CT protocols in Radiation Therapy department

Ioannis Genitsarios
DoseWatch Sales & Clinical Support – SEE, Clinical Education Specialist CT & RT

CT protocols in Radiation Therapy department

- The role of the CT in radiotherapy department.
- Special considerations for protocols in CT simulation process.
- Designing the CT simulation protocols.
- The use of contrast.
- Standardization of CT simulation.

Radiotherapy and Computer Tomography

Computer tomography (CT) is and will remain the predominant volumetric imaging modality for Radiotherapy simulation and planning:
- Structure delineation such as GTV (Gross Tumor Volume), CTV (Clinical Treatment Volume), PTV (Planning Treatment Volume), PRV (Planning organs at risk volumes).
- Treatment related Dose Calculation.
- Design of a reproducible positioning of patient using immobilization devices.
- Creation of reference images for treatment verification, (DRR, Digitally reconstructed radiograph).
- Delineation requires that images produced are geometrically faithful to the target anatomy. Maintaining this after transfer to the TPS (Treatment planning system) is also crucial.
- Accurate CT number to electron density conversion. Both for object density and heterogeneities induced by contrast, metal, scanning parameters, positioning artifacts.
- Special designed CTs (RTCT) to accommodate immobilization devices and positioning of patient. Big CT gantry bore (80cm).
Special considerations for CT simulation

**Related to CT numbers**
- kV selection based on availability of conversion to electron density charts (TPS configuration).
- Restricted use of reconstruction algorithms (usually only standard STD).
- Usually inaccurate CT numbers at the periphery of the Display Field of View.

**Related to Image Quality**
- Motion, due to free breathing during acquisition.
- Reference or RT isocenter marking: Misplacing of patient to CT isocenter.
- Additional equipment contributing to artifacts: Flat table top, immobilization devices.
- Metal artifacts.
- Proximity of patient to detector (Myllar window) due to treatment special positioning needs.

---

Scan type, kV

**Scan type**
Helical or spiral scan type is the predominant type of scan for all types of protocols.

**Selection of kV**
- Prior to any modification it is important to check if appropriate conversion tables are available in the TPS.
- Usually one selection of kV is used at 120. Pediatric Radiotherapy departments have more selections in separate protocols based on body size.

**Recommendation**
- Create more protocols with different kV from 80-140 based on SSDE for breast, thorax, abdomen, pelvis.

---

Tube rotation time, Reconstruction algorithm

**Tube rotation time**
A tube rotation time of 0.8-1 is recommended.

**Reconstruction algorithm**
- Standard algorithms (STD) is the selection suitable for dose calculations.
SFOV (Scan Field of View) selection and Patient misplacement

Scan Field of View
An appropriate SFOV should be selected depending on the size of the anatomy. RT CT is equipped with a Large Head SFOV suitable to accommodate the shoulders in the Head & Neck protocol.

Patient Centering
- In CT simulation patient centering is depending on Reference point/isocenter placement. Noise affecting the delineation capability is in projection part of CT SIM images. CT isocenter misplacement can be measured from Lateral Scout and reduce the benefits from Automatic Exposure Control.

Recommendations
- Adjust noise index according to elevation. For a 2-4 cm shift 2 Dose steps will compensate the increased noise.

DFOV (Display Field of View)

- CT simulation requires the imaging of the skin + immobilization device related to the anatomic area under investigation. It is important for the treatment planning process and the dose calculation.
- DFOV is correlated to SFOV and the size depends on the selected SFOV. RT CT DFOV available is bigger compared to Diagnostic CT. It can reach up to 65cm to cover all patient size and positioning case scenarios.
- The area between the fully sampled region and the gantry bore can be referred to as "partially sampled" in that measurements are obtained in the region at only a limited range of rotation angles. However, the missing samples can be estimated, thereby extending the reconstruction field of view.

Recommendations
- Select the appropriate size of DFOV to safely include the skin + immobilization device and maintains spatial resolution.

Full and Plus Mode

- Full recon mode affects the slice profile, and helical artifacts. Geometric accuracy of the image in CT Simulation is crucial.
- Full mode create a beam profile 20% thinner than Plus mode, an increase in MAs by 10-15% is necessary to maintain the same noise level.
- A thinner beam profile will decrease the helical artifact but will increase the dose.

Detector configuration, Pitch, Slice thickness

Overview
Historically CT simulation protocols have very little variation and overall are limited in number. The evolution took place during the early days of CT simulation practice.

- Limitations of the TPS to handle a large amount of images, usually 100.
- Radiation therapy Universities were not preparing adequately the radiographers for today’s imaging modalities.
- Conventional simulators were relatively simple x-ray equipment mimicking Linear accelerator movements and side-tabletop distance.
- CT technology limitations.
- Very limited use of contrast media.
- Radiation therapy techniques were not requiring detailed delineation.
A simplified categorization of CT simulation protocols

Radical treatments: A geometrically accurate imaging is required with a low level of noise and balanced CT Dose to Image Quality. CTDI vol close to Diagnostic reference levels. DRR images are produced from 2.5mm slice thickness.

Palliative treatments: Usually due to poor condition of patients speed is more important in this type of CT simulations. A 5mm slice thickness is acceptable and DRR can cover the verification needs of these treatments.

Advanced Radiotherapy Techniques: Requires high quality images usually at 1.25mm free of noise and artifacts.

Protocols baseline (Radical)
A channel width setting equal to half of the image thickness is sufficient to produce artifact-free and good quality images for pitch values close to 1. (Lieu et al)
16 x 1.25, 0.982, 2.5mm, 20mm (BC)

Advanced treatments
A decrease in slice thickness and pitch could provide the detail in images that is required. When scanning time is not affecting image quality due to motion (Head SRS) choosing 10mm Beam Collimation is recommended.
16 x 1.25, 0.502, 1.25mm, 20mm (BC)

Palliative treatments
Patient condition strongly define the parameters of these protocols' category. Fastest pitch selection and a slice thickness of 5mm is generally accepted.

mA / Auto mA

Auto mA: 2-axis modulation.
SmartmA: Angular or xy modulation.

Scouts:
- Only one scout is needed. The last scout will determine the mA modulation.
- Perform scouts at the same kV as prescribed in scanning series.

Dose steps:
- Increase of dose steps by one increases the mA by 10% and reduce noise by 5%

mA range:
- Select the range according to clinical scenario.

Noise Index:
- Will change automatically when the slice thickness and pitch changes.

Dose reduction:
- Set up in protocol management only when is not selected in Recon Option.

ASIR Adaptive Statistical Iterative Reconstruction

ASIR:
- In CT simulation is used mainly to reduce noise.
- Dose reduction can also be achieved in high dose protocols.

Application:
- In protocol management set a % value in Recon Option.
- Dose reduction application set a % value in Dose reduction tab in AutomA.
- Set different values in auto mA and Recon option to achieve both dose reduction and desired noise reduction. Especially in cases where second reconstruction requires thinner slices.

Metal Artifact Reduction Smart MAR

One significant advancement of technology in CT Simulation.

- The presence of objects with high atomic number (Z) such as dental fillings, orthopedic implants, or other metal objects inside the body can cause significant artifacts in the images.
- Metal artifacts can be generally classified as scatter, beam-hardening, partial volume, photon starvation.
Metal Artifact Reduction Smart MAR

- Compromise the accuracy of contouring.
- Increase the workload in dose calculation.

Must:
- Maintain accuracy of tissue CT numbers after correction.
- Maintain the shape of the metal after correction.

Recommendation:
- Always compare the corrected and uncorrected images.
Advantage 4D / Smart Deviceless 4D

Motion Management in CT Simulation
- Applicable to Chest, Abdomen
- Motion create blurred images which is difficult to delineate accurately.
- Respiratory and Cardiac motion creates inaccuracies to target moving pattern, and target shape.
- Generates opportunities of sparing healthy tissue.

Advances in treatment delivery require accurate planning and delivery.
- 3D Conformal RT
- IGRT (Image Guided RT)
- IMRT (Intensity modulated RT)

Coronal views of CT scans of a static sphere (a) and a sinusoidally moving sphere (b) (2-cm range of motion and a 4-second period).
**Advantage 4D**

**How it works:**
- An external surrogate usually plastic box with reflective material is tracked by the Varian camera and patient breathing is recorded as waveform.
- CT is acquiring images in CINE mode (usually 10 images per table position).
- Images are combined in Advantage 4D software to create either several moving axial images or a series of static images encompassing the whole range of motion.
- Datasets are used in TPS to accurately contour on the moving images or the combined images series.

**Advantages:**
- Gated treatments at specific breathing phase can be created.

**Disadvantages:**
- Complexity, reproducibility technical difficulties.

**CINE mode:**
- Axial type scanning where acquisition time is variable depending on the patient's breathing cycle.
- Cine duration is the acquisition time usually calculated as Breathing Cycle + One tube rotation time.
- Images are reconstructed based on the number of phases we want to divide the breathing cycle.

**Recommendations:**
- Restrict the 4D acquisition only to the area of interest if it is possible.
- Perform prior to 4D acquisition a helical routine CT simulation series in order to define the area of interest or evaluate the tumor position relative to moving structures like diaphragm.

**Retrospective 4D Image Acquisition**

**Un-Gated Treatment**

- Draw target volume with precise motion information.
- Treatment has increased likelihood to include the target during dose delivery.

**Gated Treatment**

- Define Treatment Threshold.
Smart Deviceless 4D

How it works:
- Breathing cycle is measured without the need of external device. The breathing waveform is created from various metrics, including thorax circumference and internal organ motion.
- CT is acquiring images in CINE mode, usually 10 images per table position.
- Images are combined in Advantage 4D software to create either several moving axial images or a series of static images encompassing the whole range of motion.

Advantages:
- Simplicity, speed.
- Accounts for internal organ motion, reduced motion artifacts.

Limitations:
- Designed for ungated treatments only.

Contrast Media (CM) in CT simulation protocols

- CT contrast can effectively delineate vessels and often increases tumor discrimination from normal tissue because of differential tissue enhancement, creating conditions for optimal contouring.
- Tumors will either hypo- or hyper enhance with CT contrast relative to surrounding structures, allowing clearer distinction of tumor margins.
- CM can enhance also anatomy that appears blurred from free breathing CT acquisition.

Applications of Contrast Media (CM) in CT simulation protocols

- Head & Neck: This is the most crucial application of CM. Small structures in close proximity such as vessels, muscles, salivary glands, and lymph nodes can create uncertainty.
- Thoracic: Lymph node involvement mediastinum or hilar.
- Gastrointestinal track: Ideal for pancreatic cancer patients. Important to accurately contour portal vein, celiac axis, and superior mesenteric artery.

Recommendation: Use the appropriate phase for the right pathology, in collaboration with Diagnostic department; create specific protocols for the given clinical task.
Applications of Contrast Media (CM) in 4D protocols of the liver.

One of the most difficult applications of CM is during 4D scanning of the liver:

- Scan time is variable depending on patient’s breathing cycle. Commonly for 20cm scanning length is 60 sec.
- Arterial phases is difficult to be captured with such a significant delay. Limiting the scanning area to the area of interest including motion can be a solution but overall needs advanced skills and experience to perform.
- Timing is extremely important. Lesions that otherwise could be visualized can be obscured.
- Author A Sambeddar Tina recommends an easy chart for specific liver diseases, but further validation needs to be done.

<table>
<thead>
<tr>
<th>Tumor Type</th>
<th>Scan Length (cm)</th>
<th>Scan Time (sec.)</th>
<th>Delay (sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metastases</td>
<td>22</td>
<td>86</td>
<td>45</td>
</tr>
<tr>
<td>Cholangiocarcinoma</td>
<td>28</td>
<td>130</td>
<td>45</td>
</tr>
<tr>
<td>Hepatocellular Carcinoma</td>
<td>28</td>
<td>89</td>
<td>270</td>
</tr>
</tbody>
</table>

Scan Length and Dose considerations

Scan length:
- Scan length in CT simulation is defined by the clinical need. It has variability and can not be compared to the standard diagnostic applications. Usually a 5cm scan length is added to include possible radiotherapy beam positions.
- Scanning to include extra anatomy than is needed for treatment becomes in some cases mandatory, e.g. prior to treatment data are missing or after long period between diagnosis and treatment.
- Complexity increases when staging imaging has not been performed.

CT simulation dose:
- CT simulation dose is only a fraction of the treatment dose, although the latter is very focused to a small area.
- Contrast media and 4D applications today increase significantly the dose to the patient.
- IGRT and IMRT techniques require almost daily imaging verification.
- Tedious process to evaluate pretreatment imaging due to different modalities, onboard kV and MeV images.

A strategy to standardization using Dose Watch

Create a dedicated team Physician, Physicist, Radiographer. Arrange monthly meetings.

Non contrast series:
- Use the DLP to analyze outliers. If big deviation from protocol, create a new one, e.g scan length, isocenter shift.
- Record any deviation from protocol using the comment feature during scanning. Collect the data analyze create new protocol.
- Connect protocols to pathology, patient positioning, body type.

Contrast series:
- Connect pathology to phases create protocols, record deviation, e.g poor condition of veins create alternative protocol.
- Evaluate image quality with IQ voting tool, optimize for image quality.
- Measure DLP setup reference levels.

Measure DLP set up reference levels.
Measure reference organ dose from all pretreatment imaging.
Evaluate / Optimize for dose.