CT Sim Protocol Standardization

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Milwaukee, Wisconsin, United States
October 4, 2018

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Prelude

- The CT simulation exam is the input to radiotherapy, and is the most important component in the radiotherapy.

- Extreme care and attention to detail is required to prevent systematic errors from propagating throughout the entire radiotherapy chain.

- All staff performing CT simulation exams must always remain vigilant and focused on creating the absolute highest quality reference images possible.

Goals

- Consistent CT simulation protocols across the enterprise
- Leverage latest technology to maximize:
  - HU accuracy (dose calculation accuracy)
  - Delineation accuracy
  - Registration accuracy
- Minimize errors, issues in dosimetry
- Achieve ”standard of care” CT imaging
- Facilitate use of advanced CT imaging methods and visualizations in target/OAR delineation
- Improve auto-contouring accuracy and robustness from MIM

Ad Hoc Committee

- Physics:
  - Eric Paulson
  - George Noid (Informaticist)
  - An Tai (FH, VA)
  - Doug Prah (SJH)
  - Kristofer Kainz (CMH)
  - Katherine Albano (DTS)
- MD:
  - Disease site leads
- Dosimetry:
  - Kirk Morris
- Therapists:
  - CT Sim Therapists (all sites)
- Radiology:
  - Bret Barnes (Diagnostic Tech)
- Siemens

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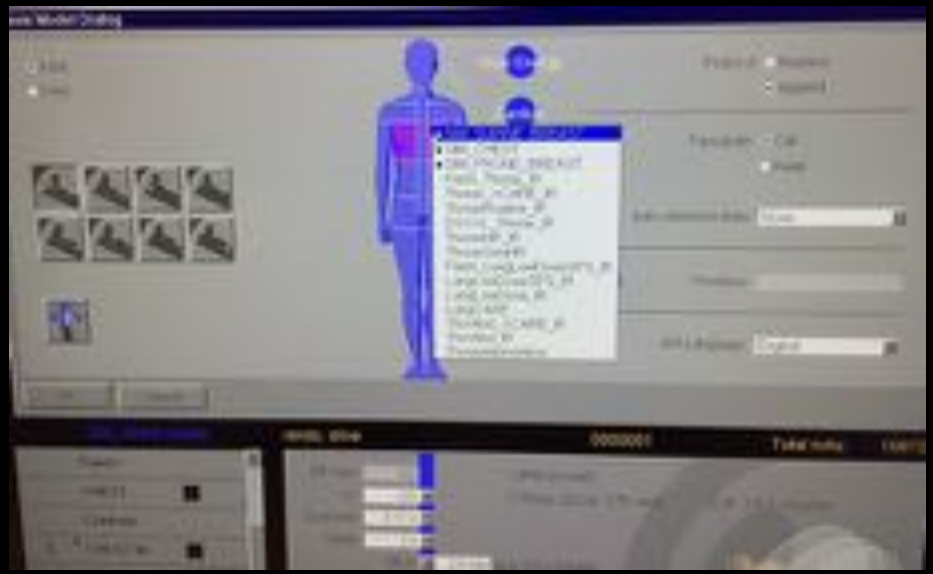
Intuitive Protocol Location and Simplification

Current

Proposed



- Reduce total number of protocols
- Combine elements into single protocol with optional scans

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Simplified Scan Queue Labeling

- Optional scans can be cut from protocol if not needed

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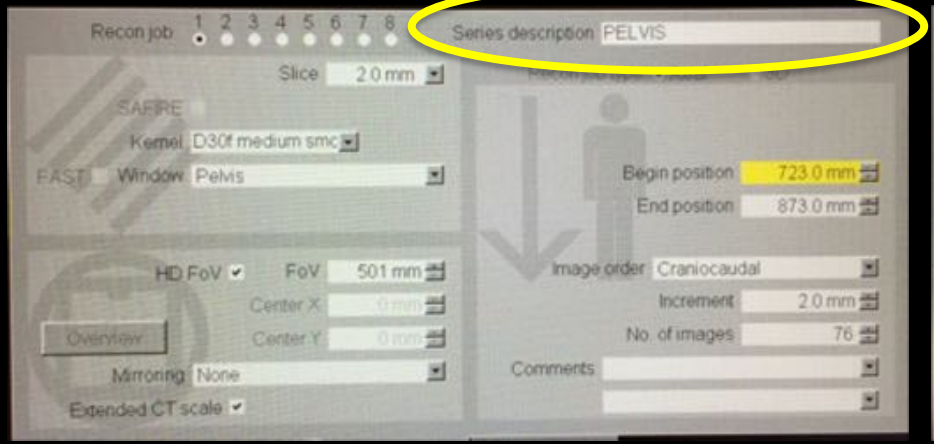
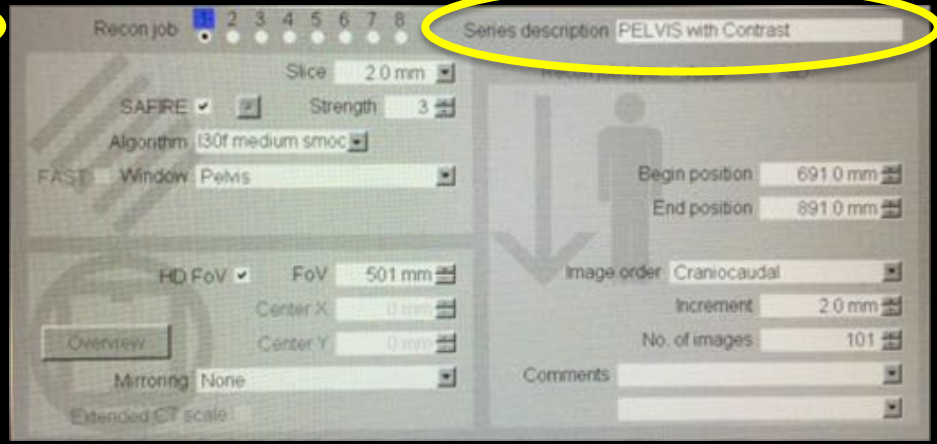
Standardized CT Series Descriptions





- No need for CT sim therapists to change series descriptions to match RadRx
  - OK to add “RESCAN” to planning CT series description
- Eliminates special characters (and issues with special characters)
- Allows auto-detection of series in MIM setup workflows
- Do not “rerun” series for CE-CT scan

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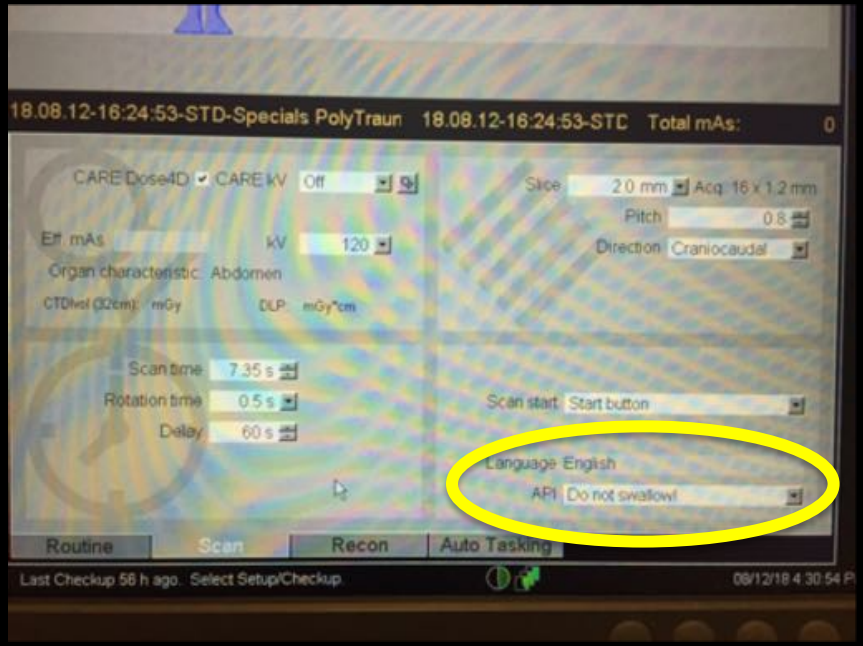
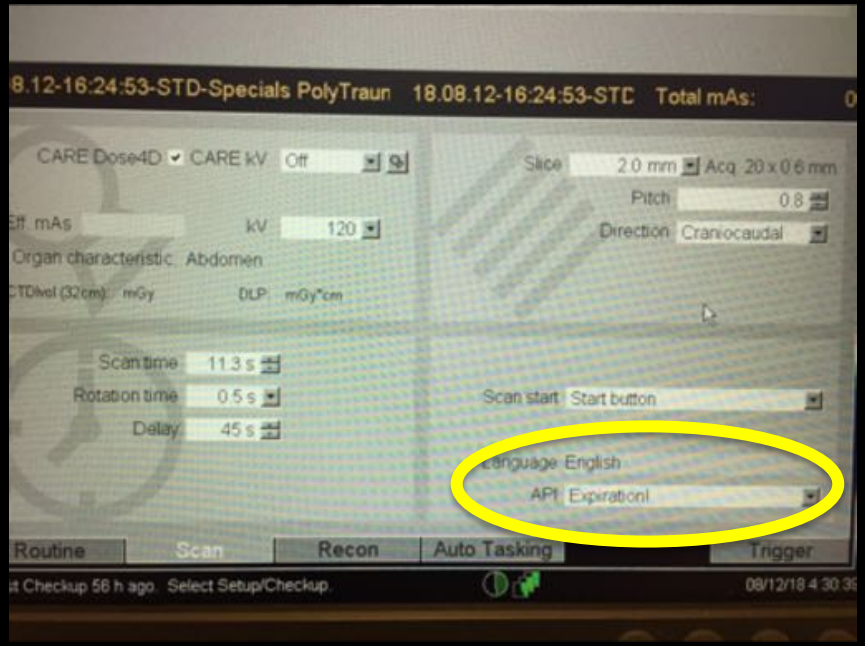
Automated Patient Instructions (API)





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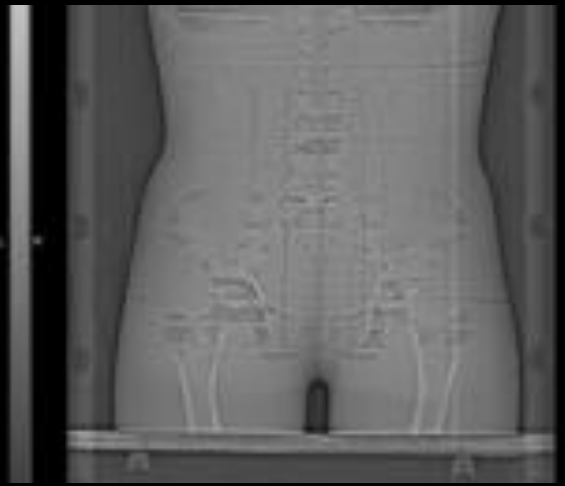
CAREDose: Effect of Patient Position in Bore

Vertically Centered

Top



Bottom

Position	Lung (CTDIvol)	Pelvis (CTDIvol)
Top	20.53 mGy	38.97 mGy
Centered	21.28 mGy	23.41 mGy
Bottom	21.52 mGy	15.04 mGy

- Important to center patients as much as possible

Topograms

- LAT and AP topograms acquired:
  - LAT first to verify vertical centering
  - More accurate estimates of tube current modulation
  - Avoids dose errors outlined in Siemens Advisory notice

- Topogram lengths optimized for each disease site:
  - CAREDose errors if 3D/4D scan prescription not within topogram

Extended HU

- Avoids saturation of HU values in metal
- Compatible with iMAR
- NOT compatible with ADMIRE/SAFIRE
- Recommend leaving ON for planning CT images:
  - Permits not forcing densities in metals that do not saturate (e.g., fillings)
- Recommend leaving OFF for non-planning images:
  - Enable ADMIRE/SAFIRE to maximize delineation accuracy

Mullins et al, J App Clin Med Phys 2016; 17:179-188

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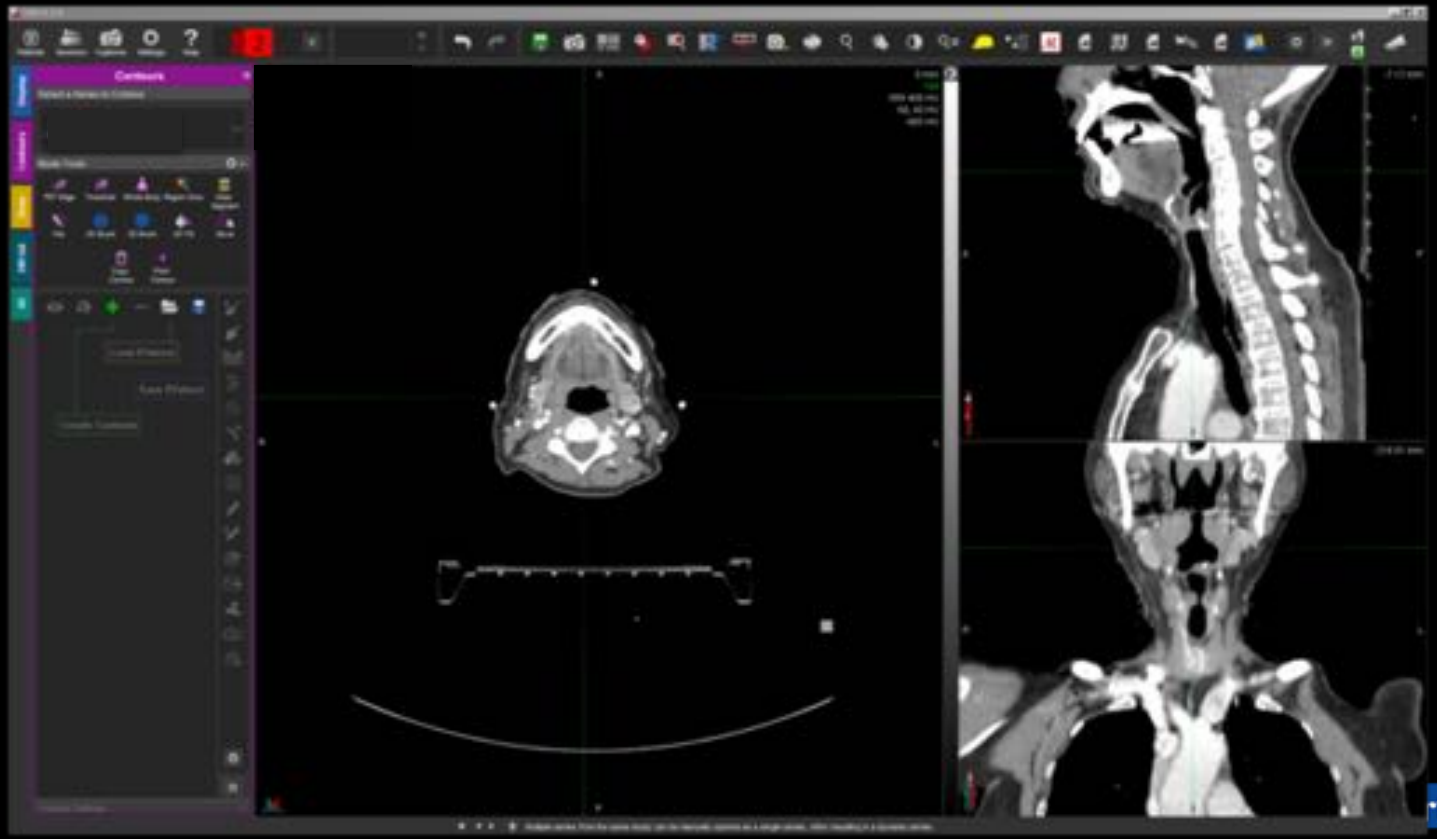
Eliminates using CECT for Planning CT



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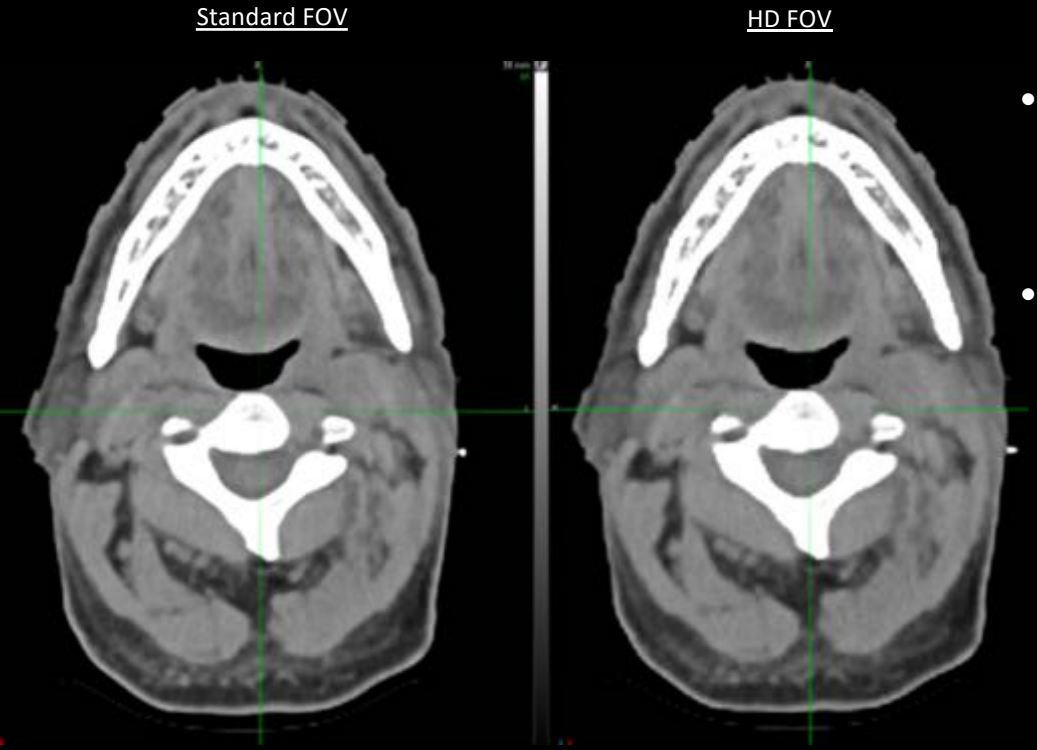
HD FOV (Extended FOV)



- Use to avoid clipping external contour for large patients
- Issue:
  - Matrix size not changed, just voxel size
    - 0.98 mm → 1.52 mm
  - Loss of spatial resolution with HD FOV
  - Affects contour resolution, image registration, and resamples secondary images

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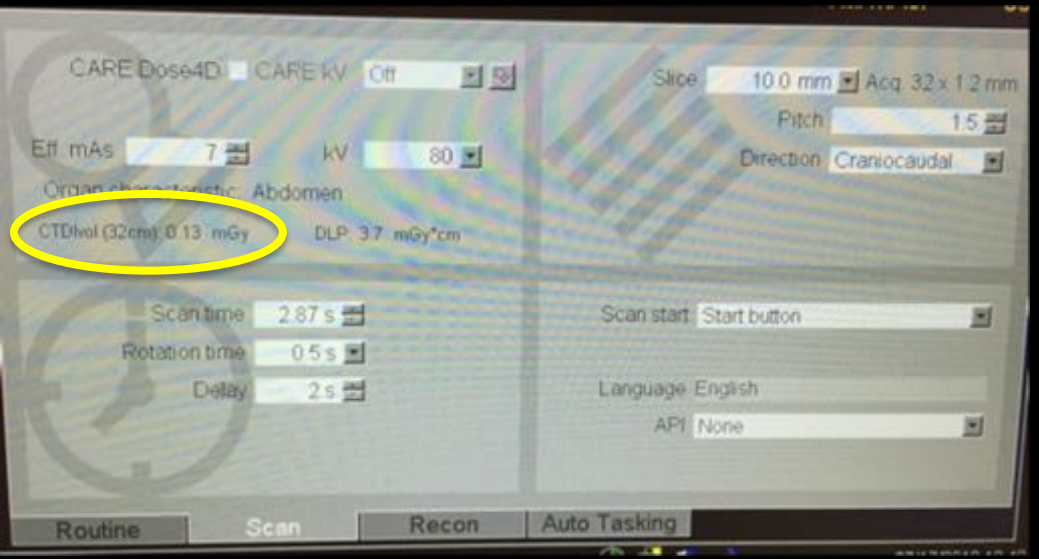
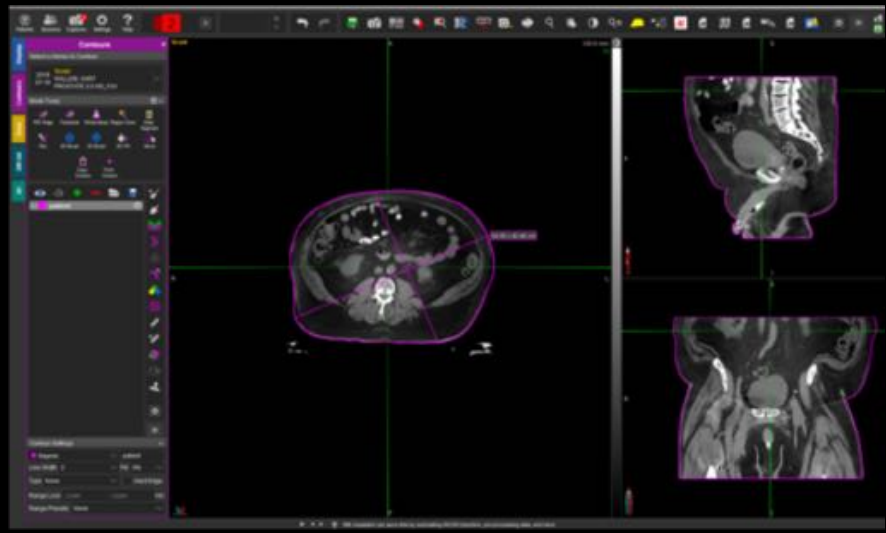
Patient-Specific FOV Check





- Topogram limited to 50cm; unable to use to calibrate FOV to avoid clipping
- Very fast 3D helical scan (**same dose as a topogram**)
- Run “FH CT Sim FOV Check” MIM workflow to determine maximum patient extent
- If extent > 50 cm, set HD_FOV to patient extent prior to recon

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iMAR (iterative Metal Artifact Reduction)

Implant	iMAR Preset
Neurostimulator implants	Pacemaker
Aneurism coils	Neuro coils
Teeth filling	Dental Fillings
Unilater shoulder prosthesis	Shoulder
Bilateral shoulder prosthesis	Hip Implants
Port	Pacemaker
Pacemaker	Pacemaker
Pacemaker leads	Pacemaker
Breast Clips	Thoracic Coil
Breast expander	Hip Implants
Sternum staples	Pacemaker
Sternum wires	Pacemaker
Stent	Extremity
Anzai bellows	Pacemaker
Hip Prosthesis	Hip Implants
Impaled buck shot	Dental Fillings
Penile Clamp	Pacemaker
Prostate Seeds	Extremity
Syed	Extremity
Spine rods	Shoulder
Spine screws, pins	Spine
Extremity pin	Extremity

- Critical to choose correct preset for specific implant:
  - Incorrect preset can introduce artifacts
- Enabled for planning CT images:
  - Shown to NOT affect dose calculation
- Disabled for IV contrast CT images:
  - May affect contrast enhancement

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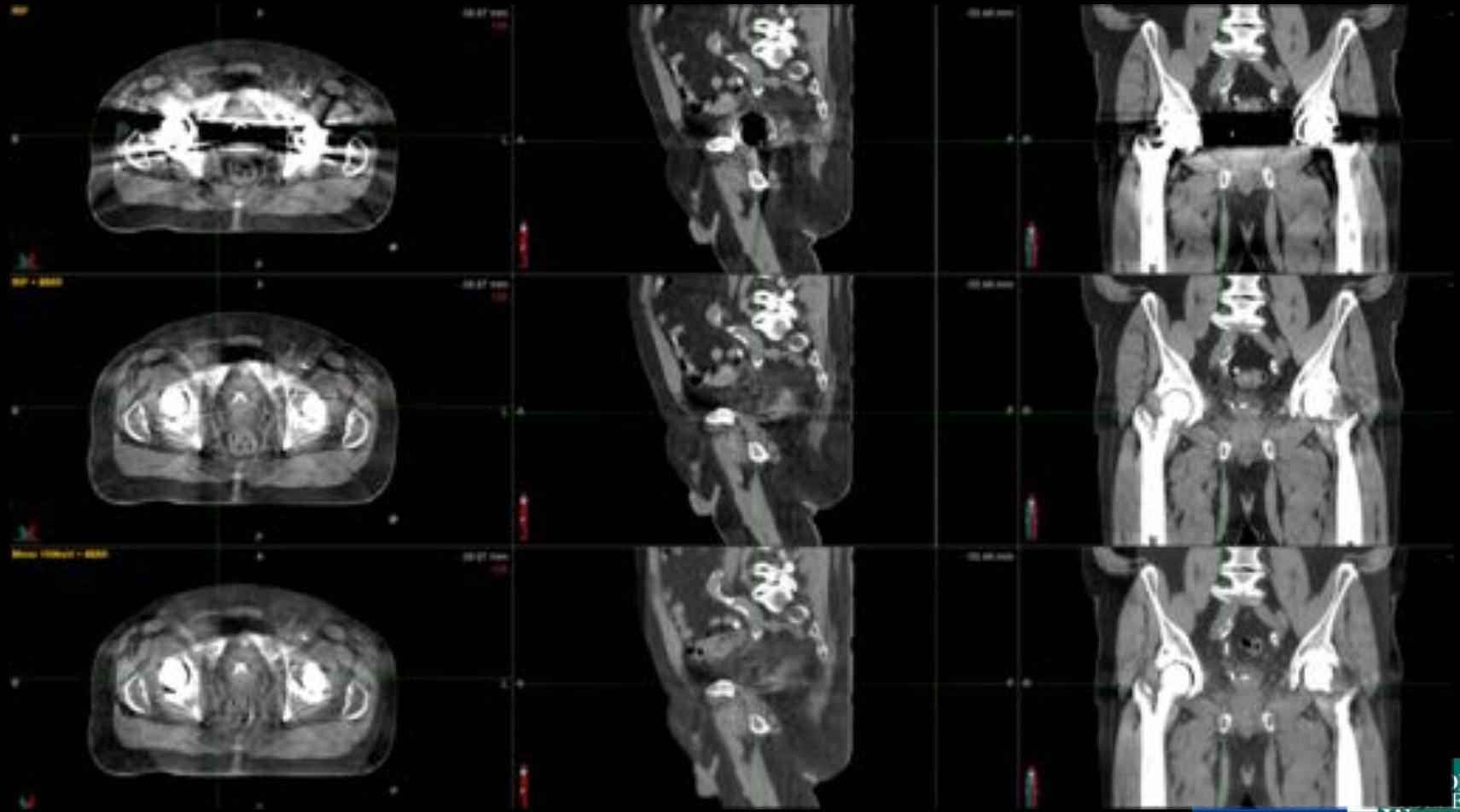
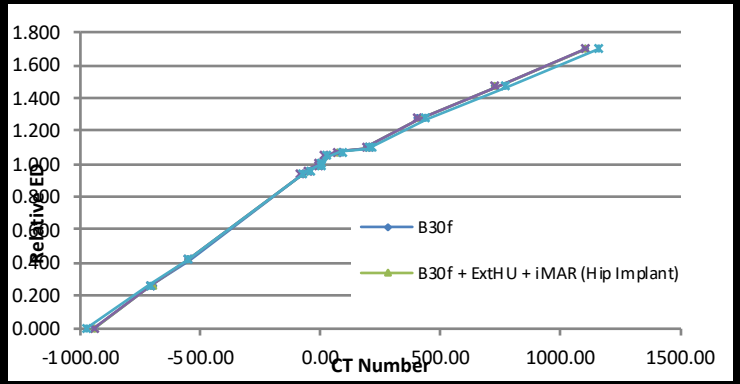


Ok to use iMAR Images for Dose Calculation

Material	UniKV	Rel ED	B30f	Calc'd rED	Δ%	B30f + ExtHU + iMAR (Hip Implant)	Calc'd rED	Δ%	B30f + ExtHU + iMAR (Hip Implant) + HD FOV	Calc'd rED	Δ%
Air	-977	0.001	-943.21	0.035	3094.28%	-943.26	0.035	3089.70%	-945.95	0.032	2843.36%
LN-300	-709	0.267	-699.09	0.277	3.71%	-700.17	0.276	3.31%	-702.61	0.273	2.39%
LN-450	-557	0.419	-551.69	0.425	1.36%	-553.04	0.423	1.02%	-556.03	0.420	0.25%
Adipose	-75	0.937	-78.36	0.933	-0.39%	-78.02	0.934	-0.35%	-81.68	0.930	-0.77%
Breast	-42	0.958	-52.47	0.951	-0.70%	-52.70	0.951	-0.71%	-55.72	0.949	-0.91%
SolidWater	2	1.000	-7.00	0.991	-0.86%	-7.18	0.991	-0.88%	-11.37	0.987	-1.28%
LiquidWater	4	0.988	-5.96	0.992	0.45%	-6.17	0.992	0.43%	-10.77	0.988	-0.02%
Brain	28	1.047	21.65	1.031	-1.49%	22.19	1.033	-1.36%	18.90	1.025	-2.14%
Liver	90	1.072	70.70	1.064	-0.73%	71.46	1.065	-0.70%	66.48	1.063	-0.88%
Inner Bone	205	1.097	191.07	1.094	-0.28%	190.08	1.094	-0.30%	187.09	1.093	-0.35%
B-200	218	1.105	202.51	1.096	-0.77%	202.02	1.096	-0.78%	198.05	1.095	-0.86%
CB2-30%	437	1.278	407.44	1.255	-1.83%	408.67	1.256	-1.75%	404.85	1.253	-1.99%
CB2-50%	772	1.466	728.48	1.442	-1.67%	728.82	1.442	-1.65%	724.51	1.439	-1.82%
Cortical Bone	1153	1.695	1100.63	1.664	-1.86%	1100.31	1.663	-1.87%	1097.17	1.661	-1.98%



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ADMIRE/SAFIRE

- Iterative reconstruction (denoising)
- Not compatible with Extended HU
- Too high of strength results in “fake” looking images
- Enabled on all IV contrast images (strength limited to 3)

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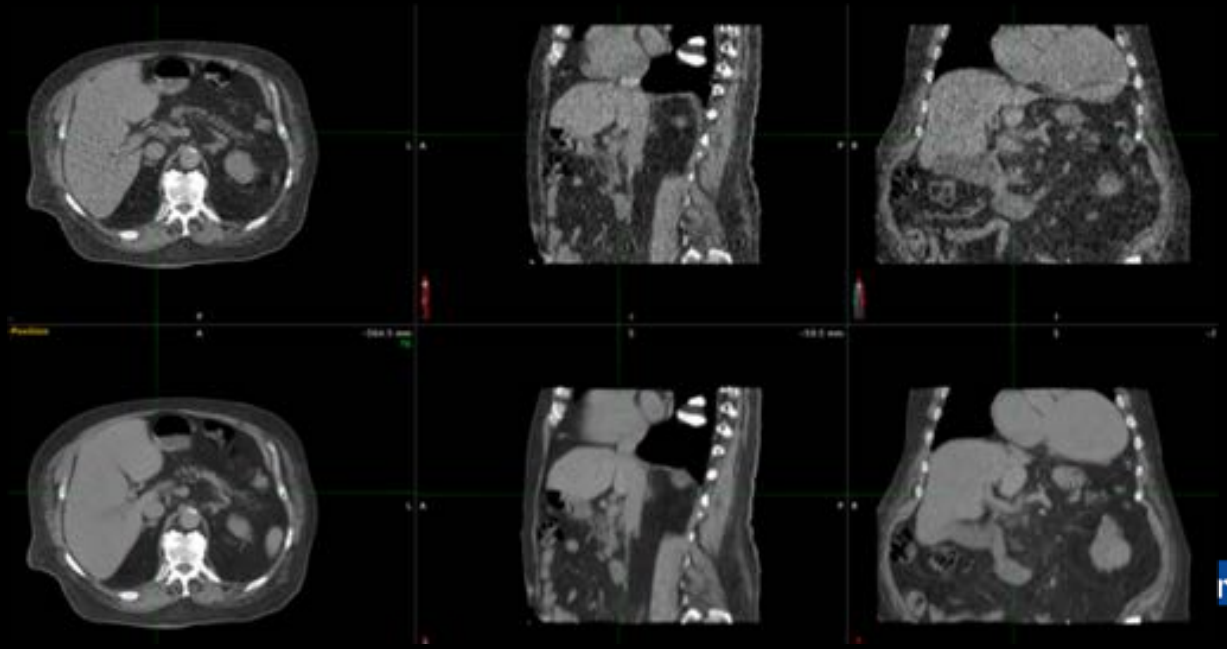
4D-CT

- Using QF=70 mAs/rot to avoid tube overheating with large coverage volumes
- Amplitude-based sorting (including derivatives)
- Recommend mid-position, rather than 3D, 20%, or 50% phase images, for planning

50% Phase

Mid-Position (MIM)



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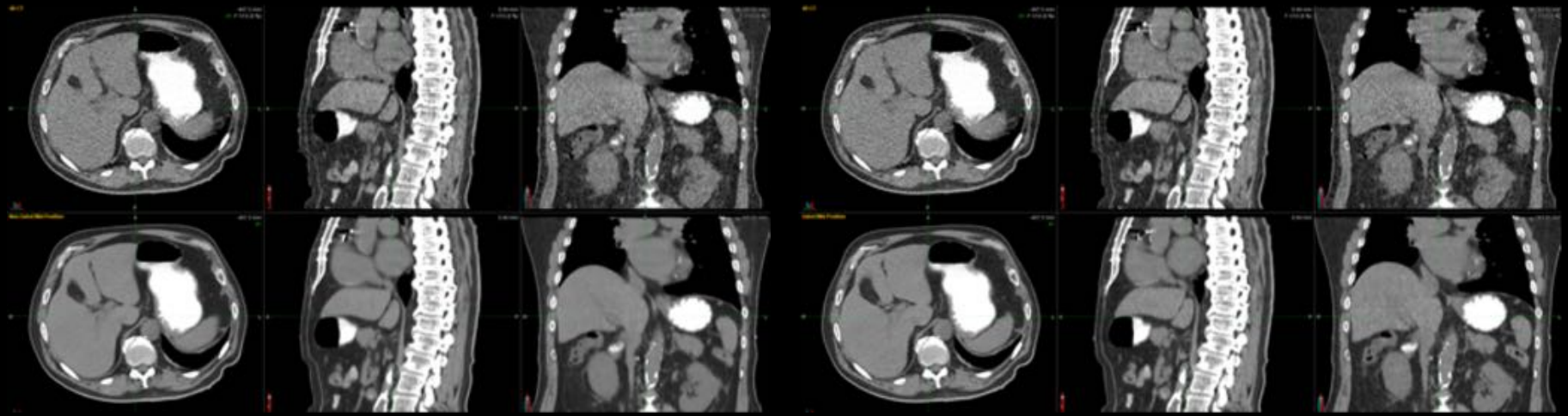
Time-weighted Mid-Position Image from 4D-CT

Non-Gated Mid-Position (0-90% phases)

Gated Mid-Position (40%, 50%, 60% phases)



- Still using ITV for target motion

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Lung SBRT: Aktina Belt

- Need to evaluate whether belt effectively reduces motion
- 4D-CT Scout (no belt)
- If motion > 1cm:
  - Inflate belt
  - Repeat 4D-CT Scout with belt
  - Did belt effectively reduced motion? If not, deflate belt
- Continue with CT Sim

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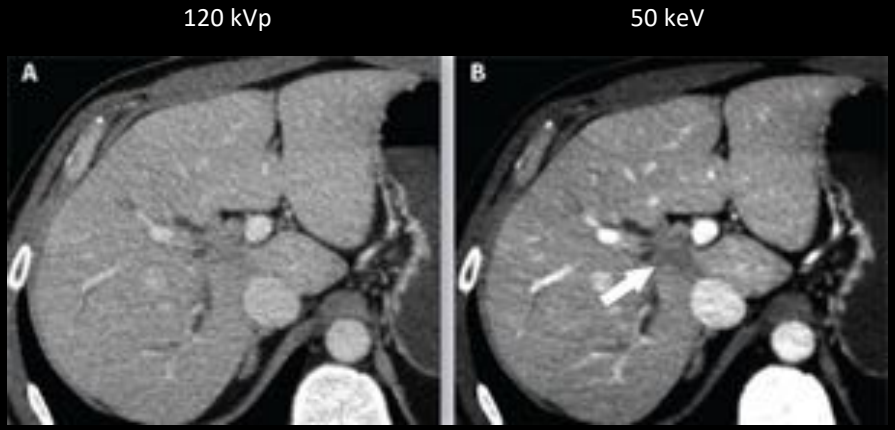
Dual-Energy CT (DECT)

- Acquisition of two CT scans at dose of single energy scan
- Improved soft tissue contrast
- Reduction of beam hardening, photon starvation artifacts
- Now integrated into nearly all protocols



Cochrane J, Radiology Rounds 2016; 14:1-6

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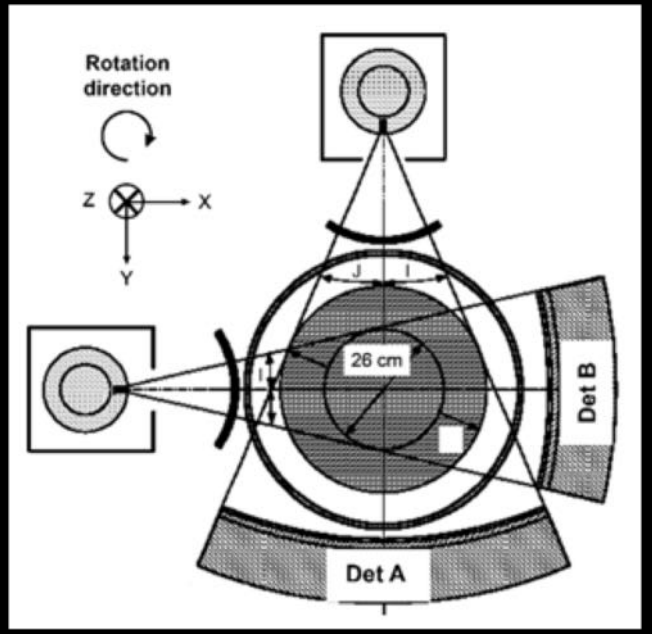
DECT Challenges

- Sequential DECT (CMH, SJH, DTS):
  - Motion (respiration, peristalsis, etc)
  - Contrast dynamics

- Simultaneous DECT (FH):
  - FOV Limits (30, 50 cm)
  - Not compatible with HD FOV
  - Not compatible with Extended HU
  - Not compatible with 4D
  - Tin filter for 140 kVp (Tube B only)
  - No sequential DECT option



Godoy et al, J Thor Imag, 2009

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Proposed Acquisition Strategies

	FH		CMH, SJH, DTS	
	Planning CT	IV CT, Other	Planning CT	IV CT, Other
Brain	Simultaneous	Simultaneous	Sequential	Sequential
Head and Neck	Sequential	Simultaneous	Sequential	Sequential
Chest	SECT (4D)	Simultaneous	SECT (4D)	SECT
Supine Breast	SECT	Simultaneous	SECT	Sequential
Prone Breast	Sequential	N/A	Sequential	N/A
Abdomen	SECT (4D)	Simultaneous	SECT (4D)	SECT
Pelvis	Sequential	Simultaneous	Sequential	Sequential
Spine	Sequential	N/A	Sequential	N/A
Extremity	Sequential	N/A	Sequential	N/A

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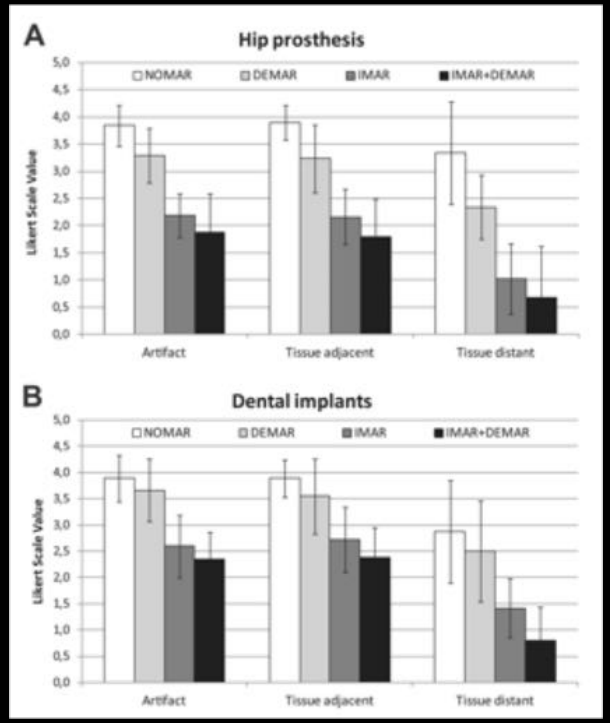
DECT Reconstructions



Bongers et al, PLOS One, 2015

- Recommend automating using MIM setup workflows:
  - Image-based
  - Syngo-Via incompatible with sequential DECT on DRIVE
  - Each monoenergetic image requires separate 80 and 140 kVp reconstructions
- Monoenergetic 50 keV
- Subtractions (120 keV – 50 keV)

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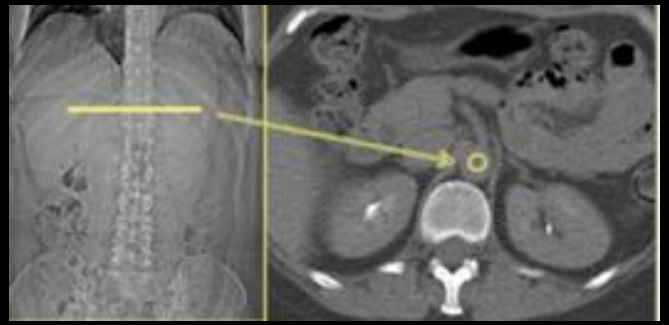
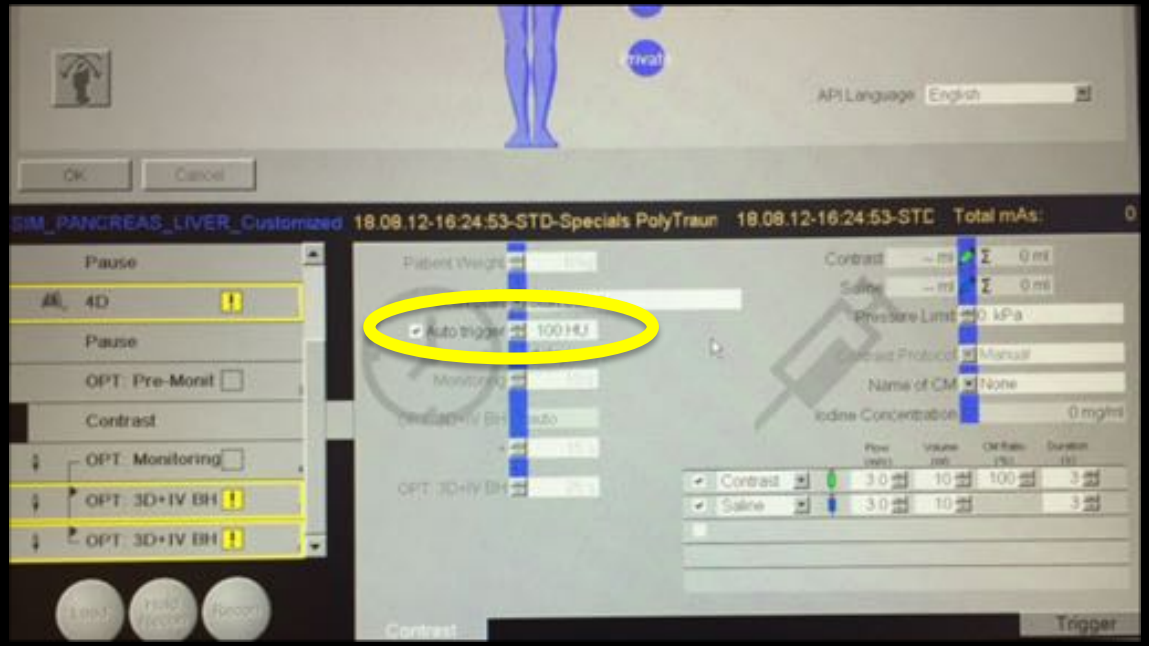
Contrast-Enhanced CT

	Routine	Pancreas/Liver
IV Contrast Medium	Omni 350, no dilution	
Oral/Rectal/Vaginal Contrast Medium	15 cc Omni 350 diluted in 16 oz of water (2x)	
Needle Size [Ga]	20-22	18-20
Flow Rate [ml/sec]	Patient-Specific (weight)	Patient-Specific (weight)
Timing Delays [sec]	Disease Site-Specific	Patient-Specific (cardiac output)
Pressure Limit [psi]	300	
Threshold [HU]	-	150
Test Injection Volume [ml]	15	15
Contrast Volume [ml]	Patient-Specific (weight)	Patient-Specific (weight)
Saline Flush Volume [ml]	30	30

Bae KT, Radiology 2010; 256:32-61
Barnes B, et al, MCW Department of Radiology

Pancreas/Liver: Multi-Phase Dynamic CE-CT





- Pancreas and liver patients
- Acquisition tailored to patient cardiac output
- Simultaneous DECT (FH); SECT (CMH, SJH, DTS)

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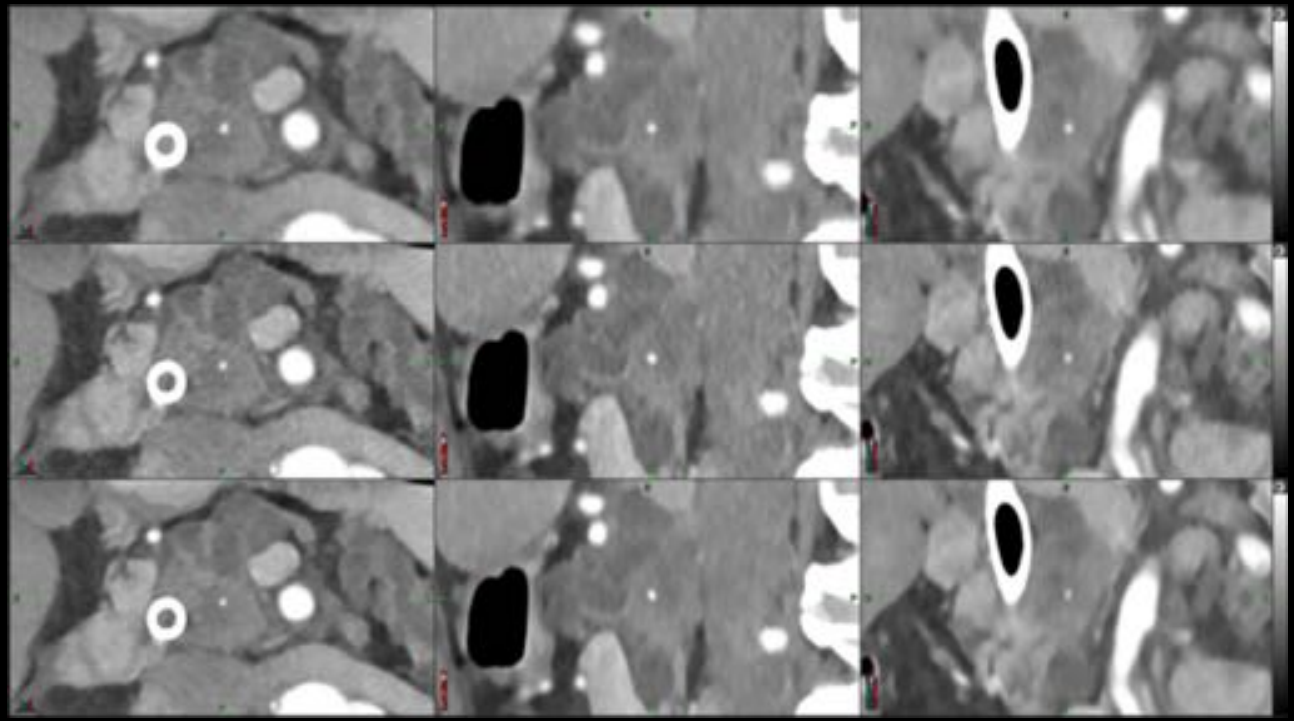
High Resolution, Reduced FOV for CE-CT

50.0 cm FOV
ADMIRE = 3
(1x1x3 mm3)

25.6 cm FOV
ADMIRE = 3
(0.5x0.5x0.5 mm3)

25.6 cm FOV
ADMIRE = 5
(0.5x0.5x0.5 mm3)



- FOV can be tailored and positioned over target during reconstruction

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Reconstruction Kernels

Single Energy	Dual Energy
H = Head, head/neck B = Body (below head/neck) I,J = Iterative (ADMIRE/SAFIRE, any site)	D = Dual energy (any disease site) Q = Quantitative DECT (ADMIRE/SAFIRE, any site)

- Kernel Size:
  - As number increases, sharpness of image increases
  - 30 = medium smoothing (default)
  - 33,34: Additional beam hardening correction (use for shoulders, metal)

- Speed:
  - f = Fast scan
  - s = Slow scan

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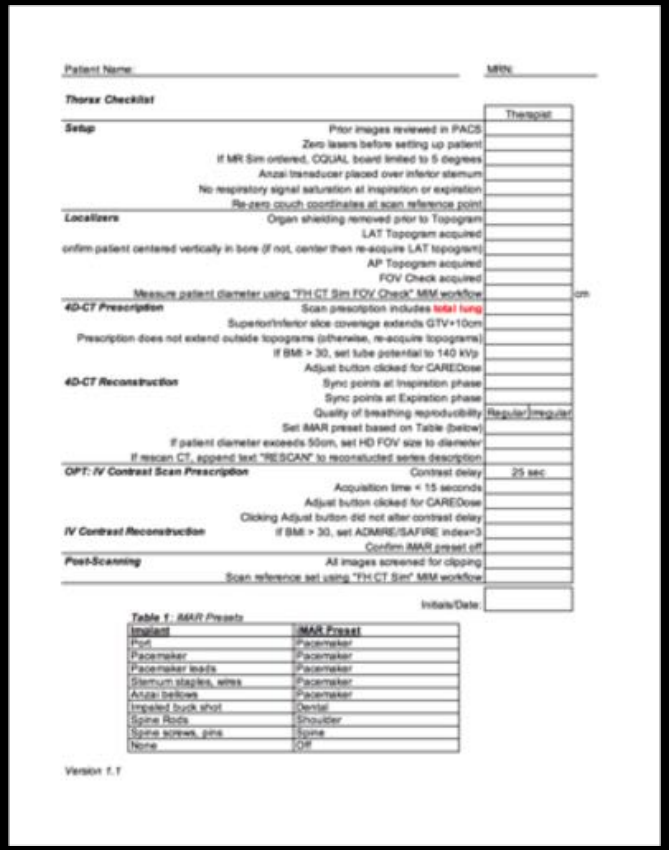
Disease-Specific Sim Therapist Checklists



Patient Name: MRN:

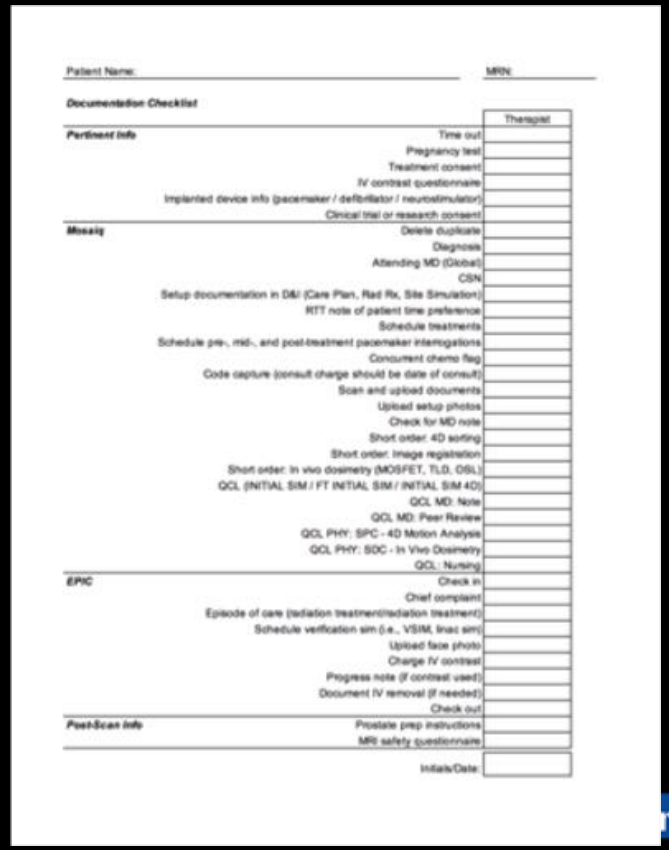
Thorax Checklist

		Therapist
Setup	Prior images reviewed in PACS	
	Zero lasers before setting up patient	
	If MR Sim ordered, CQUAL board limited to 5 degrees	
	Anzai transducer placed over inferior sternum	
	No respiratory signal saturation at inspiration or expiration	
	Re-zero couch coordinates at scan reference point	
Localizers	Organ shielding removed prior to Topogram	
	LAT Topogram acquired	
	confirm patient centered vertically in bore (if not, center then re-acquire LAT topogram)	
	AP Topogram acquired	
	FOV Check acquired	
	Measure patient diameter using "TH CT Sim FOV Check" MM workflow	cm
4D-CT Prescription	Scan prescription includes **total lung**	
	Superior/Inferior slice coverage extends GTV+10cm	
	Prescription does not extend outside topograms (otherwise, re-acquire topograms)	
	If BMI > 30, set tube potential to 140 kVp	
	Adjust button clicked for CAREDose	
4D-CT Reconstruction	Sync points at Inspiration phase	
	Sync points at Expiration phase	
	Quality of breathing reproducibility	Regular/Irregular
	Set iMAR preset based on Table (below)	
	If patient diameter exceeds 50cm, set HD FOV size to diameter	
	If rescan CT, append text "RESCAN" to reconstructed series description	
OPT: IV Contrast Scan Prescription	Contrast delay	25 sec
	Acquisition time < 15 seconds	
	Adjust button clicked for CAREDose	
	Clicking Adjust button did not alter contrast delay	
IV Contrast Reconstruction	If BMI > 30, set ADMIRE/SAFIRE index=3	
	Confirm iMAR preset off	
Post-Scanning	All images screened for clipping	
	Scan reference set using "TH CT Sim" MM workflow	
	Initials/Date:	

Table 1: *iMAR Presets*

Implant	iMAR Preset
PVR	Pacemaker
Pacemaker	Pacemaker
Pacemaker leads	Pacemaker
Sternum staples, wires	Pacemaker
Anzai bellows	Pacemaker
Impaled buck shot	Dental
Spine Rods	Shoulder
Spine screws, pins	Spine
None	Off

Version 1.1



Patient Name: MRN:

Documentation Checklist

		Therapist
Pertinent Info	Time out	
	Pregnancy test	
	Treatment consent	
	IV contrast questionnaire	
	Implanted device info (pacemaker / defibrillator / neurostimulator)	
	Clinical trial or research consent	
Mosaiq	Delete duplicate	
	Diagnosis	
	Attending MD (Global)	
	CSN	
	Setup documentation in D&I (Care Plan, Rad Rx, Site Simulation)	
	RTT note of patient time preference	
	Schedule treatments	
	Schedule pre-, mid-, and post-treatment pacemaker interrogations	
	Concurrent chemo flag	
	Code capture (consult charge should be date of consult)	
	Scan and upload documents	
	Upload setup photos	
	Check for MD note	
	Short order: 4D sorting	
	Short order: Image registration	
	Short order: In vivo dosimetry (MOSFET, TLD, OSL)	
	QCL (INITIAL SIM / FT INITIAL SIM / INITIAL SIM 4D)	
	QCL MD: Note	
	QCL MD: Peer Review	
	QCL PHY: SPC - 4D Motion Analysis	
	QCL PHY: SDC - In Vivo Dosimetry	
	QCL: Nursing	
EPIC	Check in	
	Chief complaint	
	Episode of care (radiation treatment/radiation treatment)	
	Schedule verification sim (i.e., VSIM, linac sim)	
	Upload face photo	
	Charge IV contrast	
	Progress note (if contrast used)	
	Document IV removal (if needed)	
	Check out	
Post-Scan Info	Prostate prep instructions	
	MRI safety questionnaire	
	Initials/Date:	

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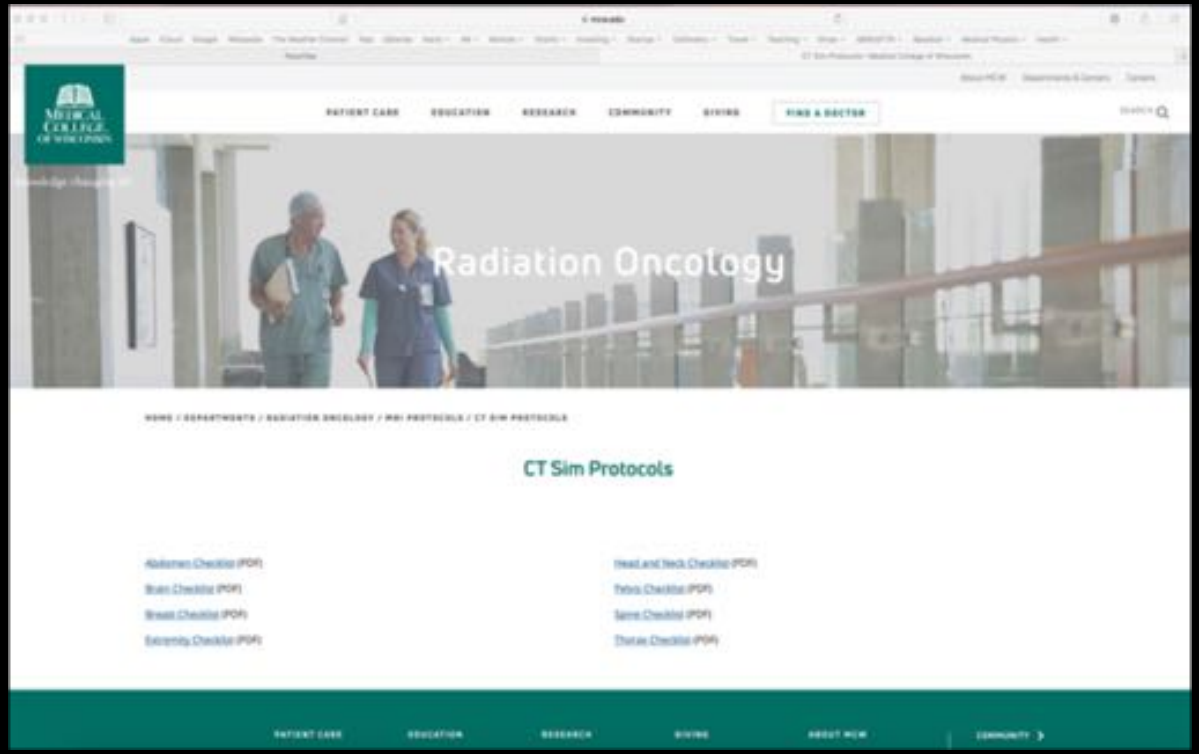
Download Checklists (ct.mcw.edu)



- Download, edit, save under R:\pdf_output\<RTNumber>

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Miscellaneous

- Auto-Transfers:
  - Planning CT:
    - Auto-Contour CT (MIMcloud atlas)
    - Important to add “RESCAN” label for rescan CTs
  - All other CTs:
    - MIM Clinic Database

- MIM:
  - New Citrix servers
  - Icons added to CT sim therapists FH PC desktops

Key Take Homes: Therapists

- Do not change CT series descriptions (except adding “RESCAN” to planning CT)
- Do not repeat or rerun series for contrast
- Use FOV check workflow
- Recons delayed (waiting for therapist input)
  - You must hit “Recon” button when ready
- Use checklists
- Provide feedback

- Follow up training:
  - How to position reduced FOV for CE-CT reconstruction
  - Re-training on 4D-CT sorting, and when to page physics (An)
  - How to evaluate 4D motion in MIM for lung SBRT with belt (An)
  - Bolus tracking using cup of water (EP, GN)

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Key Take Homes: Dosimetrists

- Planning CT:
  - Mid-position images (chest/abdomen)
  - 140 kVp images (all other sites)
- Mid-Position Workflows:
  - Non-gated: Run on 4D-CT as is
  - Gated: Extract 40%, 50%, 60% phases, then run workflow.
- If you know the material, then force the density (e.g., breast expanders, spine hardware, etc); If you do not know the material, do not force density and just use CT numbers:
  - Stop forcing fillings (continue forcing artifact) and switch to unikvext
- External contour clipping should be resolved, but may still need to force density in large FOV regions with HU rolloff
- Label study sets anatomically during import to TPS

Timeline for Deployment

- Sub-committee approval (MD): September 7, 2018
- STIRC approval: September 14, 2018
- Ops approval: September 14, 2018
- CT sim therapist, dosimetrist training: October 1, 2018
- Soft rollout: October - November, 2018

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Recommendations for Future

- Scheduling of CT sim exams in EPIC/Radiant:
  - Avoid manual entry of patient demographics
  - Increased efficiency

- VNC or Expert-I for remote assistance, remote protocol management and remote 4D sorting review