1. What is multi-detector CT?

2. How is CT used in Radiation Oncology?

Acknowledgement

Borrowed some slides from Dr. Dianna Cody, Dept of Imaging Physics, MDACC
**Axial Platforms:**
Step and shoot, rewind coil between slices

**Helical or Spiral CT**
- Slip-ring gantry allows continuous rotation
- Reduction of interscan delays
- Constant table motion during scanning
- Special reconstruction methods developed

**Slip-ring**
Spiral **Pitch** Definition

- **Image and beam width are same for conventional axial CT**
- **Pitch = table travel per rotation ÷ beam width**
- **Typical pitch values are 0.5 to 2.0**

**Pitch**

For Pitch < 1
- Spirals overlap
- Dose is increased (at same mAs)

For Pitch = 1
- Similar to Axial

For Pitch > 1
- Spirals are stretched
- Dose is decreased (at same mAs)

**Image Examples**

- **Pitch affects image quality:**
- GE LightSpeed RT

Pitch=0.75 Pitch=1.5

4×1.25
**Helical Interpolation**

Collect data (black dots) 
Interpolate to estimate image between collected data

Advantage: Can reconstruct slices at any position with any interval. Increased resolution in axial (z)-direction.

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**Multi-Channel CT**

- Acquisition of multiple images per scan
- Faster volume acquisition times
- Better bolus tracking and thin slices for 3D

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**Multi-Channel CT detectors**

Table direction (z-axis)

64 x 0.625 mm
### Detectors - GE LightSpeed RT

A 4-channel system: 16 @ 1.25mm, total 20mm

<table>
<thead>
<tr>
<th>Detector Configuration</th>
<th>Pitch = 0.75</th>
<th>Pitch = 1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>4×1.25</td>
<td></td>
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<tr>
<td>4×2.5</td>
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<td>4×3.75</td>
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<tr>
<td>4×5.0</td>
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</tr>
</tbody>
</table>

### MCCT Detectors

Detector Configuration Affects Image Quality: GE LS RT

- Pitch = 0.75
- Pitch = 1.5

#### Detector Configuration

- 4×1.25
- 4×2.5
**Image Examples: GE LS RT**

- **Detector configuration**
  - 4×1.25
  - 4×2.5

**Multi-Channel CT**

- Helical non-planar data
- Data from multiple channels

- Consequences of MCCT
  - Breath hold feasible
  - However, high scan speed may not be desirable in Rad Onc
    - Problem with synchrony of table motion and diaphragm motion giving rise to artifacts
    - That leads to 4D or average CT
**Control Console**

- Scan protocols
- Data management
- Image reconstruction
- Image analysis tools
- Network/PACS connectivity
- Archive media

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**CT – Covers Off**

- HV Transformer
- X-ray Tube Housing
- Detector array

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**Generator**

- **kVp**
  - Kilovolts-peak id voltage across tube
  - (relates to max energy of x-ray beam)
- **mA**
  - Current across tube
  - (relates to number x-ray photons produced)
- **Power rating 30 – 60 kW**
  - \[ \text{kW} = \frac{\text{kV} \times \text{mA}}{1000} \]
  - @ 120kVp, 60kW gen has max 500mA
  - Practical limit is less than max available
Spatial Resolution

- Display Field of View (DFOV)
- Reconstruction filter (kernel)
- X-ray tube focal spot size
- Image thickness (blurs edges of objects)
- Pitch (blurs edges of objects)
- Patient motion
- Image zoom

Effects of Recon Filters on Resolution & Noise

Contrast Resolution

- Effective mAs
  \( \text{mA} \times \text{time} / \text{pitch} \)
- Image thickness
- Patient size
- Reconstruction filter
- Viewing conditions
ACR Phantom - Low Contrast Section

120 kVp, 1600 mAs  120 kVp, 192 mAs

Partial Volume Averaging

Contrast
- Distance
- Ambient (room) lighting
  - Cannot see the stars in the daytime
- Monitor brightness
- Reflections
- Viewing angle (flat screens)
- [Age of eyeballs . ]

Viewing Conditions - Contrast
Pixel bit-depth of $2^{12} = 4096$ values

Contrast scale

$$\text{HU} = 1000 \times \frac{(\mu - \mu_{\text{water}})}{\mu_{\text{water}}}$$

- CT number for water = 0 HU
- CT number range: -1024 to +3072 HU

CT number affected by $\text{KVP}$

CT number in Pinnacle Treatment Planning System is $\text{HU}+1000$, 12-bit unsigned integer (detail in part 2)
Resolution Related with DFOV

- 25 cm DFOV
  - Pixel = ~ 0.5 mm

- 50 cm DFOV
  - Pixel = ~ 1 mm

Image Display

- The human eye resolves 256 shades of gray
- Display monitors have about $2^8$ gray levels
- Digital CT data has 4096 possible values
- WW/WL to select desired CT numbers for display with 256 shades of gray
**Typical CT Numbers (HU)**

- Air: -1000
- Lung: ~ -700
- Fat: ~ -120 to ~ -80
- Water: 0 +/- 5
- Brain: ~ 40
- Soft Tissue: 40 to ~ 100
- Bone: 200 to > 600
- Metal: > 1000

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**2. CT Application in Radiation Oncology**

Different from CT in Diagnostic Imaging

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**CT simulation control area: More complicated**
Differences

- Patient group
- Imaging purpose
- Bore size
- Couch
- Laser alignment
- Software
- QA procedure
- Clinical protocols/procedures

Patient Group (in a cancer center)

- Diagnostic CT: screen or diagnostic
  - General public suspected to have cancers
  - Previously cured cancer patients for follow up
  - Diagnosed cancer patients for metastases, staging or treatment evaluation
  Large group: ~23,000 patients seen by MDACC
- Therapy CT in Radiation Oncology
  - Diagnosed cancer patients who will receive radiation treatment
  - For treatment planning purposes
  Small group: ~6,500 evaluated, 5,000 treated, ~1:4

Imaging Purpose: Diagnostic CT

- Requires high image quality
  See lesions, diagnosis
- Requires low dose
  To reduce stochastic risk: radiation generated cancer or carcinogenesis
- Gold Standard in DI about radiation: ALARA
  As Low As Reasonably Achievable
Imaging Purpose: Therapy CT (1)

- Treatment planning and simulation
- Accuracy and reproducibility of patient positioning - Extremely important!
- Imaging position must represent treatment position

A Linac Treatment Machine

Imaging Purpose: Therapy CT (2)

- Treatment planning and simulation
  - Image entire outline of the patient - No truncation is allowed
  - Spatial accuracy extremely important
  
  Patient imaged 3 times to get rid of truncation!!

Display Field of View (DFOV)

- Image Matrix: 512 × 512 pixels
- Diagnostic: Optimized DFOV
  - Head, 16 - 25cm, 25 most common
  - Body, 25 - 50 cm, 36 most common
- Therapy: Large DFOV
  - Head, 50 cm (35cm for Stereotactic Radiosurgery only)
  - Partial shoulder scan is included
  - Body, 50 - 65 cm (Extended DFOV)
**Bore size**

DFOV is limited by SFOV, hence bore size.

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**Large Bore**

**Diagnostic CT**
- **Regular bore size GE 16-channel**
  - Bore Opening: 70 cm
  - SAD: 54 cm
  - SDD: 95 cm
  - SFOV: 50 cm

**Therapy CT**
- **Regular bore**
- **Large bore**
  - Philips:
    - Bore opening: 50 cm
    - FOV: 60 cm
  - GE 4-channel RT:
    - Bore opening: 50 cm
    - SAD: 61 cm
    - SDD: 106 cm
    - Field of View: 65 cm

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**Why need large bore CT?**

- To enclose treatment accessories in the large bore when needed

Patient immobilization foam for a thoracic stereotactic patient.
Flat Couch: Therapy CT

Couch Sag – Serious problem
for Therapy

- When couch moves into the gantry, couch sags due to patient weight

Displacement

Not a problem for Diagnostic

- Serious concern for Therapy (2 mm positioning accuracy required)
  - Depending on manufacture and specific scanners, sag may vary in 1-6 mm
  - Correction method is still under investigation

Courtesy of Karl Prado, PhD
Complicated Immobilization Accessories

Complicated Laser System

Patient Throughput

- Diagnostic CT
  - 20 minutes/patient
  - Contrast generally used
- Therapy CT
  - Generally ~1 hour/patient
  - Positioning takes most time
  - Mark treatment center
  - Make customized immobilization device
  - Tattoo the patient

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Clinical Protocol: kVp

- Therapy CT – Fixed kVp for all patients
  - Hounsfield Units (HUs) converted to electron density to calculate patient dose in MeV treatment beam using keV CT data
  - HU varies with kVp
  - Only one calibration curve is stored in TPS, usually 120kVp is chosen

Electron Density v.s. HU Calibration Curve

Why electron density is needed?

- MeV beam attenuation is related with tissue electron density
- KeV beam attenuation (HU) is related with electron density and Z atomic number
- A conversion from HU to electron density is needed for treatment dose calculation for MeV beams
Clinical Protocol: Scan time

- **Therapy CT:** Free breathing
  - Free breathing to simulate treatment condition
  - Special CT applications, especially for lung patients
    - Average CT
      - Slow scan to get averaged tumor position
    - 4D CT
      - Cine mode, multiple scans in the same position, sort images according to breathing phase
      - Used in gated treatment

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**Example of Average CT**

![Average CT Images]

Average CT

**Example of 4D CT**

![4D CT Images]

4D-CT images

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Courtesy of Timu Pan, PhD
Summary

- Diagnostic Imaging CT
  Image Quality

- Therapy CT
  Position
  Image Quality