CT Sim Protocol Standardization

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October 4, 2018
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**
Intuitive Protocol Location and Simplification

- Reduce total number of protocols
- Combine elements into single protocol with optional scans
Simplified Scan Queue Labeling

- Optional scans can be cut from protocol if not needed
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
Automated Patient Instructions (API)
CAREDose: Effect of Patient Position in Bore

<table>
<thead>
<tr>
<th>Position</th>
<th>Lung (CTDvol)</th>
<th>Pelvis (CTDvol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>20.53 mGy</td>
<td>38.97 mGy</td>
</tr>
<tr>
<td>Centered</td>
<td>21.28 mGy</td>
<td>23.41 mGy</td>
</tr>
<tr>
<td>Bottom</td>
<td>21.52 mGy</td>
<td>15.04 mGy</td>
</tr>
</tbody>
</table>

• 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

Eliminates using CECT for Planning CT
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
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
iMAR (iterative Metal Artifact Reduction)

- 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

<table>
<thead>
<tr>
<th>Implant</th>
<th>iMAR Preset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neurostimulator implants</td>
<td>Pacemaker</td>
</tr>
<tr>
<td>Aneurism coils</td>
<td>Neuro coils</td>
</tr>
<tr>
<td>Teeth filling</td>
<td>Dental Fillings</td>
</tr>
<tr>
<td>Unilater shoulder prosthesis</td>
<td>Shoulder</td>
</tr>
<tr>
<td>Bilateral shoulder prosthesis</td>
<td>Hip Implants</td>
</tr>
<tr>
<td>Port</td>
<td>Pacemaker</td>
</tr>
<tr>
<td>Pacemaker</td>
<td>Pacemaker</td>
</tr>
<tr>
<td>Pacemaker leads</td>
<td>Pacemaker</td>
</tr>
<tr>
<td>Breast Clips</td>
<td>Thoracic Coil</td>
</tr>
<tr>
<td>Breast expander</td>
<td>Hip Implants</td>
</tr>
<tr>
<td>Sternum staples</td>
<td>Pacemaker</td>
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<tr>
<td>Sternum wires</td>
<td>Pacemaker</td>
</tr>
<tr>
<td>Stent</td>
<td>Extremity</td>
</tr>
<tr>
<td>Anzai bellows</td>
<td>Pacemaker</td>
</tr>
<tr>
<td>Hip Prosthesis</td>
<td>Hip Implants</td>
</tr>
<tr>
<td>Impaled buck shot</td>
<td>Dental Fillings</td>
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<tr>
<td>Penile Clamp</td>
<td>Pacemaker</td>
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<tr>
<td>Prostate Seeds</td>
<td>Extremity</td>
</tr>
<tr>
<td>Syed</td>
<td>Extremity</td>
</tr>
<tr>
<td>Spine rods</td>
<td>Shoulder</td>
</tr>
<tr>
<td>Spine screws, pins</td>
<td>Spine</td>
</tr>
<tr>
<td>Extremity pin</td>
<td>Extremity</td>
</tr>
</tbody>
</table>
Ok to use iMAR Images for Dose Calculation

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

<table>
<thead>
<tr>
<th></th>
<th>FH Planning CT</th>
<th>FH IV CT, Other</th>
<th>CMH, SJH, DTS Planning CT</th>
<th>CMH, SJH, DTS IV CT, Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain</td>
<td>Simultaneous</td>
<td>Simultaneous</td>
<td>Sequential</td>
<td>Sequential</td>
</tr>
<tr>
<td>Head and Neck</td>
<td>Sequential</td>
<td>Simultaneous</td>
<td>Sequential</td>
<td>Sequential</td>
</tr>
<tr>
<td>Chest</td>
<td>SECT (4D)</td>
<td>Simultaneous</td>
<td>SECT (4D)</td>
<td>SECT</td>
</tr>
<tr>
<td>Supine Breast</td>
<td>SECT</td>
<td>Simultaneous</td>
<td>SECT</td>
<td>Sequential</td>
</tr>
<tr>
<td>Prone Breast</td>
<td>Sequential</td>
<td>N/A</td>
<td>Sequential</td>
<td>N/A</td>
</tr>
<tr>
<td>Abdomen</td>
<td>SECT (4D)</td>
<td>Simultaneous</td>
<td>SECT (4D)</td>
<td>SECT</td>
</tr>
<tr>
<td>Pelvis</td>
<td>Sequential</td>
<td>Simultaneous</td>
<td>Sequential</td>
<td>Sequential</td>
</tr>
<tr>
<td>Spine</td>
<td>Sequential</td>
<td>N/A</td>
<td>Sequential</td>
<td>N/A</td>
</tr>
<tr>
<td>Extremity</td>
<td>Sequential</td>
<td>N/A</td>
<td>Sequential</td>
<td>N/A</td>
</tr>
</tbody>
</table>
DECT Reconstructions

• 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)

Bongers et al, PLOS One, 2015
## Contrast-Enhanced CT

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

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)
High Resolution, Reduced FOV for CE-CT

- FOV can be tailored and positioned over target during reconstruction
Reconstruction Kernels

<table>
<thead>
<tr>
<th>Single Energy</th>
<th>Dual Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>H = Head, head/neck</td>
<td>D = Dual energy (any disease site)</td>
</tr>
<tr>
<td>B = Body (below head/neck)</td>
<td>Q = Quantitative DECT (ADMIRE/SAFIRE, any site)</td>
</tr>
<tr>
<td>I,J = Iterative (ADMIRE/SAFIRE, any site)</td>
<td></td>
</tr>
</tbody>
</table>

- **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
Disease-Specific Sim Therapist Checklists
Download Checklists (ct.mcw.edu)

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