sb_1237_bill_20100902_enrolled.pdf
- Other states looking to adopt similar requirements.

Root cause?

- Lack of protocol standardization and/or poor understanding of protocols & equipment capabilities likely contributing factor to incidents
- Congressional testimony by experts from ACR, AAPM, ASRT (Subcommittee on Health Committee on Energy and Commerce)
- Smith-Bindman: CT oversight is fragmented ...
 - FDA oversees scanner approval, not use
 - Radiologists determine use but few guidelines available
 - Great potential for practice variation can cause harm
 - Doses higher than reported, vary substantially between facilities and within same facility

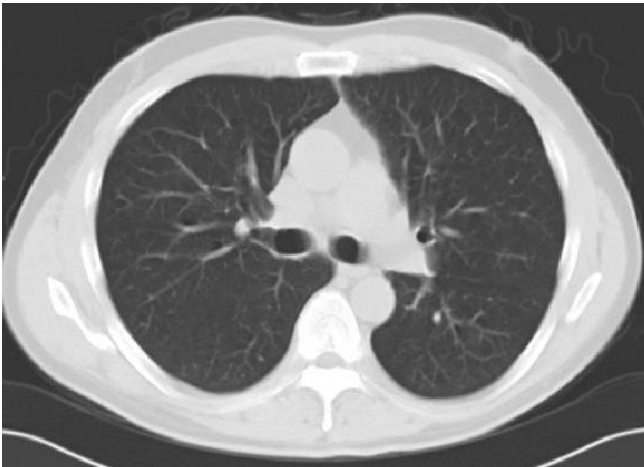
Root Cause?

- While there has been considerable concern over scanner calibration it appears majority of events publicized in the media are result of operator error and/or poor understanding or implementation of scanning protocols/supervision.
- CT scanners are technically complex and technology is constantly evolving. Scan protocols are comprised of a host of technical factors that impact both patient dose and image quality.
- Scan protocols are task specific and will vary amongst vendors and even across scan platforms for a given vendor.
- Experience/training with one scanner does not mean proficiency with another; even of same manufacture.

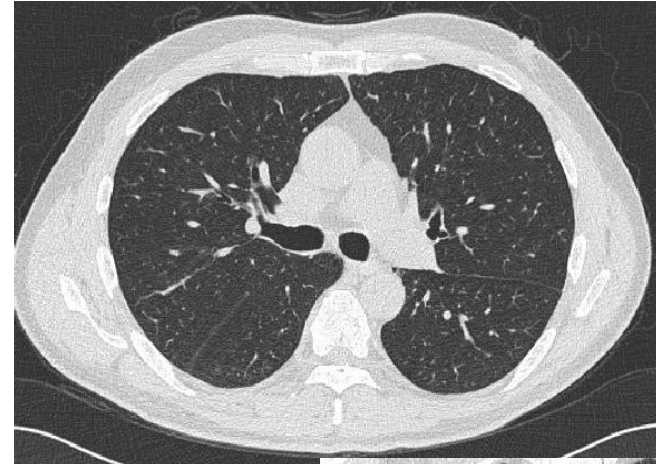
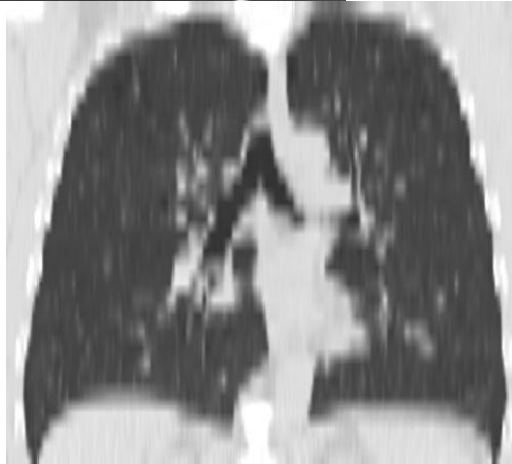
Significance of CT Scan Protocol

- CT equipment output/calibration routinely evaluated (regulations and/or physics practice)
- However scanners themselves are typically **very** stable and CT console reported dose metrics generally quite accurate. (*Mathieu K, et al. 2010*)
- It is the technical factors that are specified in scan protocols that **directly control** machine output, the delivered radiation dose delivered, and the image quality.
- Yet scan protocols themselves are **myriad, vendor specific, highly variable**, NOT regulated & have most impact on dose
- *Fear of litigation and bad publicity driving industry to review processes!*

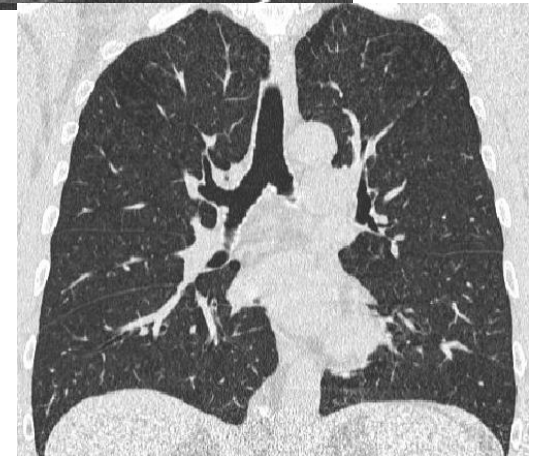
Image quality also protocol dependent. Must be tailored to diagnostic goal of the exam...



10 mm slice
smooth recon. kernel



1 mm slice
sharp recon. kernel



Challenges to standardization and Implementation: Scan Purpose/Task

CT: a powerful diagnostic tool undoubtedly over-utilized
... *but which scan was the unnecessary one?*

- Defensive Medicine in a risk averse society
 - Patient self referral
 - Emergency Room
- Top three culprits
(James Thrall, ACR)*
- Most common: Abdominal pain → High sensitivity/specificity of CT for appendicitis
 - Clinical Indication /Appropriateness Criteria/Practice guidelines?
 - Voluntary adherence, Changing standards, impact on scan protocols
 - Use of multi-phase (series) scans, generally with contrast, increases dose
 - ACR Practice Guidelines (www.acr.org)

Challenges to standardization and implementation: Protocol naming

- In addition to clinical indication, protocol naming convention varies considerably, even within an institution
 - Naming convention arbitrary? Origin w/ vendor, clinical trials, what sounded good to tech at the time? Process driven?
 - E.g.: *Routine Head* or *Standard Brain*?
- Naming convention lexicon (in development)
 - RadLex Playbook (www.RSNA.org): Clear, unambiguous names help with ordering, data sharing, dictation templates, workflow and ability to standardize imaging acquisition protocols
 - Population (*Peds, Pregnant, etc.*)
 - Body region (*Chest, Abdomen, Head, etc.*)
 - Modality modifier (*Angio, High res., Localizer, etc.*)
 - Procedure modifier and more...

Challenges to standardization and implementation: Vendor and Technology

- Constantly evolving technology and differences in implementation compounded by marketing terminology:
 - Scanner capabilities evolving: Single slice → Multi slice → TCM
 - *Helical CT vs. Spiral CT vs. Volume CT*
 - *Multi-detector row vs. Multi-channel vs. Multi-slice vs. Number of slices.*
 - *Detector rows and data channels not the same thing.*
 - *64 slice scanner may be 32 detector rows w/ z-axis flying focal spot*

Challenges to standardization and implementation: Vendor and Terminology

Different terminology used ...

- Scout (*GE*), Topogram (*Siemens*), Scanogram (*Toshiba*), Surview (*Philips*)
- mAs vs. Effective mAs (*mAs normalized by scan pitch, e.g. Siemens*)
- Definition of pitch recently standardized by IEC
- Dynamic Scan (*same anatomy*): Cine, Continuous, *Shuttle*, *Jog*, etc.
- Recon filter designation and “look”.
 - Standard, B30, FC10, B (*GE, Siemens, Toshiba, Philips*)

Challenges to standardization and implementation: Technology & Terminology

- Tube Current Modulation/Auto dose named differently and works differently across manufacturers
 - GE: Auto-mA, Smart Scan (dial noise value ↓, dose ↑)
 - Siemens: CAREDOSE, CAREDOSE4D (dial ref. dose ↓, dose ↓)
 - Philips: ACS, Z-DOM
 - Toshiba: IntelliEC, Adaptive mA
- Manufacturers may report dose differently
 - Total DLP, DLP for series
 - Peds body dose (CTDI) reported with head or body phantom

Challenges to standardization and implementation

- Help is Coming ...
 - AAPM Working Group on Standardization of CT Nomenclature and Protocols.
 - AAPM TG 225: CT Protocol Management and Review
 - Accreditation increasingly required (Calif SB1237, CMS)
 - FDA taking greater notice
- References presented here are useful in standardizing everything from clinical indications to naming to technical factors ...

What is a “Low Dose” Protocol?

- Screening protocol ... or marketing tool...?
- No “standard” definition for what constitutes a low dose protocol.
- Aren’t all protocols ALARA?
- Synonym for: Iterative reconstruction scan? Localizer scan? Screening exam? Pediatric exam? (technique must be reduced to maintain same dose for peds!)
- Sometimes expressed as “lower than ‘*standard*’ (*also not defined*) dose” or lower than ACR guidelines
- National Lung Screening Trial (NLST): 40 mAs or lower for average-sized patient for average effective dose of 1.5 mSv. By comparison, Conventional chest CT ED varies but on order of 8 mSv





120 kVp, 350 mAs



120 kVp, 50 mAs

Are we at risk of under-dosing?

- Are we in a “race to the bottom?”
- In our rush to embrace “As Low As...” we could reduce the risk/benefit ratio by reducing the benefit (*Cohen, PedRad 2011*)
- Risk of CT scans is a statistical risk. Risk is certainly low compared to risk of cancer (~40%) and everyday life.
- Concern of misdiagnosis at lower doses. Radiologist performance?
- Image Gently / Wisely → *Image Deliberately/ Intelligently*

Quantify low dose?

- Perhaps better expressed as APPROPRIATE dose for diagnostic task.
 - Radiologist comfort – how much noise can be tolerated.
 - Task specific (appendicitis vs. SPN)
 - Risk / benefit tradeoff
 - Difficult to quantify - still working on useful image quality metrics
- FDA putting pressure on vendors to substantiate quantitative low dose claims.
- Need observer studies to back up dose reduction claims and correlate image quality metrics and Radiologist performance*
- Dose reduction delta will be task specific.

**see work by E. Samei*

Who controls the protocols?

- Physicists are highly educated/trained and focus on equipment calibration/characterization but may have little involvement with scan protocols
- Physicians responsible and read images yet frequently have limited technical knowledge/expertise
- Equipment rapidly evolving – multiple technical variables involved that are not always well standardized
- Technologist actually radiates the patient, usually implements the protocols, probably has most vendor training, but typically least educated on physics principles

What protocols are you using now ?

- How many do you have?
 - Academic medical center may have *hundreds*
 - Will vary per scanner type / capabilities
- Where did they come from?
 - Vendor installed originals?
 - Migrated from older scanners?
 - ...*outdated capabilities, still pertinent?*
 - Specified for a clinical trial?
 - Adopted from an attended talk or scientific paper?
 - Referring physician's special request?
 - *Not used, never deleted, no one knows?*

Who's responsible?

- FDA – regulates equipment design/features
- State typically regulates equipment use and the users (?)
- Licensure of Physician and Technologist
 - Technologist can only operate under supervision of physician?
- Ordering/Referring physician education? Scan reference manual?
- How are your protocols vetted?
 - *Is technologist watching dose numbers?*
 - *Is physician in charge supervising?*
 - *Vendor responsibilities?*

How are your protocols vetted?

- Default vendor installed protocols
 - Vendor has most experience ... and shares responsibility!
 - Dose check and tracking software. Move towards putting more responsibility on institution
 - May be meager pickings ...
- Were protocols modified or added?
 - By whom and for what reason?
 - Are they appropriate for scanner they are installed on?
 - Are they harmonized across similar scanners or adapted to other scanner types?

Process Steps For Developing, Harmonizing, and Implementing protocols.

- Identify team & responsibilities
- Segregate protocol types: subspecialty, body region, scanner model
- Determine clinical indications
- Establish/standardize anatomical positioning, scan extents, scan type
- Determine technical factors (and rationale for changes in such)
- Document reported dose values (and understand limitations of such)
- Don't forget contrast administration and image processing
- Adapt/modify to specific scanner's abilities and limitations
- Evaluate for dose reduction opportunities & image quality (iterative process)
- Harmonize to other scanners
- Documentation! Signatures, "change order" tracking (software feature)?

Protocol Team – shared responsibility

- **Physician/Radiologist**
 - Assigns team / responsibilities (?)
 - Determines scan appropriateness and clinical indication
 - Subspecialists responsible for respective sections (neuro, MSK, etc.)
- **Technologist**
 - Assigned role? Chief, QC, or Protocol Technologist?
 - May be most familiar with scanner and is the person who programs protocols. What if multiple scanner types?
 - Likely only team member to have received vendor specific training.
- **Medical Physicist**
 - Best understanding of scanner functions, technical factors and their influence on both image quality and dose. Translates to other scanners.
 - Often most knowledgeable regarding reference standards/literature.

Protocol Type / Name

Usually will have families of scan protocols

- Population type
 - Adult, Pediatric, Oncologic ...
- Subspecialties and/or Body Region
 - Abdominal, Cardiovascular, Chest, MSK, Neuro, etc.
- Scanner type/capabilities
 - What works on one scanner may not be possible or will have to be modified to work on another scanner type
 - Siemens S-64 vs. GE Litespeed 16...
- Protocol name may incorporate above, RadLex Playbook

Clinical Indications

- Radiologist determination
- Harmonize with study appropriateness criteria (e.g. ACR)
- Harmonize with referring physicians and other subspecialists
- Helps technologist and with order entry
- Specific for a specific scan
- Tailored to use of contrast
- *Trauma, Infection, Oncologic follow-up, Lung cancer screen*

Scan Type

- Helical vs. Axial
- Older helical scans could introduce reconstruction artifacts (petrous ridges, etc.) and may have had problems with partial voluming. Largely gone with modern scanners.
- Axial (Sequential) scanning used more commonly for stationary scanning (perfusion, biopsy, cardiac)

Anatomical Positioning/ Scan Extents

- Prone or Supine
- Head or Feet first (cranio-caudal)
 - Caution! Does it carry-over from scout? Can impact scan labeling...
- Scan region
 - Cardiac: Carina to apex of heart
 - Abdomen: Diaphragm to Iliac Crest
 - Abdomen Pelvis: Diaphragm to Symphysis Pubis
- Modify scan extents for pediatrics?
- Breathing techniques or other instructions
- Specify scout (AP, Lateral)

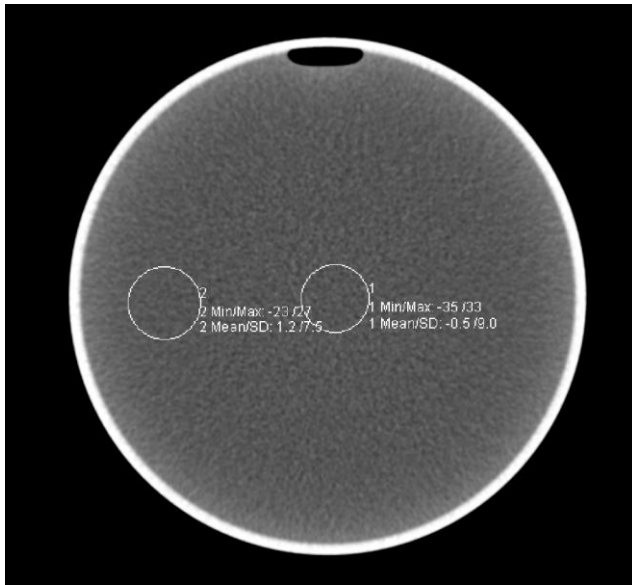
Scan Technical Factors

kVp → Contrast, penetration, and DOSE

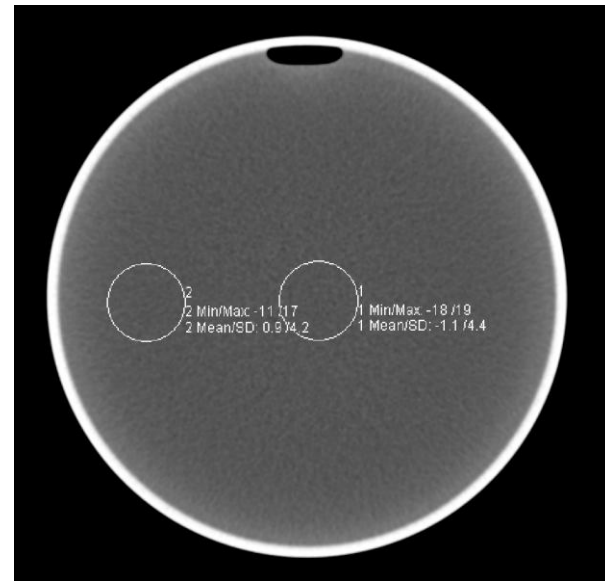
- Increasing kVp increases dose!
- Scanner calibrated at each kVp?
- 120 kVp common for most applications, Lower kVp may be used for peds, specialty exams
- Recommendations may vary amongst vendors who have different bow-tie/filtrations and beam energies.
- Quantitative CT (e.g. perfusion, ROI analysis and bolus tracking) dependent on kVp choice!

Tube current and rotation time

- mA, mAs affects image noise (low contrast objects)
- Requires large changes in mAs to have noticeable affect on noise
- Noise proportional to $(\text{mAs})^{0.5}$ *To reduce noise by half, increase mAs 4x*



120 kVp, 50 mAs $\rightarrow \sigma=9.0$



120 kVp, 200 mAs $\rightarrow \sigma=4.4$

Tube current and rotation time

- What is the mAs for an image?
- Conventionally we think of product of mA and tube rotation time but depending on data binning can create more than one image per rotation (neuroperfusion)
- User may not directly control tube rotation time
- Generally want fastest rotation time possible but can increase signal (dose) using longer rotation times if motion not an issue (for large body parts, etc.)
- May be impacted by tube limits (TCM may also be limited)

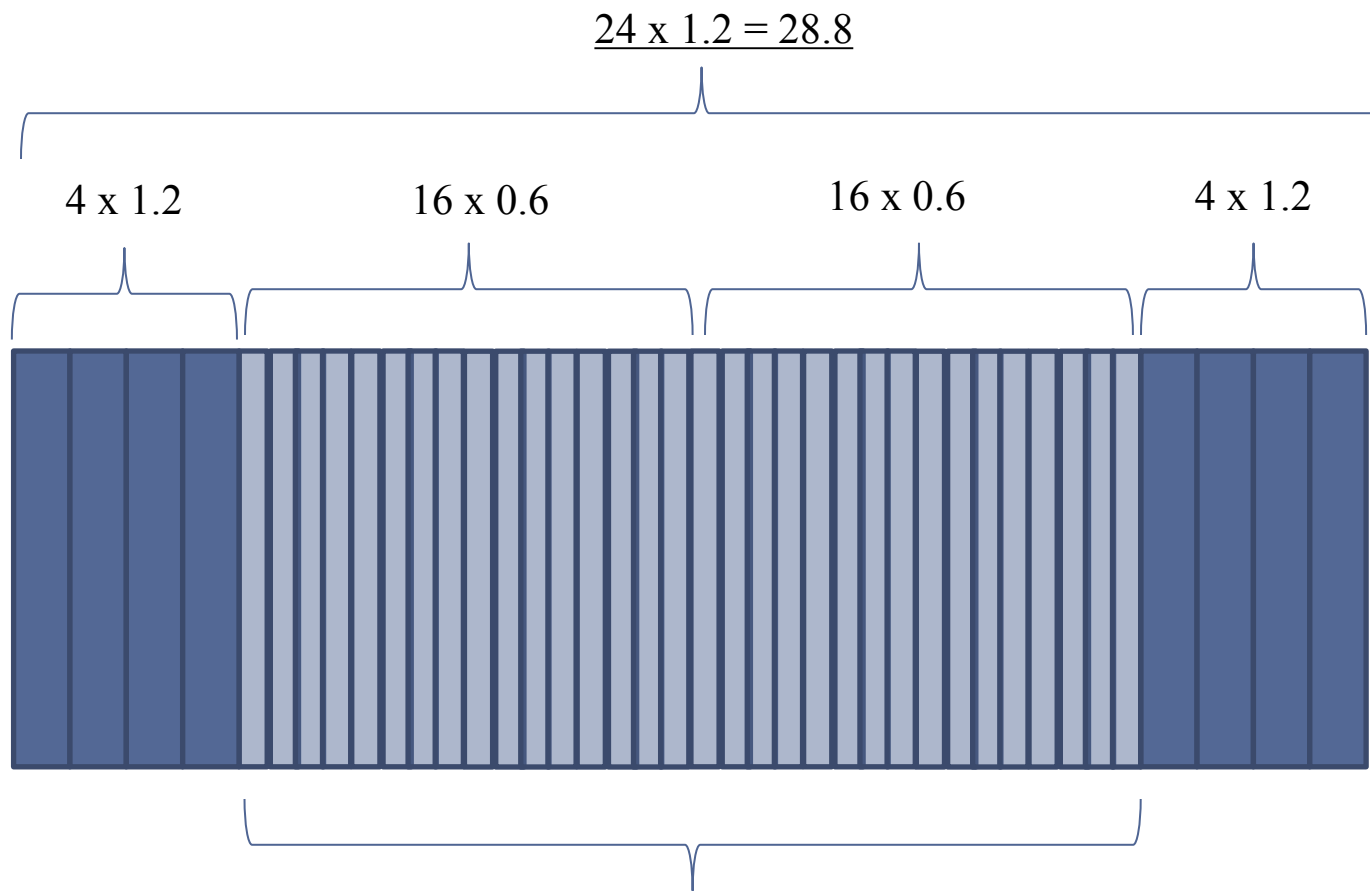
Collimation and Detector Configuration

- Slice thickness affects noise like mAs. Thicker image slices contain more photons. To half the noise need 4x slice thickness
- Slice thickness in MDCT determined by width of detector rows and collimation
- For a given number of available data channels can use individual detectors rows for thin slices or bin multiple rows together to achieve thicker slices for more coverage...
- Determines smallest reconstructed slice thickness.
- Partial voluming of lesion (less with smaller slice) vs. increased coverage with larger slices.



Collimation and Detector Configuration

- Detector configurations can be complex and are scanner model dependent
- Available configurations also depend on scan mode
- Because of penumbra and other factors certain collimations are more dose efficient than others ...larger collimations tend to be more dose efficient than smaller...
 - Reviewing displayed CTDIvol can help determine efficiencies
- Consider detector configurations with respect to:
 - Minimum desired reconstruction thickness
 - Maximizing coverage (longest scan length in shortest time),
 - Greatest dose efficiency. These may involve tradeoffs



$$\underline{32 \times 0.6 = 19.2}$$

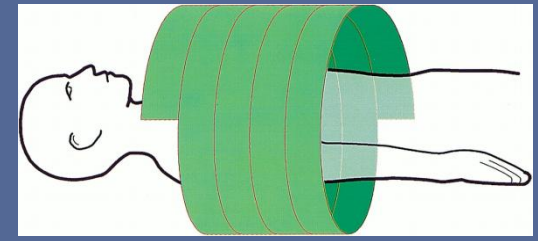
OR

$$\underline{16 \times 1.2 = 19.2}$$

OR

$$\underline{64 \times 0.6 \text{ w/ ffs}}$$

Scan Pitch and effective mAs



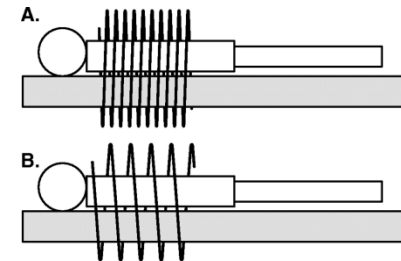
- Scan pitch: table travel (index) per tube rotation / total nominal scan width (e.g. *beam width = number slices x slice thickness*).

$$Pitch = \frac{I}{NT}$$

- Effective mAs used by some vendors (Siemens) accounts for beam pitch in helical scans (for axial pitch = 1)

$$effective\ mAs = \frac{mAs}{pitch} = \frac{mA * s}{I/NT} = \frac{tube\ current * rot.\ time}{table\ index\ per\ rotation / total\ nominal\ scan\ width}$$

- Pitch impacts scan coverage, scan time, noise, dose.
 - Pitch >1: ↑coverage, ↓dose ($1/pitch$), but ↑ noise
 - Pitch <1: over sampling in small area, timing exams
 - When changing pitch scanner may adjust mAs to compensate

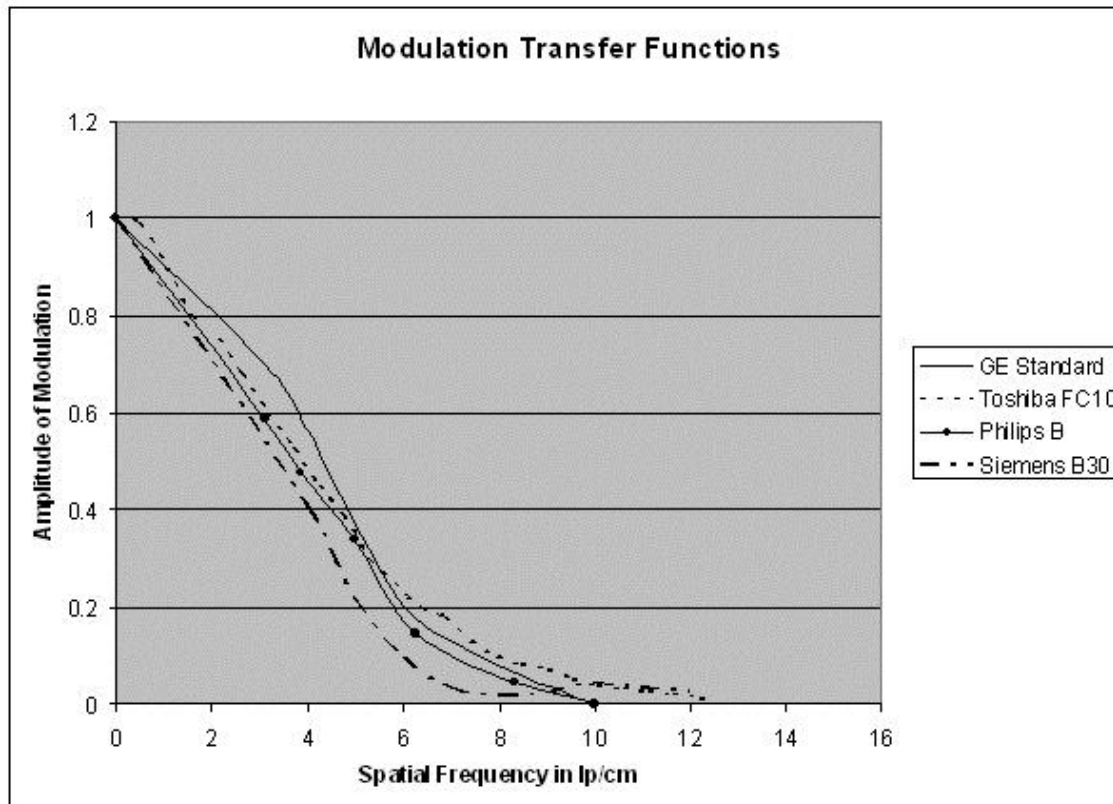


Reconstruction Kernel

- Convolution filter used with projection data in reconstruction of CT image post acquisition; no direct effect on dose!
- Shape of filter (kernel) determines degree of high frequency enhancement of image:
 - High frequency enhancement also accentuates noise – appropriate for high contrast objects that can tolerate decreased SNR – e.g. a bone filter.
 - Smooth or soft tissue filters decrease noise at cost of reduced resolution.
- Kernel choice is task and Radiologist dependent
- Can reprocess multiple times for different emphasis, but more images to read ...

Reconstruction Kernel

- Kernels are vendor unique; achieve different “niche appearance” to images



MTF comparison of
vendor reconstruction
kernels used in NLST

Cagnon, et al. 2006

Body parts and bow-tie filters

- Equalization filter that compensates for in-plane body profile thickness. Affects CTDI.
- As many as three different bow-tie filters possible on a scanner, determined by choice of body part scanned: head, body, cardiac, etc.
- Bow-tie not user selectable but determined by protocol selected. Caution! New or modified protocols built on protocol from inappropriate body part may use wrong bow-tie.
- Bow-tie in use difficult to determine. May change with FOV. Exploring FOV limits may help establish which bow-tie used in a given protocol

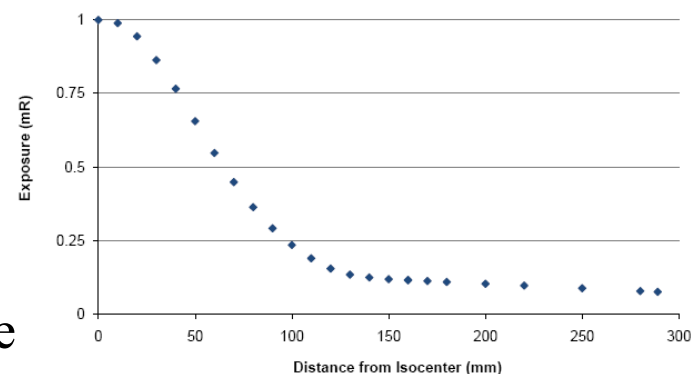
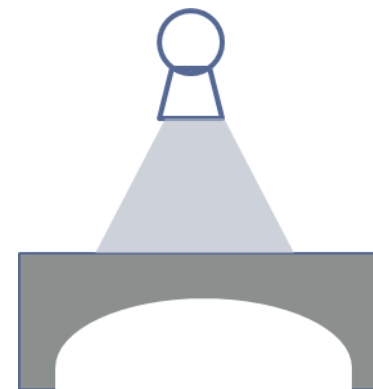
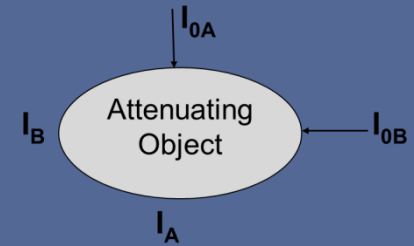


Figure 4. Example of bowtie profile measurement.

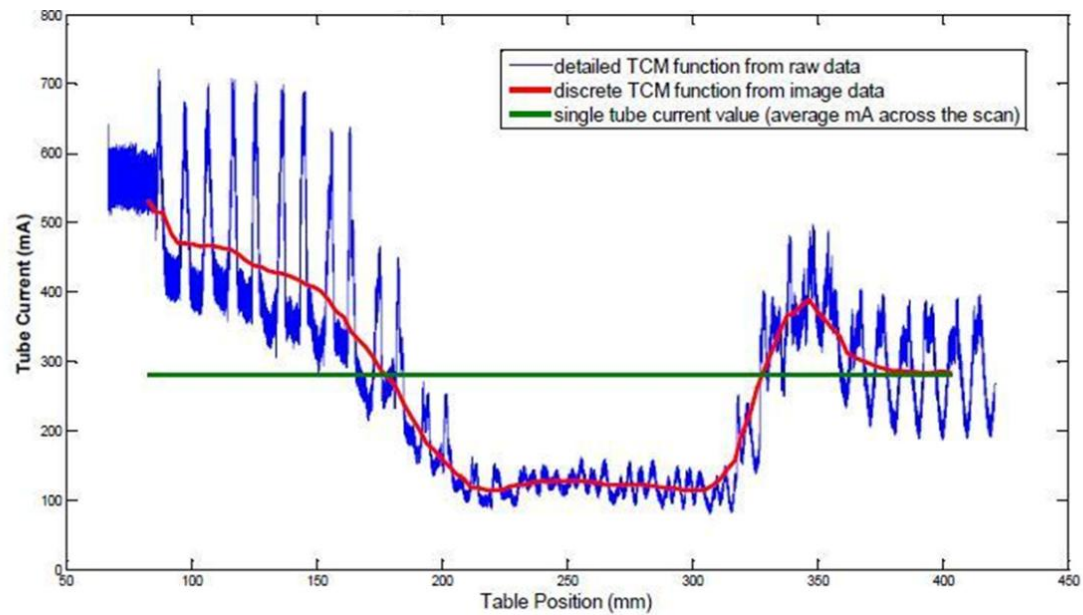
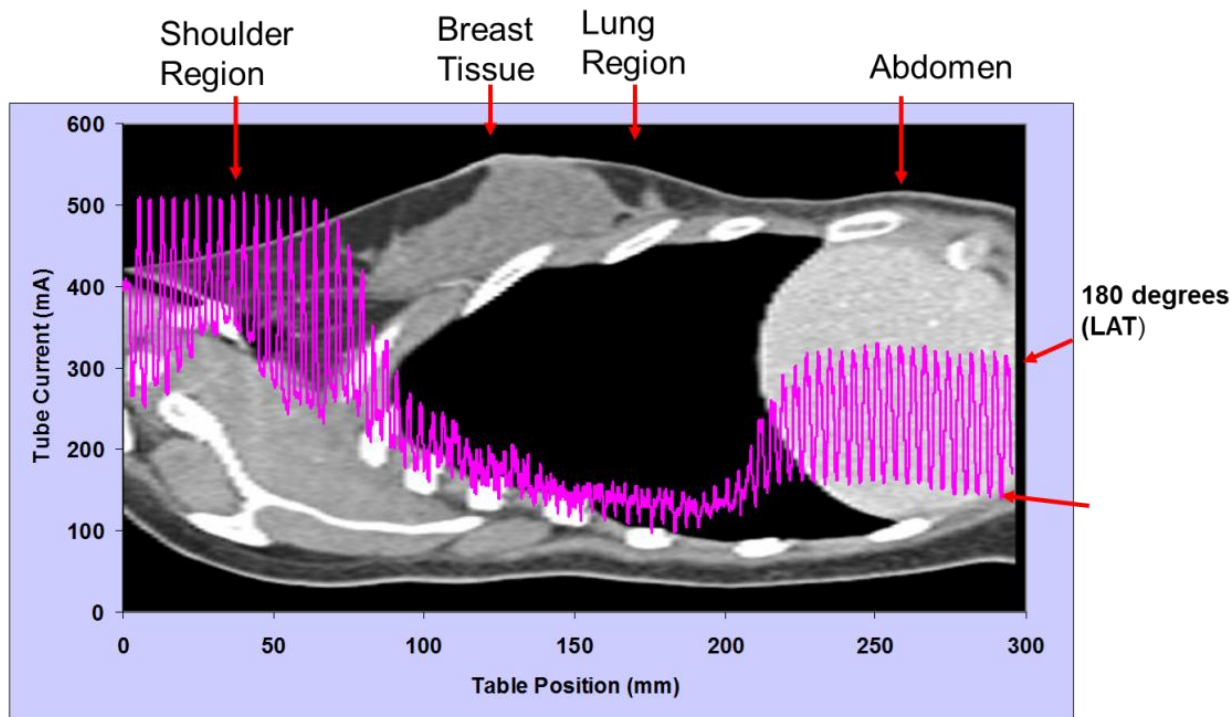
Adapted from Turner

Tube Current Modulation

(Automatic Exposure Control)



- Adaptive Dose Technology that automatically adjusts tube output (mA) to compensate for changes in patient thickness
- While frequently touted as a dose reduction tool, in reality intent is to appropriately adjust tube output/dose by increasing mA for high attenuation projections and decreasing for low attenuation.
- Near universal use with modern equipment (exceptions: head, perfusion studies, cardiac)
- Can modulate in x-y plane, z-axis, both, temporal
- Misconception: Many physicians believe that merely turning on TCM reduces patient dose and satisfies “low dose”



Tube Current Modulation

- May require user reference/input parameters and/or mA limits/floors which can impact TCM effectiveness and patient dose!
 - GE: Noise index (constant regardless of patient size)
 - Siemens: Quality Reference mAs (adjusts for patient size)
 - Philips: Reference image selection
 - Toshiba: Reference standard deviation
- Different settings for different imaging tasks!
 - Lung nodule F.U. Vs. Diffuse Lung Disease
 - Kidney stone diagnostic scan vs. follow-up scan

Tube Current Modulation

- Caution: vendor implementation and terminology varies.
- Works differently depending on vendor! → “*dial left vs. dial right*”
 - GE uses Noise Index: Set to a lower value to decrease noise and increase dose (and it takes 4x the mAs to halve the noise...)
 - Siemens uses Quality Reference mAs: Set to a higher value to decrease noise and increase dose
- Function may be dependent on Scout/Topogram selection:
 - Projection (AP vs. PA. vs Lateral) and/or kVp mismatch
- Function impacted by patient centering in gantry!

Matsubara, et al., 2008

Tube Current Modulation

- Actual dose delivered depends on selected reference values relative to patient size! mAs used for CTDI is an average.

Total mAs 5369		Total DLP 424					
	Scan	kV	mAs / ref.	CTDIvol	DLP	TI	cSL
Patient Position F-SP							
CAPTopo	1	80				5.3	1.0
PreMonitoring	2	100	20	2.40	2	0.5	1.5
I.V. Bolus							
Monitoring	3	100	20	2.40	2	0.5	1.5
Arterial	4	100	99 / 65	4.48	107	0.5	1.5
Chest	5	100	140 / 55	6.30	155	0.5	1.5
Venous A/P	6	100	97 / 65	4.85	158	0.5	0.8

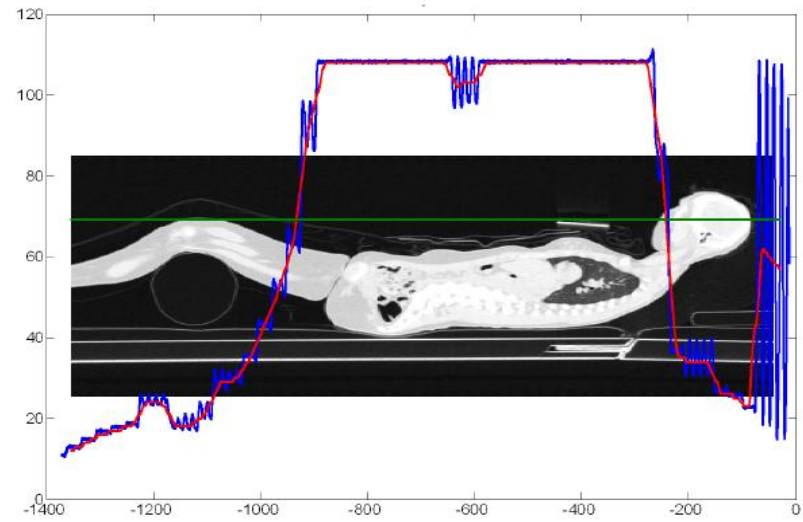
← *What was impact of TCM here?*

- Exercise caution when modifying from vendor recommendations!
 - High ref. mAs or low noise index setting will increase dose

Useful TCM reference: McNitt-Gray, AAPM CT Dose Summit, 2011

Tube Current Modulation - pitfalls

- Beware reference values and mixing peds and adult!
 - Siemens reference values: Adult - 70kg male, Peds - 20 kg (~ 5 year old)
 - If actual patient is larger mAs/dose will increase (relative to fixed reference mAs). Actual patient dose?
 - If wrong reference is used can result in poor quality or increased dose
- Tube current limits!
 - GE requires upper and lower mA limits. Set upper boundary too low and mA modulation is “clipped” effectively resulting in fixed mA scan



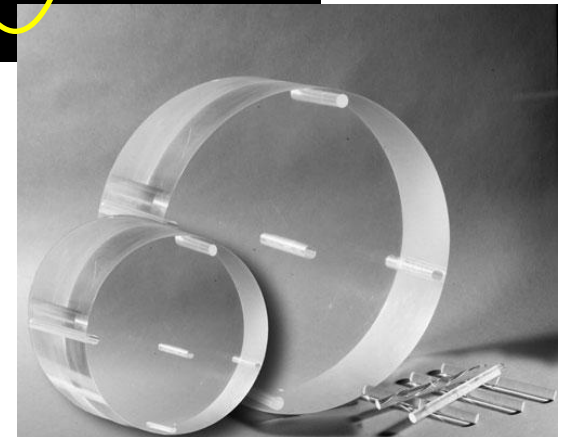
Scanner Reported Dose Values

Total mAs 5369 Total DLP 424

	Scan	kV	mAs / ref.	CTDIvol	DLP	TI	cSL
Patient Position F-SP							
CAPTopo	1	80				5.3	1.0
PreMonitoring	2	100	20	2.40	2	0.5	1.5
I.V. Bolus							
Monitoring	3	100	20	2.40	2	0.5	1.5
Arterial	4	100	99 / 65	4.48	107	0.5	1.5
Chest	5	100	140 / 55	6.30	155	0.5	1.5
Venous A/P	6	100	97 / 65	4.85	158	0.5	0.8

Useful metric for comparing protocols, but remember...

CTDI_{vol}, DLP $\neq$ patient dose!



Neither CTDI nor DLP are patient dose

- Patients aren't standard, cylindrical, or plastic
- CTDI tends to:
 - overestimate dose for large patients and
 - underestimate dose for small/pediatric patients

Why?

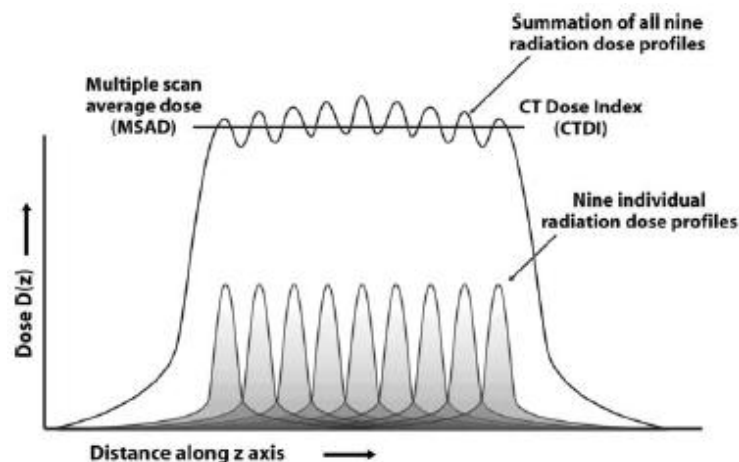
- CTDI & DLP do not consider patient size, age, gender, specific organs/region radiated

Neither CTDI nor DLP are patient dose

- A patient that has twice the DLP or CTDI of another does NOT necessarily receive more dose
 - Bigger patients have more mass. CTDI assumes a specific phantom size
- DLP under-estimates dose for exams with no table movement
- CTDI can over-estimate dose for stationary exams by as much of as a factor of two.

Reported Dose for Stationary Scans

- DLP tends to **underestimate** peak skin dose as a relatively small *length* of the body is actually being scanned.
- By definition, CTDIvol assumes multiple contiguous scan slices with scatter contribution from adjacent slices and thus overestimates peak skin dose for repeated scans in a single fixed location.
- Data for skin dose received from neuro-perfusion scans indicates that CTDIvol overestimates peak skin dose by 30 to 100%.*



Bauhs, 2008

* -Bauhs, et al., Radiographics 2008
-Zhang, et al., RSNA, AAPM 2010.

Caution!

- **Two different** phantoms are used for determination of CTDI: 16 & 32 cm.
- For pediatric protocols, manufacturers may use one or the other for calculating and reporting CTDI and DLP. (*Choice of reference phantom may or may not be indicated in report and of course yields different results*).
- Physicists must determine which phantom is used as vendor reference (*easily verified via comparison of measurement and reported value*)



Image Processing

- Multiple reconstructions possible per scan (no extra dose)
- Minimum recon. thickness (in any plane) determined by detector configuration selected.
- Helical CT acquires a volume of data. Reconstruction thickness and spacing will depend on clinical task
 - E.g. 5 by 5 for abdomen, 1 by 1 for diffuse lung disease, etc.
- Recons by plane:
 - Axial
 - Coronal
 - sagittal

Contrast administration

- Injector may be scanner integrated/controlled or separate unit
- Contrast variables include:
 - Type (e.g. Omnipaque 350)
 - Amount (by patient weight, e.g. <100lbs → 100cc)
 - Injection rate (e.g. 2cc/second)
 - Bolus tracking/trigger
 - ROI position (monitoring, e.g. mid liver)
 - Monitoring start time (e.g. 40 seconds)
 - Trigger HU (e.g. 50 HU)
 - Delay (e.g. 5 seconds)



Pediatric Protocols

- By definition Radiation Dose = Energy energy deposited per unit mass of material/tissue exposed (erg/gm, Joule/kg)
- Kids are smaller, e.g. have less mass:
 - Need to reduce technique just to maintain same dose as adult
 - ↑ radiosensitivity suggests reduced dose relative to adult is appropriate when doesn't interfere with diagnostic task (reduce mAs further)
- Multi-phase scans usually not necessary for kids and can double/triple dose
- Scan only area of specific interest (review scan extents)
- Age vs weight specific protocols
- Vary kVp with size?

Pediatric Protocols

- CT Protocols guide on Image Gently Web-Site describes how to scale adult techniques to kids (assumes fixed kVp)
- <http://pedrad.org/associations/5364/files/Protocols.pdf>

Abdomen Baseline:	kVp=	mA=	Time= sec	Pitch Abdomen=	Pitch Thorax=
PA Thickness (cm)	Approx Age	Abdomen		Thorax	
		mAs Reduction Factor (RF)	Estimated mAs = BL x RF <i>(fill in)</i>	mAs Reduction Factor (RF)	Estimated mAs = BL x RF <i>(fill in)</i>
9	newborn	0.43		0.42	
12	1 yr	0.51		0.49	
14	5 yr	0.59		0.57	
16	10 yr	0.66		0.64	
19	15 yr	0.76		0.73	
22	small adult	0.90		0.82	
25	med adult	Baseline (BL)		0.91	
31	large adult	1.27		1.16	

- TCM/AEC should automatically adjust for smaller size provided proper reference settings are used (*Can compare TCM results with IG table*)

Pediatric Protocols

- Age vs weight specific protocols
 - I.G. site varies mAs with age. Others suggest patient size/weight is more appropriate.
- Vary kVp with size?
 - I.G. site uses constant kVp and varies mAs only. Other strategies also change kVp with size:

Example: Abdomen for 64 MDCT
(*individual results may vary...*)

Weight	kVp	mAs
<18 kg	80	55
19-60 kg	100	65
> 60 kg	120	65

Other considerations

- Modified protocols for pregnant patients?
- Bismuth Shields for breast dose reduction? Some debate...
- AAPM Policy Statement (2/7/2012): *“Bismuth shields are easy to use and have been shown to reduce dose to anterior organs in CT scanning. However, there are several disadvantages associated with the use of bismuth shields, especially when used with automatic exposure control or tube current modulation. Other techniques exist that can provide the same level of anterior dose reduction at equivalent or superior image quality that do not have these disadvantages. The AAPM recommends that these alternatives to bismuth shielding be carefully considered, and implemented when possible.”*

Harmonizing protocols across scanners

- All scanners of same make/model should have identical protocols (dependent on clinical need)?
- Harmonizing a protocol to a different scanner platform involves achieving similar image quality at similar dose levels
 - Similar slice thickness, pitch, kVp, effective mAs where possible
 - Scanner reported dose values useful for comparison and estimates are displayed pre-scan. Document/include!
 - Newer scanners may have increased capabilities: Greater speed / detector width / scan length need to be considered / taken advantage of
 - Recon kernels are vendor unique and may require experimentation to identify similar equivalents (can be done retrospectively)

Protocol References and Tools

- ACR Accreditation Reference Levels (Dose)

Examination	Pass/Fail Criteria	Reference Levels
	CTDI _{vol} (mGy)	CTDI _{vol} (mGy)
Adult Head	80	75
Adult Abdomen	30	25
Pediatric Head (1 year old)	To be determined	45
Pediatric Abdomen (5 year old, 40-50 lb)	25	20

- Specific protocols by exam and machine type:

- www.ctisus.com
- www.brownct.org
- <http://www.aapm.org/pubs/CTProtocols/> (brain perfusion)

- Other resources:

- <http://mayoresearch.mayo.edu/mayo/research/ctcic/upload/ct-protocol-managment.pdf>
- <http://www.acr.org/SecondaryMainMenuCategories/NewsPublications/FeaturedCategories/CurrentACRNews/archive/ACRASNRStatementonCTProtocols.aspx>

Documentation

- Versions of scan protocols may exist on paper/notebooks, programmed on scanners, or in spreadsheets and databases. Standardized and shared templates are helpful.
- Protocols seem to change frequently at some institutions and may differ even across identical scan platforms
- Determine responsibility and document decision
 - Document ALL criteria and scan factors, ideally in on-line database
 - Harmonize across scanners
 - Include sign-off signatures!
 - Things will (and should) change. Implement change control process! Who signs off on revisions, who has access to scanner

Lowering Dose?

- In addition to standardization/appropriateness, protocol review should include looking for dose reduction opportunities.
- In practice, reducing dose likely to be an iterative process of modifying technique and radiologist review –
 - not very efficient, Radiologist “comfort” level varies considerably
- How do we quantify image quality? ROI ? MTF? CNR?
 - No existing metric accounts for all diagnostic subtleties
 - Metric used will likely depend on specific clinical task

How low can you go?

- Gold standard: trained human observer studies at different dose levels for specific clinical purpose, e.g. appendicitis
- Use “add-noise” tool to simulate reduced dose abdominal images and score across specialty and general radiologists



100% dose



20% dose

How low can you go: Findings

- No significant difference in diagnostic performance at 100%, 70%, and 50% dose level for all 6 observers
- For routine abdominal CT readers, diagnostic difference is not substantially compromised even at 30% to 20% dose levels
- For non-abdominal and non-cross-sectional image readers, the performance is noticeably impaired at 30% and 20% dose levels

D. Zhang, et al., UCLA DGSOM

Summary...

- Protocol review may be serious and painful undertaking
- Existing documentation process may be lacking; hard to modify or implement low dose protocols if unable to establish existing standard
- May encounter large number of protocols, many rarely used
- May require multiple review sessions with specialty area
- Will likely need to implement a review and change order process
- In addition to protocol standards, need to identify process for the trained technologist to modify settings on the fly...

Strategies ...

- Determine reference/default protocol (vendor knows best!)
- Determine rationale for specific changes (and document!)
- Compare scanner reported CTDI values
- Image quality standardization is difficult
 - In general, don't want the nicest looking image, rather want image sufficient for the clinical task.
 - Subjective - what may be acceptable for a given patient and a given radiologist may not suffice for another patient/radiologist
- All other factors equal (kernel, kVp, slice thick.) it takes significant change in mAs/dose for visible impact on noise

Questions ...