Impact of spectral change through MLC and tissue heterogeneity on a Monte Carlo based IMRT simulation system

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The transmission dose verification system

- In order to verify patient dose for IMRT
  - EPID dose measurement
  - Monte Carlo simulation

- Two problems must be considered
  - MLC simulation (Efficiency map - weighting)
    - IMRT dose distribution in simulation
  - Patient CT image phantom (heterogeneity)
<table>
<thead>
<tr>
<th>Simulation</th>
<th>Phantom</th>
<th>Real Patient Dose Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLC</td>
<td>Phantom</td>
<td>• Compare patient dose with simulation result</td>
</tr>
<tr>
<td>• Design MLC</td>
<td>• Create CT Ramp</td>
<td></td>
</tr>
<tr>
<td>• Energy Spectrum</td>
<td>• Proper subset number</td>
<td></td>
</tr>
<tr>
<td>• Beam hardening effect</td>
<td>• The subset range</td>
<td></td>
</tr>
</tbody>
</table>
The MLC simulation

- Simulate IMRT dose delivery
  - The total dose distribution weighting
  - Simulation the MLC

X-Y scatter plot

/home/beamnrc/egsnrc/BEAM_test2/MLC3.egsphsp1

IQ = 2: NO LATCH CHECK
MLC Simulation

- Rounded end, single focus design
- Tungsten alloy
  - 90% W, 6% Ni, 2.5%Cu, 1.5%Fe
  - density 16.0 g/cm³
- Field
  - Open, MLC-blocked, 1 cm, 3 cm, 5 cm, 10 cm
  - Let photon jaw at 10×10 cm² position
6MV photon beam quality

Energy Spectrum

Percent Depth Dose

PDF (1/MeV)

Energy (MeV)

PDD (%)

Depth (cm)

BlockField

OpenField

6MV photon beam quality

Energy Spectrum

Percent Depth Dose

Open

Block
LATCH tracking particle's history

LATCH 8

LATCH 9

Particles

Scoring plane

Primary Particle Track

Scatter Particle Track
Larger field dose deviation

Depth Dose for Field Size 10 cm

Depth Dose for Field Size 5.0 cm

Total dose, Primary beam, MLC scatter beam
Depth Dose for Field Size 3.0 cm

- Total Dose
- MLC scatter beam
- Primary beam

Depth Dose for Field Size 1.0 cm

- Total Dose
- MLC scatter beam
- Primary beam

Depth Dose for Field Size 0.5 cm

- Total Dose
- MLC scatter beam
- Primary beam

Small field size

Total dose

Primary beam

MLC scatter beam
### Dose fractions for various field sizes

<table>
<thead>
<tr>
<th>Field size (cm)</th>
<th>0.5</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary beam</td>
<td>80.96%</td>
<td>96.53%</td>
<td>99.62%</td>
<td>99.65%</td>
<td>100.00%</td>
</tr>
<tr>
<td>MLC scatter beam</td>
<td>19.01%</td>
<td>3.58%</td>
<td>0.54%</td>
<td>0.35%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

\( D_{\text{max}} \), and normalized to total dose
Dose difference for each field

Dose Difference (for $D_{\text{max}}$)

Normalized to $D_{\text{max}}$
CT images based Phantom
Clinical dose distribution can be significantly influenced by tissue heterogeneities.

CT image used in Radiotherapy:

- CT scans provide the anatomical information.
- CT number includes quantitative information about the radiological properties of the different tissues.
The patient CT image phantom

- Why?
- Construct the CT Ramp
  - BEAMnrc Default curve
- How to construct the phantom?
  - Classify the tissue materials
  - The subset CT number range
CT scanner effective energy

Energy dependence

Electron density relative to water

CT number

- 80kVp
- 100kVp
- 120kVp
- 140kVp
Classify the tissue materials

- Take different material dose simulation
  - Normal density
  - Lung, Adipose, Water, Brain, Heart, Cartilage, Cortical Bone, Air, Tissue
  - Effective depth correction
  - Inverse Square Law correction
<table>
<thead>
<tr>
<th>Tissue</th>
<th>H</th>
<th>C</th>
<th>N</th>
<th>O</th>
<th>Na</th>
<th>S</th>
<th>Cl</th>
<th>P</th>
<th>K</th>
<th>Fe</th>
<th>Ca</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung</td>
<td>10.3%</td>
<td>11.0%</td>
<td>3.1%</td>
<td>74.9%</td>
<td>0.2%</td>
<td>0.3%</td>
<td>0.3%</td>
<td>0.2%</td>
<td>0.2%</td>
<td></td>
<td></td>
<td>0.28</td>
</tr>
<tr>
<td>Adipose</td>
<td>11.4%</td>
<td>60.0%</td>
<td>0.7%</td>
<td>27.8%</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.95</td>
</tr>
<tr>
<td>Water</td>
<td>11.2%</td>
<td>88.8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Brain</td>
<td>10.7%</td>
<td>15.0%</td>
<td>2.2%</td>
<td>71.2%</td>
<td>0.2%</td>
<td>0.2%</td>
<td>0.3%</td>
<td>0.4%</td>
<td>0.3%</td>
<td></td>
<td></td>
<td>1.04</td>
</tr>
<tr>
<td>Heart</td>
<td>10.3%</td>
<td>12.0%</td>
<td>3.2%</td>
<td>73.4%</td>
<td>0.1%</td>
<td>0.2%</td>
<td>0.3%</td>
<td>0.1%</td>
<td>0.2%</td>
<td>0.1%</td>
<td></td>
<td>1.06</td>
</tr>
<tr>
<td>Cartilage</td>
<td>9.6%</td>
<td>10.0%</td>
<td>2.2%</td>
<td>74.4%</td>
<td>0.5%</td>
<td>0.9%</td>
<td>0.3%</td>
<td>2.2%</td>
<td></td>
<td></td>
<td></td>
<td>1.1</td>
</tr>
<tr>
<td>Cortical Bone</td>
<td>3.4%</td>
<td>16.0%</td>
<td>4.2%</td>
<td>43.5%</td>
<td>0.1%</td>
<td>0.3%</td>
<td></td>
<td>10.3%</td>
<td></td>
<td></td>
<td></td>
<td>22.5%</td>
</tr>
</tbody>
</table>

Tissue dose heterogeneity

- Air
- Lung
- Adipose
- Brain
- Heart
- Tissue
- Cartilage
- Cortical Bone

Dose (cGy/#) vs. Depth (cm)
Classify the tissue materials

- Divided into four groups
  - Air
  - Lung
  - Tissue
  - Cortical Bone

- Then, find each group range
  - Air ~ Lung
  - Lung ~ Tissue
  - Tissue ~ Cortical Bone
The subset CT number range

Patient CT image Histogram

Air ~ Lung
Lung ~ Tissue
Tissue ~ Bone
The subset CT number range

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Lower CT# Limit</th>
<th>Upper CT# Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>0</td>
<td>33</td>
</tr>
<tr>
<td>Lung</td>
<td>34</td>
<td>819</td>
</tr>
<tr>
<td>Tissue</td>
<td>820</td>
<td>*1065</td>
</tr>
<tr>
<td>Bone</td>
<td>1066</td>
<td>1155</td>
</tr>
<tr>
<td></td>
<td>1156</td>
<td>2500</td>
</tr>
</tbody>
</table>

*R. P. PARKER PHYS. MED. BIOL. 1979*
Scanner specific CT Ramp

- Implement the **tissue heterogeneity** into:
  - treatment planning system (TPS)
  - Monte Carlo simulation system

- Convert the CT number into tissue radiation characteristics:
  - ex: linear attenuation coefficient, electron density
Get the scanner specific CT Ramp

- The corresponding range of CT numbers for each subset was found from a calibration curve
  - Obtained by scanning a RMI CT density phantom in a GE Bright Speed CT scanner
- Analyzing the ROI pixel value
GE Bright Speed CT Scanner
CT phantom image
CT Ramp

CT Ramp Fitting

\[ y = 6.67765 \times 10^{-4}x + 3.33682 \times 10^{-1} \]

\[ R^2 = 0.994737 \]

\[ y = 1.01886 \times 10^{-3}x - 3.70996 \times 10^{-2} \]

\[ R^2 = 0.994177 \]
Monte Carlo CT Ramp Curve

Density (g/cm^3) vs. CT number (HU)
CT phantom summarize

- Constructed CT image based Phantom
  - Analyzing the CT calibration image
  - Divide several subsets
  - Find the CT number range for each subset
  - Construct image based patient phantom
  - Compare with patient dose and simulation result
Real Patient Dose Verification

EPID transmission dose measurement
Monte Carlo simulation
Phantom

- Scan IMRT Phantom
  - 120 kVp, heterogeneity phantom
  - CT image based phantom
  - Head phantom
  - Pelvis phantom

- Scan CT phantom
  - 120 kVp, create CT Ramp
  - Property CT Ramp curve
Phantom study- H&N Ca.
Phantom study - Cx Ca. G4
Phantom study - Cx Ca. G4

Coronal View

Transverse View
Clinical Study

60 million histories
Reference

- 林慕涵, 強度調控放射治療線上病患治療劑量驗證系統, 國立清華大學碩士論文, 2005
- Weidong Li et al., ”Using fluence separation to account for energy spectra dependence in computing dosimetric a-Si EPID images for IMRT fields”, Med. Phys. 33 (12), Dec. 2006
Thanks for your attention~~~