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Computed Tomography Imaging: CT Protocol Management

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AAPM Annual Meeting
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Slides at: goo.gl/k8N8JF

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Caveat

- Coordination amongst QMP, Radiology section heads, and lead technologist(s) is key to CT Protocol Management
- Use vendor applications specialist when available for further assistance in management and optimization

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Outline

Slides at: goo.gl/k8N8JF

- **Protocol – What's in a Name?**
- Role of Protocols in CT Imaging
- Quality Assurance of Protocols
- Matching Protocols Across Scanners
- Generating/Reviewing Protocols on New Scanners
- Using External Benchmarks and Reference Levels

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Protocol – what's in a name?

- A radiologist *protocols* a scan
- An institution has a master *protocol* book
- The scanner technologist *protocols* a scan
- The patient was scanned with this *protocol*

We Need Definitions and Categorizations to Communicate Effectively

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Protocol – what's in a name

- DICOM Supplement 121: CT Protocol Storage
  - Published in 2016
- Defines two SOP classes for protocol storage that include
  - Patient preparation & positioning
  - Equipment characteristics
  - Acquisition technique
  - Reconstruction technique
  - Image handling (post processing)
  - Data storage

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Protocol – what's in a name?

- *Defined Procedure Protocol:* Is independent of a specific patient; may describe acquisition parameters common to multiple device models; and may include information such as the clinical purpose, indications, appropriate device models, etc.

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Example Defined Procedure Protocol

Attribute	Tag	Value
Protocol Name	(0018,1030)	CT Tumor Volumetric Measurement
Potential Scheduled Protocol Code Sequence	(0018,9906)	(6678-1, 99DP, "DP6678 Phase III CT Protocol")
Potential Requested Procedure Code Sequence	(0018,9907)	(72253-8, LN, "CT CAP WO contrast")
Potential Reasons for Procedure	(0018,9908)	Metastatic non-small cell lung cancer/tumor volumetric measurements
Contraindications Code Sequence	(0018,9908)	(F-84000, SRT, "Patient currently pregnant")
Content Creator's Name	(0070,0084)	Jane Investigator
Protocol Design Rationale	(0018,9910)	See DP6678 Phase III Protocol documents: http://ctrialdocs.tyrell.co.ca/DP6678_protocol.aspx In particular, see discussion in Section 3 (CT Acquisition Parameters and Image Data Analysis) of the Protocol Document The Spacing Between Slices may be increased as long as the overlap between slices is maintained between 0% and 20% overlap. The Slice Thickness may be increased up to 1.5mm as long as the Spacing Between Slices is correspondingly increased to maintain between 0% and 20% overlap.
Protocol Planning Information	(0018,990F)	Use of intravenous contrast media, presence of motion artifacts or violation of slice width, slice interval or voxel size constraints will disqualify the CT scan series.

http://dicom.nema.org/medical/dicom/2016d/output/chtml/part17/sect_AAAA.3.html

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Protocol – what's in a name?

- *Performed Procedure Protocol:* Is associated with a specific patient and encodes the parameters values used in an acquisition

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Example Performed Procedure Protocol

Attribute	Selector Attribute	Selector Value Number	Selector Sequence Pointer	Selector Sequence Pointer Items	Constraint Type	Constraint Value
>Acquisition End Location Sequence (0018,9932)						
Reference Location Label	(0018,9900)	1	(0018,9920), (0018,9932)	3\1	EQUAL	"Top of Head"
Reference Basis Code Sequence	(0018,9902)	1	(0018,9920), (0018,9932)	3\1	EQUAL	(T-D1120, SRT, "Vertex of Head")
Reference Geometry Code Sequence	(0018,9903)	1	(0018,9920), (0018,9932)	3\1	EQUAL	(128120, DCM, "Plane through Superior Extent")
>CT X-Ray Details Sequence (0018,9325) - First Beam						
Beam Number	(300A,00C0)	1	(0018,9920), (0018,9325)	3\1	EQUAL	1
KVP	(0018,0060)	1	(0018,9920), (0018,9325)	3\1	EQUAL	120
X-ray Tube Current in mA	(0018,9330)	1	(0018,9920), (0018,9325)	3\1	EQUAL	220
Exposure Modulation Type	(0018,9323)	1	(0018,9920), (0018,9325)	3\1	EQUAL	NONE
Data Collection Diameter	(0018,0090)	1	(0018,9920), (0018,9325)	3\1	EQUAL	240

http://dicom.nema.org/medical/dicom/2016d/output/chtml/part17/sect_AAAA.2.2.html

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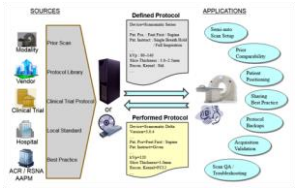

http://dicom.nema.org/medical/dicom/2016d/output/chtml/part17/chapter_AAAA.html

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Protocol – what's in a name

- Implementation of protocol SOP classes is key for quantitative imaging and clinical trials to compare results from serial scans
- QiBA profiles require scan protocols to meet certain benchmarks
  - Protocol SOP classes may be used to assess conformance to profiles

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Outline

- Protocol – What's in a Name?
- **Role of Protocols in CT Imaging**
- Quality Assurance of Protocols
- Matching Protocols Across Scanners
- Generating/Reviewing Protocols on New Scanners
- Using External Benchmarks and Reference Levels

Role of Protocols in CT Imaging

- Protocols define how imaging acquisition proceeds
  - Patient Preparation
  - Acquisition(s)
  - Reconstruction(s)
  - Post Processing
  - Transmission to PACS

Role of Protocols in CT Imaging

- Initial order from clinician sets in process the steps to image the patient
  - Electronically transmitted to [illegible] rings in order
  - Patient scheduled and instructions given (NPO, medications, etc)
  - Institution's Procedure Code identified (associated with CPT codes for billing)
  - Patient arrives and prepped (oral contrast, remove necklaces, belt, etc)
  - Radiologist protocols study based on Procedure Code and history
  - Tech positions patient for scan
  - Tech selects protocol on scanner corresponding to defined procedure protocol
    - Possibility of auto-protocoling

Role of Protocols in CT Imaging

- The Joint Commission Standard PC.01.02.15 Element of Performance 10 requires that prior to a diagnostic study the institution verifies:
  - Correct patient
  - Correct imaging site
  - Correct patient positioning
  - Correct CT imaging protocol
  - Correct CT scanner parameters

How to demonstrate correct positioning and protocol?

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Role of Protocols in CT Imaging

- TJC requires **traceable documentation from order to protocol** on the system used to scan patient
- In absence or in association with Radiologist Protocoling a Defined Procedure Protocol can be used to document the correct protocol is used
  - Can include associated procedure codes
  - Can include scanner protocol names

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Example Defined Procedure Protocol

SOMATOM Definition Flash [Included]			
Localizer:			
kV	120.0 185.0		
Series 1 : PRE PELVIS			
kV	120.0	**Recon 1: PRE PELVIS 3.0 I40f 2**	
mAs	168.0	Slice	3
Eff. mAs	210.0	Kernel	I40f medium
Quality Ref mAs	190	Window	Abdomen
Pitch	0.8	No. of Images	67
Dose Modulation	ON	Comments:	
Dose Modulation Type	CARE Dose4D	NO CONTRAST	
Acquisition	128x0.6		
CARE kV	ON		

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Role of Protocols in CT Imaging

- Master Protocols (containing Defined Procedure Protocols) are roadmap for technologist
  - Start at patient preparation
  - End at images sent to PACS
- Master Protocols may include
  - Pictures
  - Reference CTDI ranges
  - Radlex Playbook IDs

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Role of Protocols in CT Imaging

- Protocol may call for patient preparation
  - NPO
  - Oral Contrast
  - Removal of belt/bra/necklaces….
  - IV location and gauge
  - Positioning orientation and location of arms

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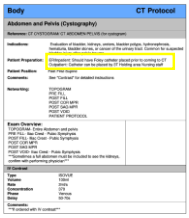

Body **CT Protocol**

Colonography

Reference:

Indications: Evaluation for colorectal polyps or tumors, blood in stool, unexplained weight-loss. Usually performed after incomplete colonoscopy.

Patient Preparation: ***Ensure pt has recieved a bowel cleansing prep!**

1. Patient should be on a clear liquid diet (Water, tea, apple juice, etc)
2. Barvlos will order GoLytely (Bowel Cleansing)- Taken overnight, prior to test date
3. Gastrografin- (30ml,)diluted- to be taken day of exam ** Requires revision**

Patient Position: Feet First-Supine

Comments: SUPPLIES:
1- Rectal tube or Foley catheter
2- Lubricating Jelly
3- Insufflator Bulb
4- Balloon Inflator
5- Hemostat
6- Chucks

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Role of Protocols in CT Imaging

- Protocols define acquisitions and timing
  - Extent of scan
  - Target image quality
  - Number of acquisitions
  - Timing of acquisitions and contrast

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Role of Protocols in CT Imaging

- Protocols define reconstruction, post processing and image transmission
  - Reconstruction kernel
  - Iterative reconstruction
  - Window Level/Width
  - Reformats, MPRs, MIPs
  - DE or 3D post processing
  - Series to send to PACS

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Example Defined Procedure Protocol

SOMATOM Definition Flash [Included]	
Localizer:	
kV	120.0 185.0
Series 1 : PRE PELVIS	
kV	120.0
mAs	168.0
Eff. mAs	210.0
Quality Ref mAs	190
Pitch	0.8
Dose Modulation	ON
Dose Modulation Type	CARE Dose4D
Acquisition	128x0.6
CARE kV	ON

Recon 1: PRE PELVIS 3.0 I40f 2	
Slice	3
Kernel	I40f medium
Window	Abdomen
No. of Images	67
Comments:	
NO CONTRAST	

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Role of Protocols in CT Imaging

- Control and understanding of CT Protocols ensures
  - Regulatory compliance
  - Consistent application of patient preparation
  - Consistent image quality

You CANNOT just 'Set it and Forget it"

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Outline

- Protocol – What's in a Name?
- Role of Protocols in CT Imaging
- **Quality Assurance of Protocols**
- Matching Protocols Across Scanners
- Generating/Reviewing Protocols on New Scanners
- Using External Benchmarks and Reference Levels

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Quality Assurance of Protocols

- Good clinical practice to review protocols
  - Ensure producing required results
  - Examine inter-scanner variations
- ACR requires annual review/QA of protocols
  - 2012 CT QC Manual calls for review of:
    - CT protocols to be used, including pertinent information on radiation dose, positioning, and contrast agent administration that includes dose

Quality Assurance of Protocols

- The Joint Commission Standard PC.01.03.01 requires
- EOP 2: [The institution] establishes computed tomography (CT) imaging protocols based on current standards of practice, which address key criteria including clinical indication, contrast administration, age (to indicate whether the patient is pediatric or adult), patient size and body habitus, and the expected radiation dose index range.
- EOP 3: Diagnostic computed tomography (CT) imaging protocols are reviewed and kept current with input from an interpreting radiologist, medical physicist, and lead imaging technologist to make certain that they adhere to current standards of practice and account for changes in CT imaging equipment. These reviews are conducted at time frames identified by the [institution]

Quality Assurance of Protocols

How do we meet these requirements?

Quality Assurance of Protocols

- AAPM practice guideline 1.a CT Protocol Management and Review
- Portions of practice guideline incorporated into ACR QC Manual
- Revision of practice guideline (published in 2013) due in 2018
- Feedback on usefulness of guideline is welcome (direct comments to Dianna Cody [dcody@mdanderson.org])

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Quality Assurance of Protocols

- Practice guideline calls for:
  - Protocol review team of QMP, Lead Tech and Radiologist
  - Protocol review must comply with federal and state/local regulations
  - Frequency must comply with requirements of regulatory and accrediting bodies
  - Protocols that **must** be reviewed annually
    - Peds head
    - Peds abdomen
    - Adult head
    - Adult abdomen
    - High Res Chest
    - Brain Perfusion

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Quality Assurance of Protocols

- Practice guideline calls for:
  - Evaluating current protocols and considering new techniques
  - Taking into account capabilities of each scanner protocol is on
  - Review of current literature to ensure state of the art protocols are employed

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Quality Assurance of Protocols

- Practice guideline recommends
  - Review of acquisition parameters
  - Permissions to modify protocols on scanners
  - Expected CTDIvol ranges and DRLs for protocol
  - Documentation of review and changes to protocols
  - Use of consistent nomenclature

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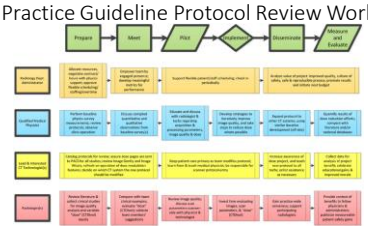
AAPM Practice Guideline Protocol Review Workflow



(2013), AAPM Medical Physics Practice Guideline 1.a: CT Protocol Management and Review Practice Guideline. Journal of Applied Clinical Medical Physics, 14: 3–12. doi:10.1120/jacmp.v14i5.4462

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Quality Assurance of Protocols

- AAPM practice guideline recommends consistent naming of protocols across scanners
  - If possible, consistent naming of each reconstruction series is key
  - Allows easy implementation of hanging protocols for radiologists on PACS

How should we name our protocols?

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Quality Assurance of Protocols

- CT Protocol Nomenclature
  - **You can't do QA if you don't know the names of your protocols!**
  - Use of Radlex Playbook ID (RPIDs) is recommended
    - Used by ACR Dose Index Registry
    - Unique Identifier codes for names
  - RPIDs allow apples to apples comparisons of dose indices of protocols across scanners or institutions

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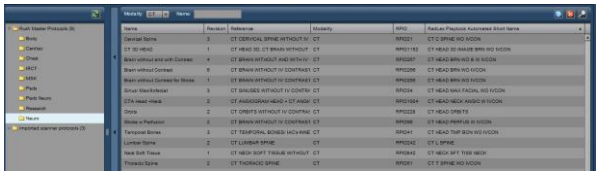

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Quality Assurance of Protocols

- Submission of radiation dose information (in the future image quality data) to registries
  - Review dose distributions at institution
  - Identify protocols with dose distributions higher than averages
  - Identify scanners with different dose distributions

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Quality Assurance of Protocols

- Use of Radiation Dose Index Monitoring software
  - **You can't do QA if you don't have the data!**
  - AAPM Practice Guideline 6.a: Performance characteristics of radiation dose index monitoring systems

Use of RDIMs discussed later this session

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Quality Assurance of Protocols

- Review current literature/best practices
- Use RDIM/Registry data to review dose distribution
- Examine Outliers
- Review acquisition parameters
- Implement changes
- COMMUNICATE CHANGES

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Quality Assurance of Protocols

- Key Parameters to review
  - Acquisition time
  - Detector configuration
  - Reconstruction thickness
  - Image quality reference parameter (or manual setting)
  - Tube potential(s)
  - Beam shaping filter
  - Iterative reconstruction

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Quality Assurance of Protocols

- References on QA of protocols
  - Kofler JM, Cody DD, Morin RL: CT protocol review and optimization. J Am Coll Radiol 11:267–270, 2014.
  - Szczykutowicz TP, Bour RK, Pozniak M, et al, Compliance with AAPM Practice Guideline 1 . a: CT Protocol Management and Review—from the perspective of a university hospital, J Appl Clin Med Phys 16 (2015) 443–457.
  - Szczykutowicz TP, Siegelman J: On the same page—Physicist and radiologist perspectives on protocol management and review. J Am Coll Radiol 1–7, 2015.

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Matching Protocols Across Scanners

- Ideal world
  - All the scanners at institution are latest and greatest and the protocols are all the same
- Real world
  - Different scan
  - Different capa
  - Matching prot del can be challenging

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Matching Protocols Across Scanners

How do we ensure protocols are consistent across same/similar model scanners?

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Matching Protocols Across Scanners

- IHE profile on Management of Acquisition Protocols
  - http://ihe.net/uploadedFiles/Documents/Radiology/IHE_RAD_Suppl_MAP.pdf
  - Establishes framework for development of protocol management tools
  - Allows for use of DICOM Protocol SOP classes to be pushed/pulled from scanners to/from Protocol Manager

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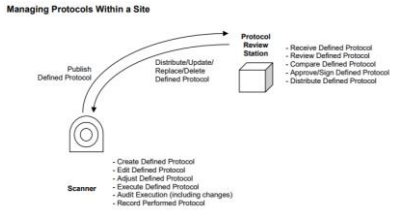
Matching Protocols Across Scanners



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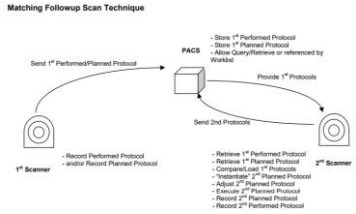
Matching Protocols for FOLLOW UP



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Matching Protocols Across Scanners

How do we match protocols across different models/brands?

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Matching Protocols Across Scanners

- Target same image quality across scanners
- Radiation dose distribution may be different due to scanner capabilities
- Some scans may not be able to be done on some scanners
- Routing of certain cases (Multi Energy, Cardiac) to particular scanners may be required

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Matching Protocols Across Scanners

- 3 Key Image Quality Metrics to match
  - For quantitative imaging and consistent image quality
    - SSP
    - MTF
    - NPS
  - Following Images from: Favazza CP, Duan X, Zhang Y, et al: A cross-platform survey of CT image quality and dose form routine abdomen protocols and a method to systematically standardize image quality. Phys Med Biol 60:8381-8397, 2015.

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Matching Protocols Across Scanners

- Tomographic Section Thickness (Slice Sensitivity Profile)
- Basic metric is Reconstructed Tomographic Section Thickness
- Advanced metric is Slice Sensitivity Profile
  - Measure using thin high contrast object
- Affects partial volume artifacts and volumetry

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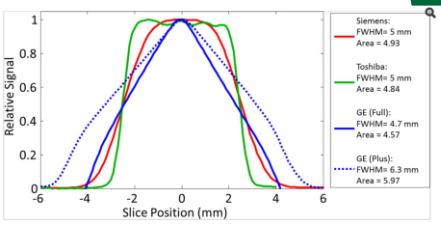

Plot of four representative slice sensitivity profiles obtained from Siemens (red curve), Toshiba (green curve), and GE scanners, both "Full" (solid blue) and "Plus" (dashed blue) reconstruction modes on GE scanners.

Favazza et al, Phys Med Biol 2015

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Matching Protocols Across Scanners

- In Plane Spatial Resolution (Modulation Transfer Function)
- Basic metric of spatial resolution (line pairs/mm)
- Advanced metric of MTF
  - Measure using edge or wire and use Fourier analysis
- Affects ability to resolve small objects or sharp edges

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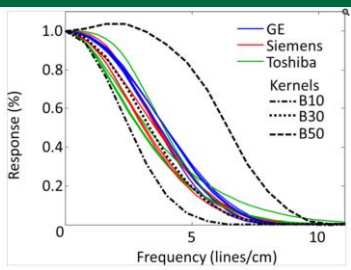

Favazza et al, Phys Med Biol 2015

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Matching Protocols Across Scanners

- Standard Deviation of Noise (Noise Power Spectrum)
- Basic metric of Noise Standard Deviation (ROI measurement)
- Advanced Metric of NPS
  - Measure using scans of uniform object
  - Fourier analysis of noise only image
- Must consider scanned object size as different AEC approaches are attenuation dependent
- May need to have size specific protocol settings

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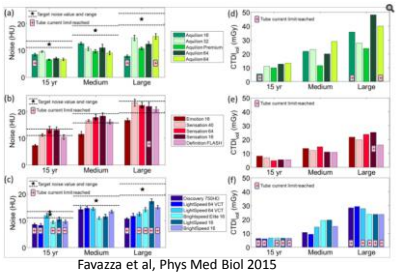

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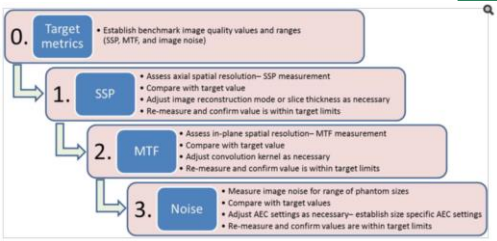

Favazza et al, Phys Med Biol 2015

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Matching Protocols Across Scanners

- Additional considerations
  - Impact of iterative reconstruction
    - Noise (and spatial distribution)
    - Spatial resolution
    - Low contrast resolution
    - Required radiation dose
  - Scan time
    - Older scanners may have slow rotation time
    - Possibility of tube current limitation at fast rotation times

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Matching Protocols Across Scanners

- AAPM Alliance for Quality in CT
  - Medical Physicists
  - ASRT
  - ACR
  - Vendors
- Publish reasonable protocols for wide variety of scanners for common exams
- http://www.aapm.org/pubs/CTProtocols/

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- **Generating/Reviewing Protocols on New Scanners**
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Generating/Reviewing Protocols on a New Scanner

- New scanners must come with reference adult and pediatric protocols (per NEMA XR-29)
- Reference protocols may not match radiologist preferences or standard practices at site
- Most common adjustments
  - Image quality reference parameters
  - Reconstruction kernels
  - Reconstructed series

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Generating/Reviewing Protocols on a New Scanner

- Introduction of Iterative Reconstruction to protocols requires GREAT CARE
  - Start at standard dose with iterative turned on and gradually decrease dose until image quality is just acceptable
  - Iterative reconstruction may result in loss of low contrast resolution

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Generating/Reviewing Protocols on a New Scanner

- New scanners typically come with many hours of applications specialist training
  - Make full use of training time
  - Consider breaking up applications specialist time
  - Ensure automated patient instructions are accurate (and available in required languages)

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External Benchmarks and Reference Levels

- TJC Elements of Performance for Diagnostic Imaging requires institutions performing CT to:
  - Review of scans exceeding dose notification levels
  - Compare scans exceeding those levels to external benchmarks
  - Include expected dose distribution in CT Scan Protocol

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External Benchmarks and Reference Levels

- Review of scans exceeding notification levels
  - Most easily documented by use of Radiation Dose Index Monitoring software
  - Categorization of reason for exceeding notification level useful for analysis
    - Large patient
    - Patient positioning
    - Metal implant
    - Tech error
    - ….

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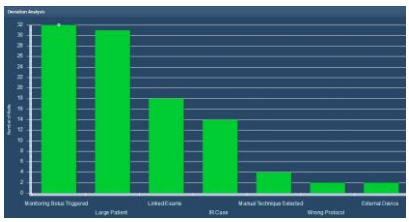
External Benchmarks and Reference Levels



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External Benchmarks and Reference Levels

- External Benchmarks
  - Comparison of scans to ACR DIR data/reference levels
  - Comparison of scans to AAPM dose notification levels
- External Dose Reference Levels/Benchmarks are NOT SIZE DEPENDENT

Should they be size dependent? Should we review scans BELOW typical radiation dose levels?

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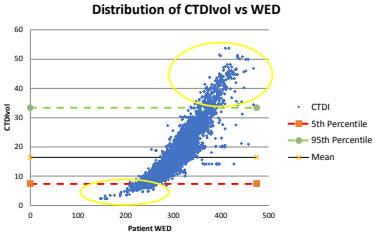
CTDI vs WED with Fixed DRL



Exams above and below the 95th and 5th percentile are highlighted.

Are these the scans we should review?

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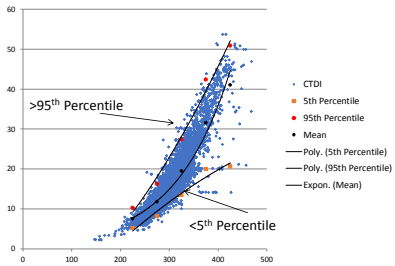
CTDI vs WED with Size Specific DRL



Size specific DRLs in WED bins established.

Scans outside Size specific DRLs may be most useful outliers to examine.

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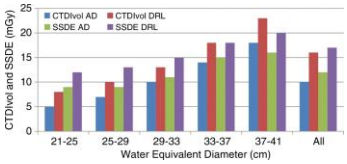

Figure 2c: Graphs show chest AD achievable dose s and DRL diagnostic reference level s. (a) **AD achievable dose and DRL diagnostic reference level for chest without contrast material—CTDIvol volume CT dose index and SSDE size-specific dose estimate**. **(b)** AD achievable dose and DRL diagnostic reference level for chest without contrast material–DLP dose-length product . **(c)** AD achievable dose and DRL diagnostic reference level for chest with contrast material—CTDIvol volume CT dose index and SSDE size-specific dose estimate . **(d)** AD achievable dose and DRL diagnostic reference level for chest with contrast material–DLP dose-length product . **(e)** AD achievable dose and DRL diagnostic reference level for chest pulmonary arteries with contrast material—CTDIvol volume CT dose index and SSDE size-specific dose estimate . **(f)** AD achievable dose and DRL diagnostic reference level for chest pulmonary arteries with contrast material–DLP dose-length product .

Published in: Kalpana M. Kanal; Priscilla F. Butler; Debapriya Sengupta; Mythreyi Bhargavan-Chatfield; Laura P. Coombs; Richard L. Morin;
Radiology **2017**, 284, 120-133.
DOI: 10.1148/radiol.2017161911

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External Benchmarks and Reference Levels

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Thank You