Comparison of Monte Carlo and Pencil Beam Calculations for SBRT Lung Using Q.A. Test with Various Phantoms

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Special Thanks!!

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Disclaimer

No Conflicts
Outline

• Objectives
• Motivation
• Current IMRT QA method
• Heterogeneous phantom design
• Radiotherapy plan
• QA plans
• Plan Delivery
• 2-D diode array used for measurements
• $\gamma$-analysis software
• Results
• Future Work
Objective

• To introduce a heterogeneous phantom for pre-treatment quality assurance (QA) for SBRT

• To compare 2-D diode array measurements with calculated dose distributions for:
  – Monte Carlo (MC)
  – Pencil Beam (PB)

• To compare fixed gantry angle delivery vs. planned gantry angle delivery
  – Combined fields
  – Individual fields
Task Group 65 specifically disallows the use of pencil-beam algorithms for the situation of a target surrounded by low-density tissue as this class of algorithms does not account for lateral scattering in the small field sizes used in SBRT.
Motivation

• The patients’ tissue is heterogeneous not homogeneous

• TG-244 (Commissioning and QA of External Beam Treatment Planning System Dose Calculations)
Current situation

1. Plan done on heterogeneous material (Lung case)
2. QA planning done on **homogeneous** phantom (solid water or equivalent)
3. QA testing done on **heterogeneous** phantom (Solid Water and MapCHECK 2).
   - Granted the MapCHECK 2 has 2 cm water equivalence but, it is not Solid Water!
4. Comparison is done between 2) and 3)

*Question: Are we comparing the same thing?*
IMRT QA Illustration

Plane of dose distribution calculation

Homogeneous material

Diode Array

Actual Measurement Situation

Calculation Environment

Plane of dose distribution measurement

Homogeneous material

All beams set to the same angle

Zhuang et al.

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Design of Heterogeneous Phantom

- Rib equivalent
- Soft tissue equivalent
- Lung equivalent

Diagram showing the design of the heterogeneous phantom with different regions labeled as Superior, Inferior, Anterior, and Posterior.
Heterogeneous Phantom

- **Dimensions**
  - 30X30X9.8 cm$^3$

- **Components**
  - High density foam
    - Lung tissue
      - $[\rho_e \sim (0.2-0.5)\rho_W]$
  - Delrin®
    - Rib tissue
      - $(\rho_e \sim 1.2\rho_W)$
  - Polystyrene
    - Soft tissue
      - $(\rho_e \sim 1.0\rho_W)$
  - Bolus material
    - Lesion tissue
      - $(\sim 10 \text{ cm}^3)$
  - Solid Water™
    - Soft tissue
      - $(\rho_e \sim 1.0\rho_W)$
Radiotherapy (RT) Plan

- **Total dose**
  - 50 Gy in 5 fractions
- **$D_{PTV}= 97\% \text{ of Rx}$**
- **6 beams**
  - 6 MV photons
    - 600 MU/min
- **Beam angles**
  - $253^\circ$
  - $214^\circ$
  - $188^\circ$
  - $166^\circ$
  - $142^\circ$
  - $117^\circ$
- **MC and PB calculations**
QA Plans

- Heterogeneous phantom
  - Combined beams
    • Anterior to posterior
    • Planned gantry angles
  - Individual beams
    • Anterior to posterior
    • Planned gantry angles

- Homogeneous phantom
  - Combined beams
    • Anterior to posterior
    • Planned gantry angles
  - Individual beams
    • Anterior to posterior
    • Planned gantry angles

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Delivery

• Varian Novalis Tx linear accelerator
  – Measured with MapCHECK 2™

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2-D Diode Array (MapCHECK 2™)

- Sun Nuclear Corporation
- 1527 n-type diode detectors
- Active detector area
  - 0.64 mm²
- Maximum Field
  - 32.0 x 26.0 cm²
  - 7.07 mm spacing
- Photons
  - Co-60 (1.25 MeV) to 25 MeV
- Electrons
  - 6 MeV to 25 MeV
- Build up
  - 2.0 ± 0.1 g/cm²
\( \gamma \)-analysis

- SNC Patient\textsuperscript{TM} software
Beams Analyzed

• Heterogeneous/Homogeneous phantom
  – Combined beams
    • MC at anterior to posterior gantry angle (180°)
    • PB at anterior to posterior gantry angle (180°)
    • MC at planned gantry angles
    • PB at planned gantry angles
  – Individual beams (1-6)
    • MC at anterior to posterior gantry angle (180°)
    • PB at anterior to posterior gantry angle (180°)
    • MC at planned gantry angles
    • PB at planned gantry angles
  – Central axis dose differences
### Gamma (3%/3mm) for Heterogeneous Phantom with Monte Carlo and Pencil Beam for planned and fixed gantry angle

<table>
<thead>
<tr>
<th>Beam Number</th>
<th>MC 180°</th>
<th>PB 180°</th>
<th>MC planned</th>
<th>PB planned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam 1</td>
<td>95</td>
<td>93</td>
<td>91</td>
<td>90</td>
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<tr>
<td>Beam 2</td>
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<td>Beam 3</td>
<td>93</td>
<td>91</td>
<td>90</td>
<td>89</td>
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<tr>
<td>Beam 4</td>
<td>92</td>
<td>90</td>
<td>89</td>
<td>88</td>
</tr>
<tr>
<td>Beam 5</td>
<td>91</td>
<td>89</td>
<td>88</td>
<td>87</td>
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<tr>
<td>Beam 6</td>
<td>90</td>
<td>88</td>
<td>87</td>
<td>86</td>
</tr>
</tbody>
</table>

Planned angles:
- Beam 1-235°
- Beam 2-214°
- Beam 3-188°
- Beam 4-166°
- Beam 5-142°
- Beam 6-117°

### Gamma (2%/2mm) for Heterogeneous Phantom with Monte Carlo and Pencil Beam for planned and fixed gantry angle

<table>
<thead>
<tr>
<th>Beam Number</th>
<th>MC 180°</th>
<th>PB 180°</th>
<th>MC planned</th>
<th>PB planned</th>
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</thead>
<tbody>
<tr>
<td>Beam 1</td>
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<td>93</td>
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<tr>
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<td>Beam 5</td>
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<tr>
<td>Beam 6</td>
<td>93</td>
<td>91</td>
<td>89</td>
<td>88</td>
</tr>
</tbody>
</table>

Planned angles:
- Beam 1-235°
- Beam 2-214°
- Beam 3-188°
- Beam 4-166°
- Beam 5-142°
- Beam 6-117°

### Central Axis Dose Difference for Heterogeneous Phantom with Monte Carlo and Pencil Beam for planned and fixed gantry angle

<table>
<thead>
<tr>
<th>Combined Beams</th>
<th>MC 180°</th>
<th>PB 180°</th>
<th>MC planned</th>
<th>PB planned</th>
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</thead>
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</tr>
</tbody>
</table>
Individual vs. Combined Fields

Beam 1 at 235°

Beam 2 at 214°

Beam 3 at 188°

Beam 2 at 166°

Beam 2 at 142°

Beam 2 at 117°

Combined Beams 1-6

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Gamma (3%/3mm) for Solid Water Phantom with Monte Carlo
and Pencil Beam for planned and fixed gantry angle

Gamma (2%/2mm) for Solid Water Phantom with Monte Carlo
and Pencil Beam for planned and fixed gantry angle

Gamma (1%/1mm) for Solid Water Phantom with Monte Carlo
and Pencil Beam for planned and fixed gantry angle

Central Axis Dose Difference for Solid Water Phantom
with Monte Carlo and Pencil Beam for planned and fixed gantry angle
Summary of the results

• Heterogeneous phantom
  – MC is typically showing better agreement to measured values compared to PB
    • MC using the planned gantry angles is showing better agreements for individual and combined beams
  – Central axis dose differences are showing more calculated dose

• Homogeneous phantom
  – MC and PB show similar agreement to measured values for most beams
    • PB delivered at 180 is showing better agreements for individual beams
    • MC at 180 is showing better agreements for combined beams
  – Central axis dose differences are showing more measured dose
Future Work

Incorporate the diode array into the calculation environment
Future Work

- Affix the phantom and diode array to the gantry for rotational dosimetry
Future Work

Film measurements

Ionization chamber measurements
Acknowledgements

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References


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Thank You!