MODELING OF MD ANDERSON SCANNING PROTON BEAM FOR QUALITY ASSURANCE IN INTENSITY MODULATED PROTON THERAPY AND MRI-GUIDED PROTON THERAPY SIMULATIONS

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To create a realistic Monte Carlo (MC) beam model of the MD Anderson Cancer Center (MDACC) clinical scanning proton beam for the use in:

- patient specific quality assurance (QA)
- simulation of experimentally challenging setups
- future simulation studies for Magnetic Resonance Imaging (MRI) guided proton therapy

PURPOSE

Using the TOol for PArticle Simulation (TOPAS)[1] a MC model was created of the clinical scanning proton beam of the MDACC[2], using measurement data of:

- integrated depth dose curves (IDDs)
- lateral profiles
- multi-energetic fields

The model is tested by simulation of a clinical prostate plan of 2 lateral fields. To quantify the errors, a 3% - 3 mm and a 2% - 2 mm gamma analysis[3] are performed.

The impact of the magnetic field on the proton beamlets is evaluated inside a 1.5 T magnetic field.

METHODS

- The range error of all the IDDs is < 0.5 mm. For the fit of the lateral profiles, a double sigma model is used (figure 1).
- For the MC clinical prostate plan, the pass rate of the 2% - 2 mm gamma analysis is ≥ 98.3% and for the 3% - 3 mm ≥ 99.9% (figure 2 and table 1).
- The magnetic field does not lead to a changed shape of the beam. The shift of the lateral profile leads to a significant range reduction (figure 3).

RESULTS

- The TOPAS MC model is in good agreement with the measurement data.
- The clinical plan simulation reaches very high gamma analysis pass rates.
- This model can be used as a second-check for patient QA dose calculations and further studies of MRI-guided proton therapy[4].
- The effect of a magnetic field results in an expected lateral shift and reduced range and an unchanged lateral beam shape.

CONCLUSION

- The TOPAS MC model is in good agreement with the measurement data.
- The clinical plan simulation reaches very high gamma analysis pass rates.
- This model can be used as a second-check for patient QA dose calculations and further studies of MRI-guided proton therapy[4].
- The effect of a magnetic field results in an expected lateral shift and reduced range and an unchanged lateral beam shape.


Figure 1. IDD (a) and lateral profile (b) for E = 73.4 MeV. The range error on the IDD is 0.18 mm. The lateral profile shows both the single source (SS) and double source (DS) model. The DS model fits the measurement data nicely, while the SS model has an underdosage at the tails. Number of histories: (a) 1 000 000 (b) 5 000 000.

Table 1. Gamma pass rates for the clinical prostate plan (measurement vs MC) at all depths and for both fields, with gantry angle 90° (A) and 270° (B). For the 2% - 2 mm gamma analysis, the pass rates are ≥ 98.3%, for the 3% - 3 mm analysis ≥ 99.9%. Number of histories: 25 000.

<table>
<thead>
<tr>
<th>Field</th>
<th>Depth (cm)</th>
<th>MC gamma pass rate (%)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>2% - 2 mm</td>
</tr>
<tr>
<td>A (90°)</td>
<td>1.4</td>
<td>99.4</td>
</tr>
<tr>
<td></td>
<td>9.4</td>
<td>99.3</td>
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<td>99.5</td>
</tr>
<tr>
<td></td>
<td>21.4</td>
<td>98.3</td>
</tr>
<tr>
<td></td>
<td>24.4</td>
<td>99.9</td>
</tr>
<tr>
<td>B (270°)</td>
<td>1.4</td>
<td>99.3</td>
</tr>
<tr>
<td></td>
<td>9.4</td>
<td>99.6</td>
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<tr>
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<tr>
<td></td>
<td>24.4</td>
<td>99.9</td>
</tr>
</tbody>
</table>

Figure 2. Dose profiles of field A of a clinical prostate plan at 1.4 cm (a-c, first row) and 24.4 cm depth (d-f, second row). The measured (first column) and MC profiles (second column) are shown and the result of the 2% - 2 mm gamma analysis (third column). The pass rate is 99.4% for the 1.4 cm profile (c) and 99.9% for the 24.4 cm profile (f). Number of histories: 25 000. Number of proton spots: 2091. Calculation time: ~ 35 seconds per spot.

Figure 3. Effect of 1.5 T magnetic field for E = 221.8 MeV on the lateral profile (a) with a shift of 4.8 mm and the range (b), with a range reduction of 9 mm. After shifting the lateral profile back to the measured profile, it is clear that there is no change of beam shape. The range reduction is due to the beam curvature and the resulting reduced path length along the proton beam axis.