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Useful strategies for protocol development

@uwiscradiology

August 1, 2018

Conflict of Interest

TPS supplies CT protocols to GE Healthcare under a licensing agreement, is a consultant to GE Healthcare, receives research support from GE Healthcare, is on the MAB of iMALOGIX LLC, is the founder of Protocolshare.org, is co-owner of LiteRay Medical LLC.

This presentation includes materials posted on Protocolshare.org

TALK FOCUS

Essential elements of a CT protocol

Example data mining you can do to help your clinical partners

USEFUL STRATEGIES FOR PROTOCOL DEVELOPMENT/ AGENDA

Essential elements of a CT protocol

01 | compliance/regulatory details

02 | clinical details

03 | workflow details

04 | technical details

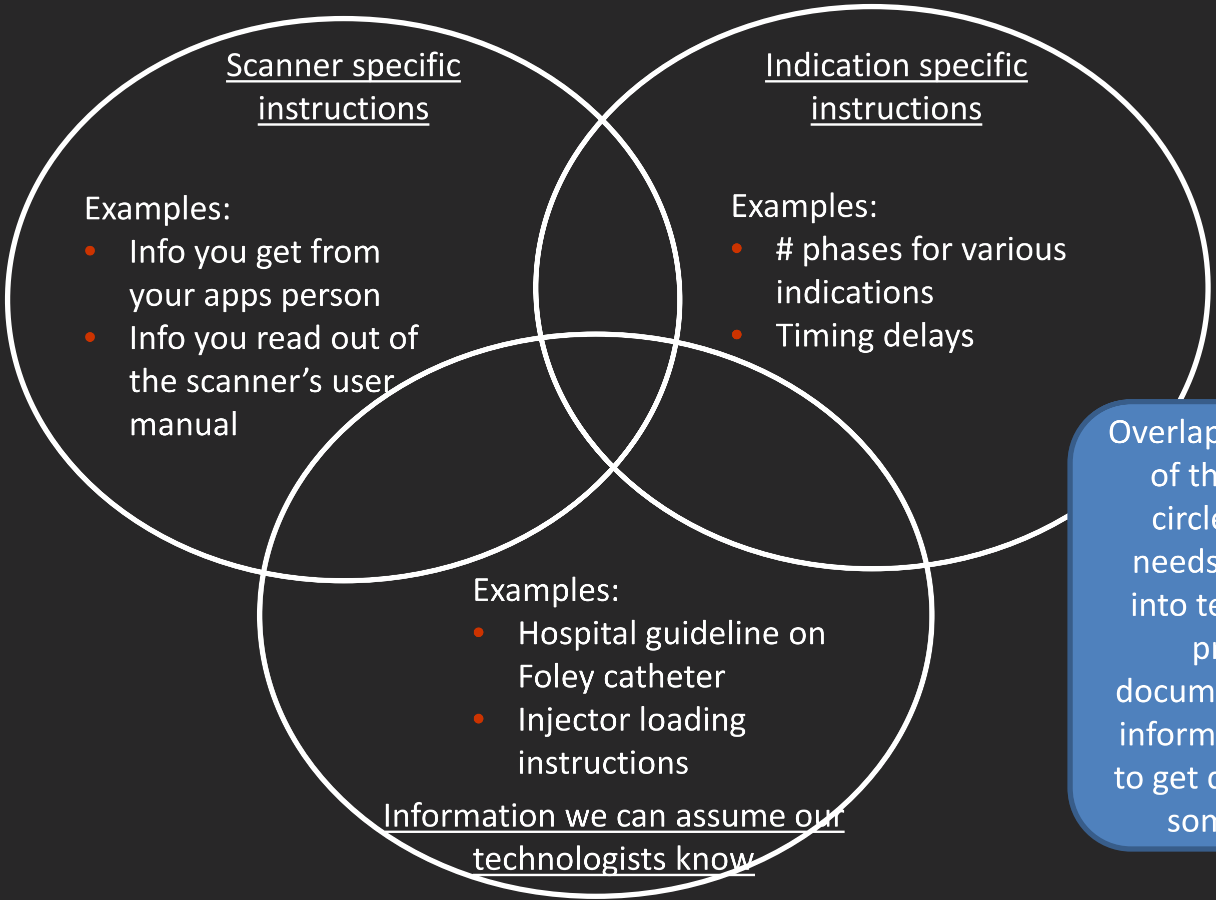
Data mining/analysis: physicist contributing to CT protocol optimization team

05 | clinical background: contrast dynamics

06 | clinical background: breath hold

07 | using dose data to get scan time/length

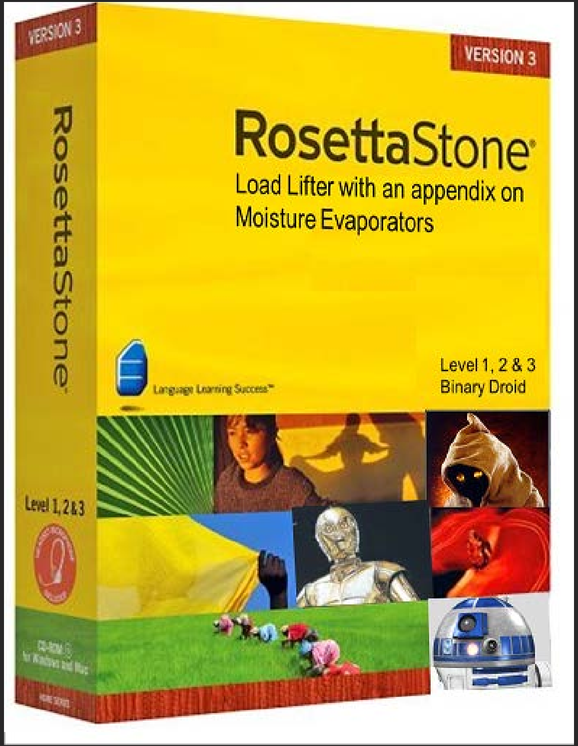
08 | optimized protocols across your fleet



Overlap/Integration of these three circles is what needs to make it into technologist protocol documentation, all information needs to get documented somewhere

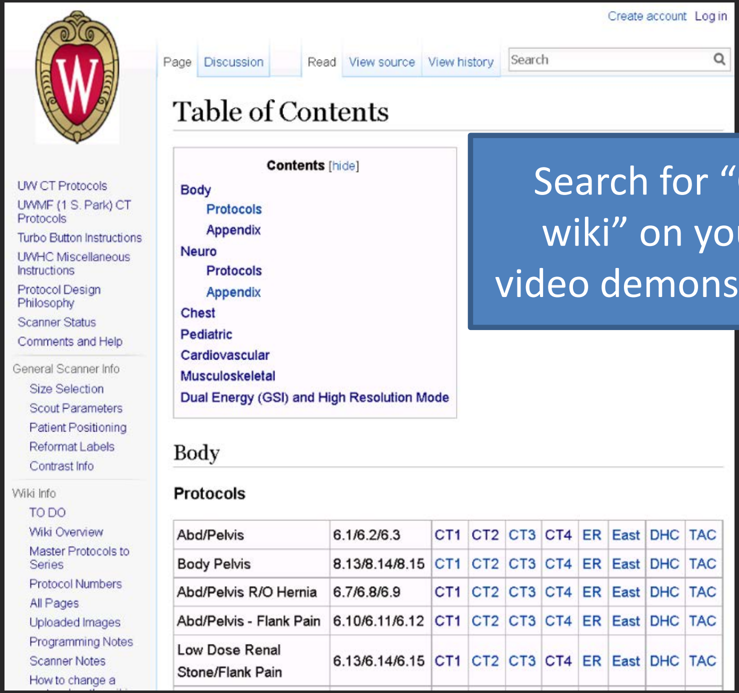
ESSENTIAL ELEMENTS OF A PROTOCOL: RESOURCES

- AAPM lexicon
  - "Rosetta stone" Of CT scanners
  - Best resource for sites using multiple vendors
  - Great resource for sites desiring to come up with their own standard layout for CT protocol information
  - May point your team to consider facets of your protocols you currently do not document

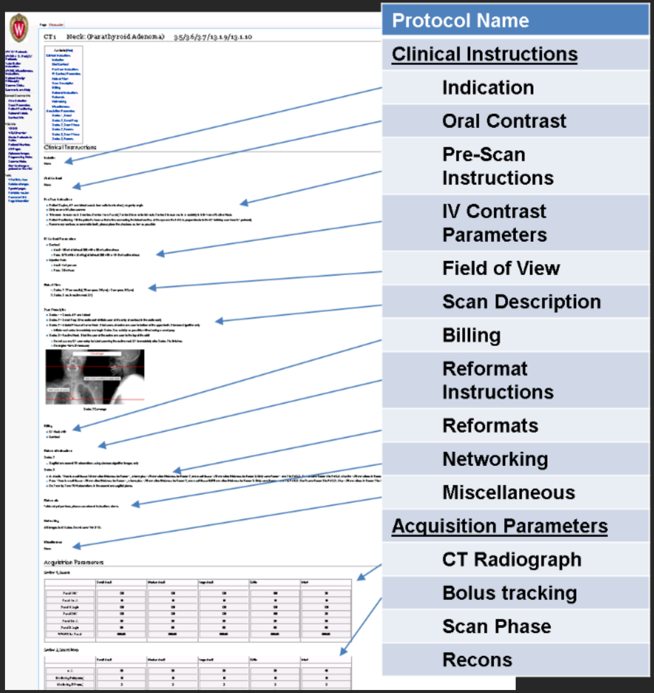


http://www.quarkquark.com/electronman/

ESSENTIAL ELEMENTS OF A PROTOCOL: RESOURCES



Search for “CT protocol wiki” on youtube for a video demonstration of this



Szczykutowicz *et* al. “A wiki based CT protocol management solution” Radiology Management November 2015

Szczykutowicz *et al.* “A wiki based solution to managing your institution’s Imaging Protocols” JACR 2016

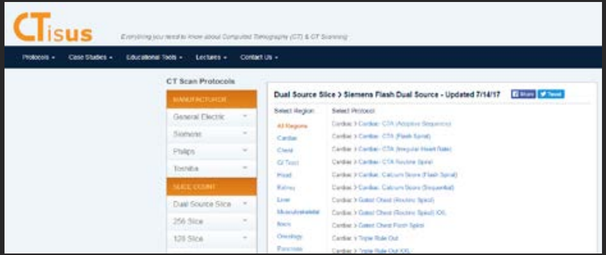
ESSENTIAL ELEMENTS OF A PROTOCOL: RESOURCES

Other examples of nice CT protocols:

- AAPM CT protocols

- Device company CT protocols (Heartflow/Sapien have great publicly available CT protocols)

- Ctisus.com



COMPLIANCE/REGULATORY DETAILS

Contributors	Who wrote the protocol and what qualifications do they have?	See TJC Provision of Care, Treatment, and Services PC.01.03.01 A26
Design Philosophy	Why are the timing delays/dose levels/slice thicknesses/etc. set at the values they are?	See TJC Provision of Care, Treatment, and Services PC.01.03.01 A26
Clinical Indication/s	Most protocol can be used for many indications, what are they?	See TJC Provision of Care, Treatment, and Services PC.01.03.01 A25
Dose Data	Document expected dose index ranges (ideally size/age based)	See TJC Performance Improvement PC.02.01.01 A6

COMPLIANCE/REGULATORY DETAILS

Protocol Name

Easily a source of confusion, so you need to document well and develop a systematic approach for this. Be aware different roles think of protocol names in unique ways.

- Scanner specific — Tech “6.23 ABD-LIVER BIPHASIC MEDIUM ADULT”
- Site specific — Radiologist “Biphasic liver”
- Institution specific — Billing department “CT Abdomen Angio”
- Country specific — Dose Repository “RPID5”

Protocol Compliance

What programs/studies/trial does the protocol comply with?

e.g. ACR LCS, ACR CTC, Research trial, Device manufacturer (robotic surgery), OPTN/UNOS, etc.

Protocolshare.org template

COMPLIANCE/REGULATORY DETAILS

Billing Code

Mistakes made by techs here will cause downstream issues. Each protocol should explicitly state what billing code (usually techs just choose text description, billing department will assign code) to use and any modifications due to scan time changes to the protocol.

RSNA reporting template

Whether your site uses RSNA or in house templates, what template to use should be documented somewhere linked to the protocol used to realize that study.

CLINICAL DETAILS

See TJC Provision of Care, Treatment, and Services PC.01.03.01 A25

A 25. The [critical access] hospital establishes or adopts diagnostic 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 an adult), patient size and body habitus, and the expected radiation dose index range. 3

Patient Preparation	Jewelry removal, practice breathing, IV access, etc.
Oral Contrast Instructions	How to mix, how much to give, when to give, frequency of drinking.
IVC Contrast Instructions	Volume, rate, chaser volume, timing, IV access details, etc.
Patient Coaching Instructions	Breath hold, Valsalva maneuver, etc.

Protocolshare.org template

CLINICAL DETAILS

See TJC Provision of Care, Treatment, and Services PC.01.03.01 A25

Patient Preparation

Pre-Scan Instructions [edit]

Clamp Foley catheter prior to scanning. Make sure to place Foley below the level of the bladder.

Oral Contrast Instructions

Oral Contrast [edit]

Give a total 400 mL of water prior to scan (A 200mL dose every 15 minutes over 30 minutes).

Give an additional 200mL dose of water on the CT scan table.

IVC Contrast Instructions

IV Contrast Parameters [edit]

Medrad™ P3T PA protocol

To set up P3T= choose P3T, Thorax, PA then click on ok. Confirm contrast and load fluids. Enter scan duration and click ok.

Iopamidol (Isovue 370) 76% injection

For sites without the Medrad™ P3T or P3T PA option, refer to the weight based contrast tables we provide in the protocol booklet. Click here to access these tables

Patient Coaching Instructions

Pre-Scan Instructions [edit]

Practice the 3 breaths for scouts, smart prep, and the actual helical scan, we do not want to induce a transient interruption of contrast (TIC) which would can mimic a PE and or produce an indeterminate exam. Please give the patient these instructions: **When you take your last breath before the exam, please do not bear down, take a deep breath, tense up or strenuously hold your breath. This exam will be over in about 4 seconds from when we tell you hold your breath to when you may breath again.**

We would like to visualize contrast in the pulmonary arteries and aorta because this is a double rule out protocol. If you see the contrast in the pulmonary arteries at a much lower intensity than the SVC and aorta, the patient likely had a TIC which kept the PA from enhancing correctly. This is not a scan timing issue, but an issue with un-opacified blood entering the heart faster from the IVC than opacified blood from the SVC caused by a pressure imbalance between the thorax and abdomen. This is why the breathing instructions we provide above are critical for this exam.

CLINICAL DETAILS

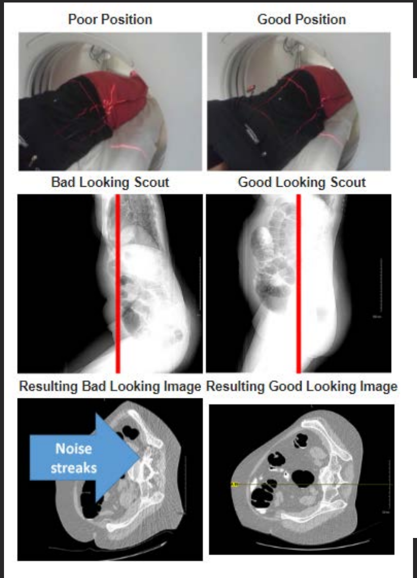
See TJC Provision of Care, Treatment, and Services PC.01.03.01 A25

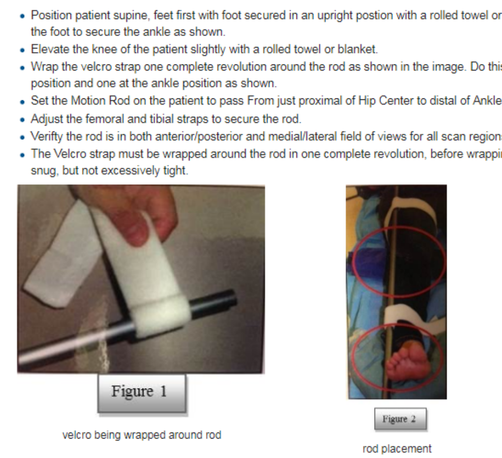
Radiologist/ Physician/Nurse Monitoring Instructions

Documentation of what physicians should be looking for to guide the diagnostic exam. For example in coronary CTA, if after the non con a patient's coronaries are full of Calcium, the CCTA may be skipped.

Patient Positioning

Most important for MSK where joint angles are important. Details (ideally with pictures) should be given to guide patient set-up.





WORKFLOW DETAILS

Exam Logistics by series	High level description of what the tech will be doing for each part of the exam.
Reformat Instructions	What planes and what source data to use to make them.
Networking Instructions	What to send where. Not trivial since you may send to PACS, 3D lab, perfusion processing, etc. which will likely differ at different sites.

WORKFLOW DETAILS

Exam Logistics by series

Scan Description [edit]

- Series 1- PA and Lateral Scout
- Coverage: Lower Neck to Below lung Base
- Series 2- Non - Contrast – Calcium Score
  - Coverage: Carina to below heart
- Series 3 – Timing Bolus = on the ascending aorta (use your without series to find the level)
  - Use 10 ml of Iodixanol and 50 ml of saline
  - Take 16 + Bolus time = Prep delay
  - If the timing for the prep delay is less that 20 seconds, please change the prep group to 20 seconds. We do not want to use anything less than 20 seconds for a delay.
- Series 4 – CTA
  - Use Timing Bolus
  - Coverage: Same as non - contrast scan
  - Number 13 breathing instructions on the scanner (10 s breath in and out + 4 s pause)

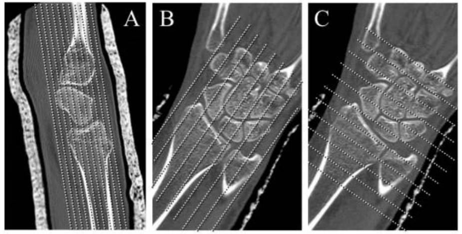
Reformat Instructions

Reformat Instructions [edit]

Use DMPR on THIN ST.

Reformats [edit]

Name	Source Recon	DMPR or Manual	Type (MIP, Average, etc.)	WW/WL	Slice Thickness (mm)	Interval (mm)	Orientation
SA BODY	THIN ST	DMPR	Average	450/50	5	2.5	sagittal
CO BODY	THIN ST	DMPR	Average	450/50	5	2.5	coronal



↑ (A) & (B) are parallel to long axis of radius ↑ ↑ (C) is perpendicular to (B)

Reformats A,B and C

Protocolshare.org template

TECHNICAL DETAILS

Scanner Platform

Acquisition Details

Recon Options

In the interest of time, I am not going to go into the details of technical acquisition parameters. This should be the wheel house of the physicist. For good references, see the parameters listed within the AAPM CT protocols.

This is not trivial, you should worry about all the recons the techs/docs need, not "just recon 1" or the acquisition parameters.

TECHNICAL DETAILS: RESOURCES

This is online as well.
https://www.radiology.wisc.edu/uw-ge-ct-protocol-project/resources/
We made this because we were sick of "making these names up" which lead to complete non uniformity across our thousands of CT protocols. Hopefully you can find value in it as well! ☺

UW-Madison CT Protocol Series Naming Scheme

Each series description is composed of 6 possible modifiers:

Thickness + Recon Type + Time + Contrast** + Energy*** + Special Options****

Thickness
THIN
(default is to leave empty which denotes a thick recon)

Slice Thickness Modifiers by Section	THIN	THICK
Abdominal/Pediatric/ Thoracic/Neuro/CV	<2.5 mm	>=2.5 mm
MSK	<1 mm	>=1 mm

Recon Type
ST (soft tissue)
BONE
LUNG

Time
LATE (i.e. for differentiating early and late arterial phases)
DELAY XX MINUTES (i.e., XX is the number of minutes the phase is delayed and varies by protocol)
TIMING BOLUS*
(default is empty)

Contrast**
W/C
W/O
CTA
CTV (CT venogram)
ARTERIAL
LATE ARTERIAL
(default is empty)

Energy***
50 keV
67 keV
140 keV
QC
VNC (virtual non contrast)
VUE (virtual unenhanced)
Water (Iodine)
Iodine (Water)
(default is empty, only used for DECT)

Special Options****
MAR (metal artifact reduction)
SSF (snap shot freeze)
XX-XX% (i.e., cardiac phase range)
XX% (i.e., centered cardiac phase)
EXP (expiration)
INSP (inspiration)
EXP HI-RES (high resolution)
INSP HI-RES
ABER (abduction and external rotation)
TAVI
PRO (prospective)
RETRO (retrospective)
LT (left side)
RT (right side)
(default is empty, use sparingly)

*A timing bolus series normally only has 1 reconstruction; therefore, no modifiers are needed for naming a timing bolus series other than the label "TIMING BOLUS".
**If the series is single phase and non contrast, this modifier is empty. If a protocol has multiple series, the non contrast series has the "W/O" modifier. In general, it is preferred to use time to specify specific contrast phases (i.e., use "DELAY 10 MINUTES" instead of "UROGRAPHIC" to denote a delayed CT urography phase).
***This is where DECT names are detailed. Energy here refers to monochromatic energy level. Only 50, 67, and 140 are shown; your practice will likely use different energy levels. These levels do not refer to the beam energy used in SECT (i.e., 120 kV). SECT energy levels should not be specified. Basis material images should be denoted using <material name> (<partner basis material name>).
****We do not have orthopedic device modifiers in the list as they vary site to site. The "Special Options" modifier should capture vendor/device/practice-specific naming conventions.

Examples:
- "5 mm soft tissue recon from a non contrast single energy scan" → "ST"
- "0.5 mm bone recon at 140 keV from a non contrast DECT scan" → "THIN BONE 140 keV"
- "1.25 mm soft tissue recon from an angio phase single energy scan" → "THIN ST CTA"
- "0.6 mm soft tissue recon from the CTA phase centered at 75% R-R of a gated single energy cardiac scan" → "THIN ST CTA 75%"

USEFUL STRATEGIES FOR PROTOCOL DEVELOPMENT/ AGENDA

Essential elements of a CT protocol

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Data mining/analysis: physicist contributing to CT protocol optimization team

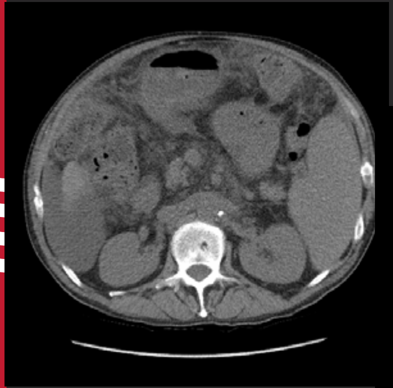
05 | clinical background: contrast dynamics

06 | clinical background: breath hold

07 | using dose data to get scan time/length

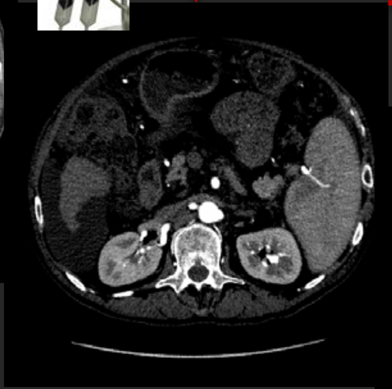
08 | optimized protocols across your fleet

CLINICAL BACKGROUND: CONTRAST DYNAMICS



Non contrast localizer phase

~20 seconds

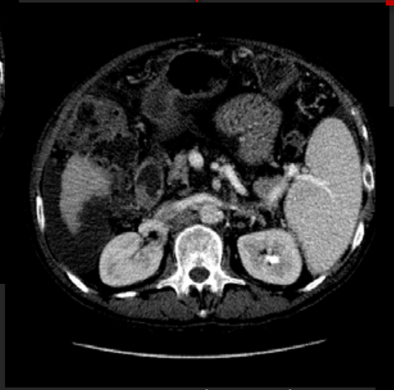


Arterial Phase

~20 seconds

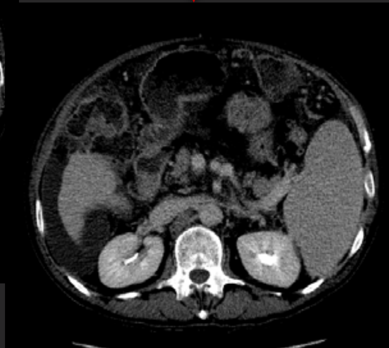
Late Arterial Phase

~30 seconds



Parenchymal Phase

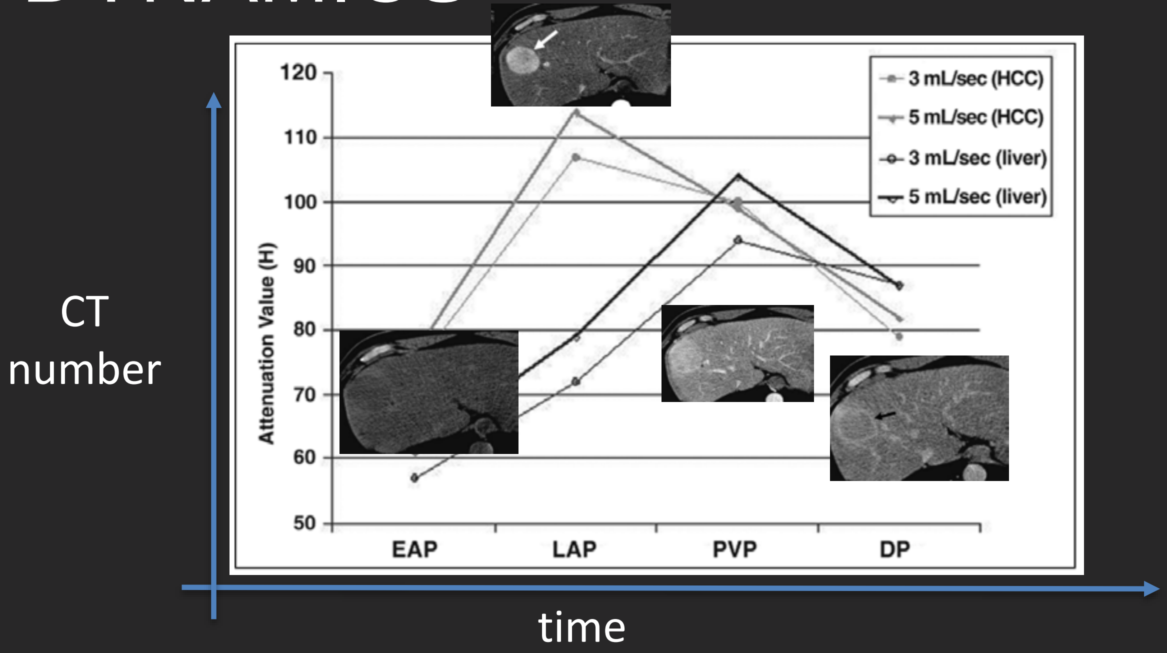
~2 minutes



3 Minute Delays

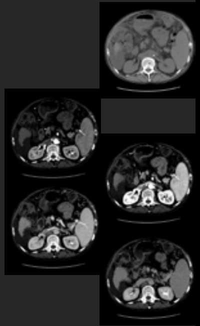
HCC (hepatocellular carcinoma) Liver protocol

CLINICAL BACKGROUND: CONTRAST DYNAMICS



Hennedige, Tiffany, and Sudhakar Kundapur Venkatesh. "Imaging of hepatocellular carcinoma: diagnosis, staging and treatment monitoring." *Cancer Imaging* 12.3 (2012): 530.
Schima, Wolfgang, et al. "Quadruple-phase MDCT of the liver in patients with suspected hepatocellular carcinoma: effect of contrast material flow rate." *American Journal of Roentgenology* 186.6 (2006): 1571-1579.

CLINICAL BACKGROUND: CONTRAST DYNAMICS



Exam Description: CT ANGIO ABDOMEN

Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	-	-	-	-
2	Helical	S78.750-I179.250	5.91	176.97	Body 32
3	Axial	I50.250-I50.250	60.71	30.35	Body 32
4	Helical	S78.750-I179.250	16.00	478.60	Body 32
4	Helical	I179.250-S78.750	6.29	188.40	Body 32
4	Helical	S78.750-I431.250	6.91	381.26	Body 32
6	Helical	S78.750-I179.250	9.10	272.37	Body 32
			Total Exam DLP:	1527.95	

258 mm

258 mm

258 mm

510 mm

258 mm

Just liver coverage

Diaphragm to pubic synthesis

CLINICAL BACKGROUND: CONTRAST DYNAMICS

258 mm imaged @ 0.516 pitch @ 40 mm collimation @ 0.4 sec rotation time → 5 sec

258 mm imaged @ 0.516 pitch @ 40 mm collimation @ 0.6 sec rotation time → 7.5 sec

510 mm imaged @ 0.516 pitch @ 40 mm collimation @ 0.4 sec rotation time → 9.9 sec

258 mm imaged @ 1 pitch @ 10 mm collimation @ 1 sec rotation time → 26 sec

510 mm imaged @ 1 pitch @ 10 mm collimation @ 1 sec rotation time → 51 sec

Scan time is given in DICOM (tag 0018,1150) which may or may not be in your image volume or dose sheet

Scan time can be calculated as $\frac{scan\ length * rotation\ time}{collimation * pitch}$

These two methods will likely give slightly different results as DICOM will include helical over scanning time

CLINICAL BACKGROUND: BREATH HOLD

INVESTIGATIVE RADIOLOGY
Volume 29, Number 9, 848–851

Preliminary Report

Breath-Holding Capability of Adults

Implications for Spiral Computed Tomography, Fast-Acquisition Magnetic Resonance Imaging, and Angiography

SPENCER B. GAY, MD,* CHRIS L. SISTROM, MD,† CHAD A. HOLDER, MD,* AND PAUL M. SURATT, MD‡

TABLE 1. Patient Parameters and Performance Results

	Mean value	Standard deviation	Minimum value	Maximum value
Patient age (years)	54	17	17	78
Smoking history 27 smokers (pack years)	28	21	3	80
Instruction time required (seconds)	104	20	75	178
Maximum breath hold (seconds) trial 1	32	3.2	0	114
Maximum breath hold (seconds) trial 2	35	3.8	0	131
Serial breath holds trial 1	5.7	0.3	0	7
Serial breath holds trial 2	5.5	0.3	0	7

TABLE 3. Breath-Holding Performance

	Inpatients or >29 pack years or COPD or CHF	Outpatients <30 pack years no COPD or CHF
Maximum breath-holding mean (seconds)	25	45
Maximal breath-holding 5th percentile (seconds)	18	38
Maximal breath-holding 95th percentile (seconds)	32	56
Serial breath holds mean	5	7
Serial breath holds 5th percentile	4	6
Serial breath holds 95th percentile	6	7
Number of patients	31	19

Some patients who simply cannot hold their breaths at all, others can only do so for ~18 seconds→ this study was not on patients with cancer…

CLINICAL BACKGROUND: BREATH HOLD

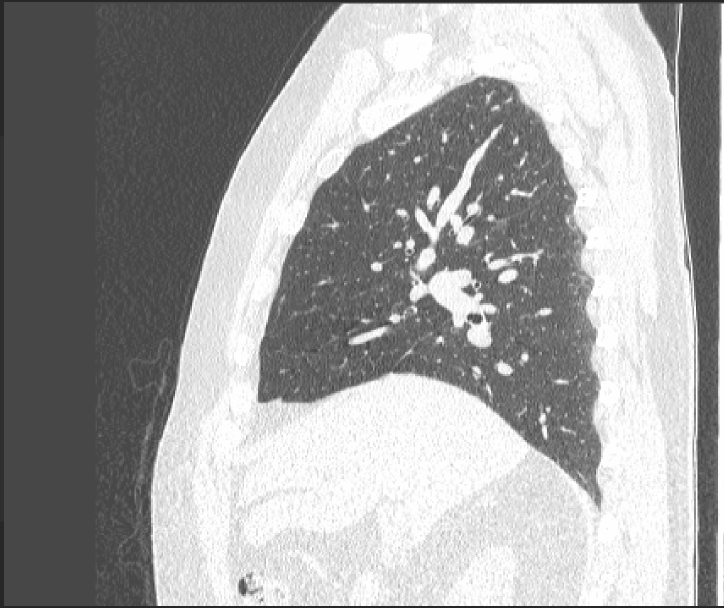
ADULT LUNG CANCER SCREENING TECHNICAL SPECIFICATIONS		
Adult Chest for Lung Cancer Screening		
Technique Parameters (Items in bold are designation requirements. Failure to meet these requirements will result in deferral of Designation)		
Scan Parameter	**Parameter Specification**	**Comments**
Scanner type	**multidetector helical (spiral) detector rows ≥ 4**	non helical and single detector scanners are not appropriate for lung cancer screening CT
Required Series		No IV or oral contrast should be used
kV	100 to 140 acceptable for standard sized patient	Should be set in combination with mAs to meet CTDIvol specifications
mAs	Should be set in combination with kVp to meet CTDIvol specifications.	The mAs selected should result in diagnostic-quality images of the lungs Should take into account the patient's body habitus and age, slice width, kVp, and unique attributes of the scanner and acquisition mode
Max.Tube Rotation Time	≤ 0.5 seconds	0.75 second is acceptable if a single breath hold ≤15 seconds can be achieved for scanners that cannot perform 0.5 second rotation time
Pitch (IEC Definition)	Between 0.7 and 1.5	Should be set with other technical parameters to achieve single breath hold scan and CTDIvol specifications
Respiration	**single breath hold full inspiration**	
Scan duration/ Acquisition time	≤ 15 seconds	e to acquire the scan though entire s within a single breath
Reconstructed image width (nominal width of reconstructed image along z-axis)	**≤ 2.5 mm**	≤ 1 mm preferred
Reconstructed image spacing (Distance between two reconstructed images)	≤ slice width	Overlapping reconstructions are not necessary but are acceptable

CLINICAL BACKGROUND: BREATH HOLD

2 YO M, 15 cm coverage

51 YO F, 23 cm coverage

55 YO M, 34 cm coverage



CLINICAL BACKGROUND: BREATH HOLD

15 cm imaged @ 1.5 pitch @ 40 mm collimation @ 0.4 sec rotation time → 1 sec
23 cm imaged @ 1.5 pitch @ 40 mm collimation @ 0.4 sec rotation time → 1.5 sec
34 cm imaged @ 1.5 pitch @ 40 mm collimation @ 0.4 sec rotation time → 2.3 sec

15 cm imaged @ 1 pitch @ 10 mm collimation @ 1 sec rotation time → 15 sec
23 cm imaged @ 1 pitch @ 10 mm collimation @ 1 sec rotation time → 23 sec
34 cm imaged @ 1 pitch @ 10 mm collimation @ 1 sec rotation time → 34 sec

Scan time is given in DICOM (tag 0018,1150) which may or may not be in your image volume or dose sheet

Scan time can be calculated as $\frac{scan\ length * rotation\ time}{collimation * pitch}$

These two methods will likely give slightly different results as DICOM will include helical over scanning time

USING DOSE DATA TO GET SCAN TIME/LENGTH

Almost all dose monitoring vendors allow a ``data dump''

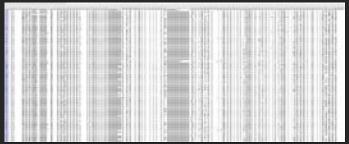
Fields in the data dump will likely include fields usable to either directly yield scan length/times or provide the values needed to calculate them

- Your Dose monitoring system will either directly give you
  - Scan range, scan time
- Or you can can get scan range and time
  - Scan range ~DLP/CTDIvol
  - Scan time = $\frac{scan\ length * rotation\ time}{collimation * pitch}$

Your dose monitoring vendor should output these values for each irradiation event which can be filtered by patient age, protocol name, location, etc.

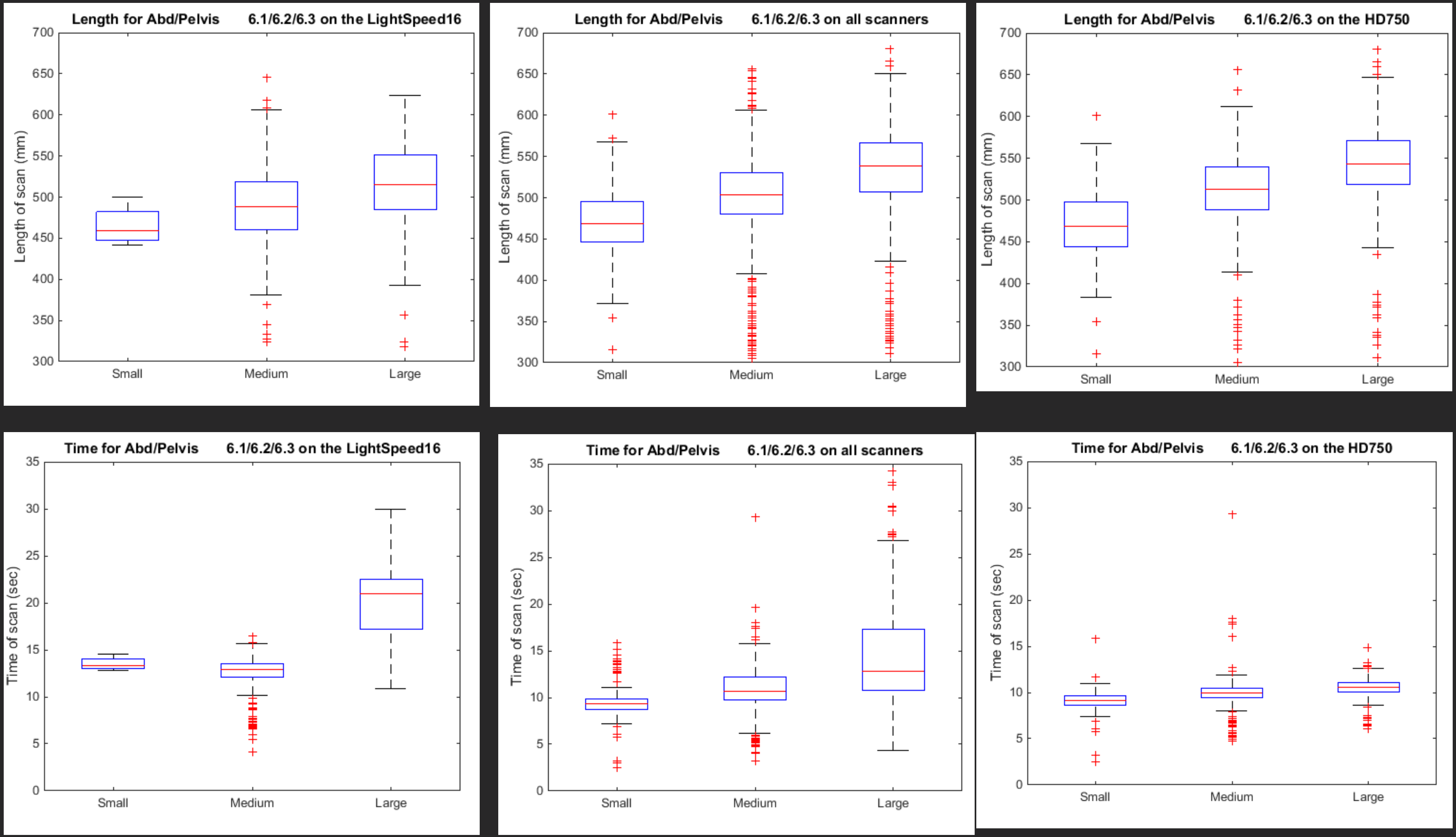
USING DOSE DATA TO GET SCAN TIME/LENGTH

Data export in csv format



Trivial spreadsheet filtering and math

Protocol Name	Patient Age	Scan Length	Scan Time
Routine abd/pel	41	52	10.3
Routine head	16	20	4
Chest PE	67	40	3


Length for Abd/Pelvis 6.1/6.2/6.3 on the LightSpeed16
Length for Abd/Pelvis 6.1/6.2/6.3 on all scanners
Length for Abd/Pelvis 6.1/6.2/6.3 on the HD750
Length of scan (mm)
300
350
400
450
500
550
600
650
700
Small
Medium
Large
Time for Abd/Pelvis 6.1/6.2/6.3 on the LightSpeed16
Time for Abd/Pelvis 6.1/6.2/6.3 on all scanners
Time for Abd/Pelvis 6.1/6.2/6.3 on the HD750
Time of scan (sec)
0
5
10
15
20
25
30
35

OPTIMIZED PROTOCOLS ACROSS YOUR FLEET

Using the method shown on the last slide, you can monitor scan times for any protocol on any scanner in your fleet.

	Mean	Median	25th	75th
Abdomen/Pelvis	9.6479	10.0514	9.4179	10.5806
Routine Chest	3.0938	2.8288	2.6533	3.1447
Lung Screening	2.6999	2.7856	2.6751	2.9052
CTA for PE	3.5978	3.3898	3.1359	4.1985
Upper Extremity	8.4346	8.1231	6.6434	9.9302
Lower Extremity	13.0668	13.0471	9.0972	16.9920

OPTIMIZED PROTOCOLS ACROSS YOUR FLEET

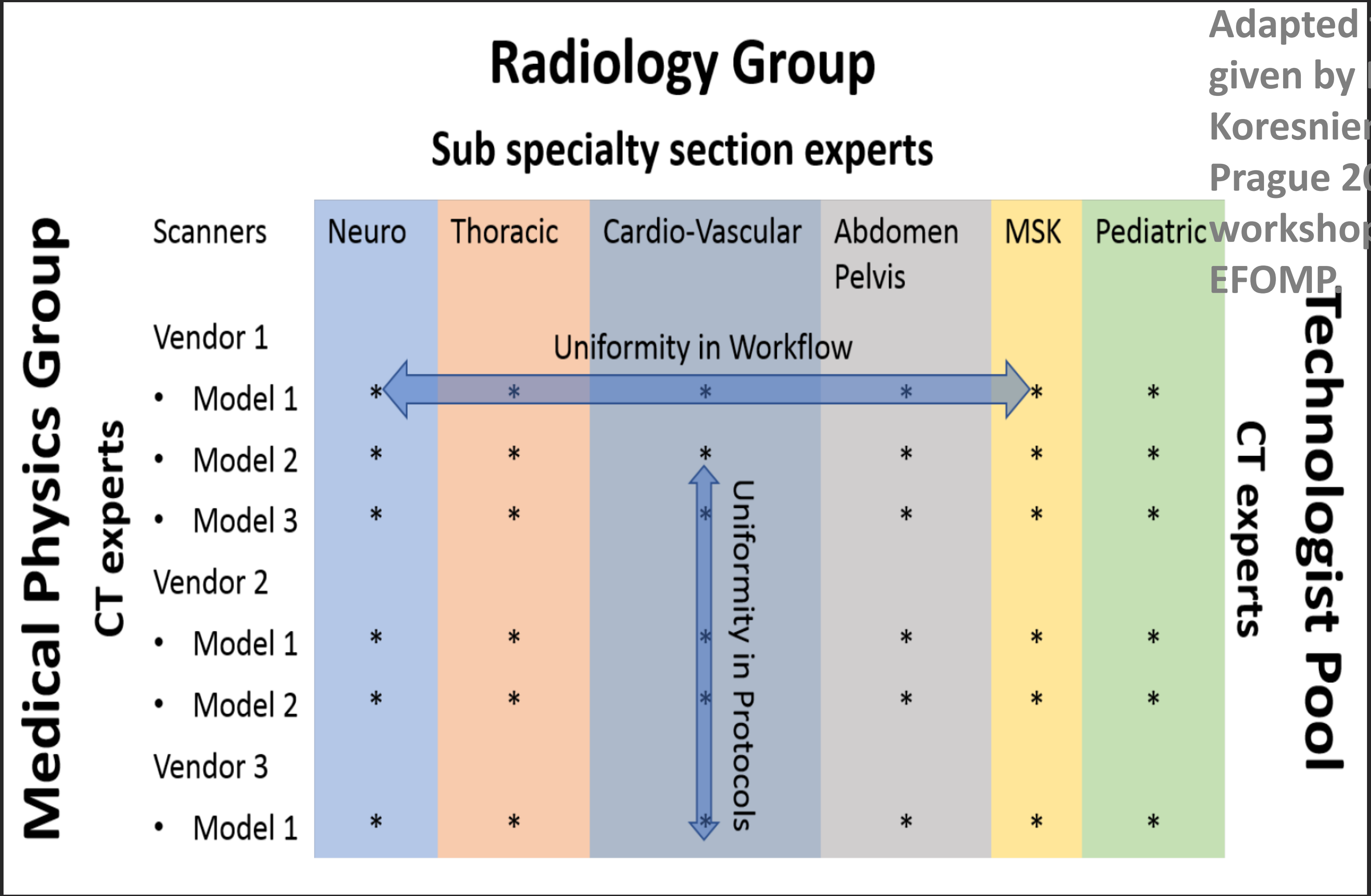
Using the data from the last slide, you can sit at the table with your clinical colleagues armed with real data on how long scans will take. You can make informed decisions on scan delay lengths for complicated multiphasic protocols. Or scan delay adjustments as a function of patient size and scanner capabilities.

Taller patients will need longer scan ranges for the same body region.

Scan time = $\frac{\uparrow scan\ length * rotation\ time}{collimation * pitch}$

Bigger (i.e. water equivalent diameter) patients will need higher tube outputs for the same body region relative to smaller patients.

Scan time = $\frac{scan\ length * \uparrow rotation\ time}{collimation * \downarrow pitch}$



Adapted from a slide given by Professor Mika Koresniemi at the Prague 2018 CT workshop hosted by EFOMP

THANK YOU.

Feel free to contact me at tszczykutowicz@uwhealth.org