Conclusion: This study has shown that accounting for the effects of the magnetic field during treatment planning allows for design of clinically acceptable lung SBRT treatments with a MR-linac. Furthermore, it was found that the ability of real-time tumor tracking to decrease dose exposure to healthy tissue was not degraded by a magnetic field.

OC-0550 Investigation of magnetic field effects for the treatment planning of lung cancer

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Purpose or Objective: Combining the capabilities of high resolution soft tissue MR imaging and intensity modulated radiation therapy into a hybrid device has the potential to increase the accuracy of radiotherapy. However, it is known that the magnetic field of the MR manipulates the trajectory of the secondary electrons and leads to a deviation of dose especially at the interfaces between high and low density materials. This study aims to introduce a routine for the evaluation of magnetic field effects to dose delivery and plan optimization.

Material and Methods: An EGSnrc Monte Carlo environment, based on the egs++ class library, was developed which can be used for the simulation of IMRT plans in the presence of a 1.5 T magnetic field. The effect of a magnetic field on the dose distribution was investigated for simulations in a porcine lung phantom. Based on Monte Carlo simulations of patient specific beamlets, plan optimization was performed and analyzed.

Results: Comparison showed that the Monte Carlo simulations of IMRT plans at 0 T are in good agreement with RayStation dose calculations. The effect of a 1.5 T lateral magnetic field on the dose distribution showed distinct alteration in tumor dose. Differences appear to be less when an opposing field technique is used. It could further be proven that the routine is capable of performing plan optimization based on Monte Carlo simulated beamlets in the presence of a magnetic field (see figure 1).

Conclusion: A routine for dose calculation of IMRT plans with EGSnrc and for plan optimization based on Monte Carlo simulations was developed. This implementation provides the possibility to analyze the effects of a magnetic field during radiotherapy in detail. Additionally it enables the investigation of optimization strategies for an MRI-LINAC system.

Acknowledgments: We thank Dr. Iwan Kawrakow for providing the egs++ magnetic field macro for the EGSnrc code system.

OC-0551 Advantage of IMPT over IMRT in treatment of gynaecological cancer with para-aortic nodal involvement

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Purpose or Objective: High costs and limited capacity in proton therapy requires prioritizing according to expected benefit. The aim of this work is to quantify the clinical advantage of robust intensity-modulated proton therapy (IMPT) in terms of sparing of organs at risk (OARs) for three target volumes in treatment of gynaecological cancers compared with state-of-the-art intensity-modulated photon therapy (IMRT), and to evaluate for which target volume the benefit would justify the use of IMPT.

Material and Methods: An EGSnrc Monte Carlo environment, based on the egs++ class library, was developed which can be used for the simulation of IMRT treatment plans in the presence of a magnetic field, based on patient CT data. A routine for the processing of treatment planning parameters and Monte Carlo simulation data was implemented into the in-house open source treatment planning system matRad. In order to basically validate the implementation, dose distributions at 0 T were compared against collapsed cone calculations by the treatment planning system RayStation. The effect of a magnetic field to the dose distribution was investigated for simulations in a porcine lung phantom. Based on Monte Carlo simulations of patient specific beamlets, plan optimization was performed and analyzed.

Results: Comparison showed that the Monte Carlo simulations of IMRT plans at 0 T are in good agreement with RayStation dose calculations. The effect of a 1.5 T lateral magnetic field on the dose distribution showed distinct alteration in tumor dose. Differences appear to be less when an opposing field technique is used. It could further be proven that the routine is capable of performing plan optimization based on Monte Carlo simulated beamlets in the presence of a magnetic field (see figure 1).

Conclusion: A routine for dose calculation of IMRT plans with EGSnrc and for plan optimization based on Monte Carlo simulations was developed. This implementation provides the possibility to analyze the effects of a magnetic field during radiotherapy in detail. Additionally it enables the investigation of optimization strategies for an MRI-LINAC system.

Acknowledgments: We thank Dr. Iwan Kawrakow for providing the egs++ magnetic field macro for the EGSnrc code system.
boost dose), para-aortic region alone (para-aortic recurrence, N=5, all with boost dose). Robust IMPT (minimax method) and 20-beam IMRT plans were generated with an in-house developed system for automated treatment planning. Prescription dose was 48.6 Gy with or without a simultaneous integrated boost to 58.05 Gy. IMPT and IMRT plans were made for wide (15 mm primary CTV/7 mm nodal CTV) and small (5/2 mm) CTV-PTV margins. IMPT plans included range robustness of 3% and setup robustness of 2 mm assuming online setup correction and adaptive radiotherapy. Relevant dose-volume parameters of OARs were used to compare both techniques.

Results: IMPT reduced the dose in all OARs for similar target coverage (>99%). The benefit of IMPT was higher in the lower dose region than in the higher dose region. Figure 1 compares OAR dose-volume parameters per patient. For treatment of the pelvic region, the dose in pelvic bones was on average 27% lower with IMPT, and in femoral heads 5% lower. For treatment of pelvic and para-aortic region, kidney and spinal cord dose was lower for IMPT (left kidney 1.1 Gy vs 7.8 Gy; right kidney 2.4 Gy vs 11.8 Gy; spinal cord 14.5 Gy vs 28.0 Gy). For the para-aortic region alone an important advantage in favour of IMPT was seen (left kidney 4.4 Gy vs 38.6 Gy; right kidney 0.5 Gy vs 5.8 Gy; spinal cord 29.2 Gy vs 39.7 Gy), see Table 1. For all target volumes clinically relevant reductions in V15Gy for the bowelbag were found, reducing V15Gy by 153 cc, 1231 cc, and 523 cc, respectively. Differences in dose to most OARs were similar for wide and small margins, while the advantage of IMPT was more pronounced for rectum, bladder, and sigmoid using small margins.

Conclusion: For all gynaecological target volumes, IMPT reduced the dose to all OARs compared with IMRT, mainly in the lower dose region and for both wide and small margins. Considerable reduction of the bowel volume receiving 15 Gy or more was seen. The greatest and clinically relevant advantage of IMPT was found for treatment of macroscopic disease in the para-aortic region, justifying the use of proton therapy for this indication.

### OC-0552

**Skin-NTCP driven optimization for breast proton treatment plans**


**Purpose or Objective:** Proton beam therapy represents a promising modality for left breast irradiation due to negligible dose to non-target volume, as heart and lung. However skin toxicity and poor cosmesis inherent to protons physical properties are of major concern. Radiation-induced skin toxicity (RIST) is a side effect impacting on the quality of life in breast cancer patients treated with radiation therapy. Purpose of the present study is twofold: a) to develop a normal tissue complication probability (NTCP) model of severe acute RIST in BC patients treated with conventional three-dimensional conformal radiotherapy (3DCRT) and b) to use the implemented skin NTCP model to guide breast proton therapy plan optimization.

**Material and Methods:** We evaluated 140 consecutive BC patients undergoing 3DCRT after breast conserving surgery in a prospective study assessing acute RIST. Acute RIST was classified according to the RTOG scoring system. Dose-surface histograms (DSHs) of the body-structure in the breast region were extracted. DSHs of the body were considered as representative of the irradiation in epidermis and dermis layers and extracted by an in-house developed library using the relative complement in the body of its 3D erosion defined by a spherical structuring element of radius r = 3 mm (assumed as mean skin thickness). On such shell, the absolute dose-volume histogram was regularly computed and then divided by r to obtain the DSH. NTCP modeling by Lyman-Kutcher-Burman (LKB) recast for DSHs and using bootstrap resampling techniques was performed. Five randomly selected left BC patients were then replanned using proton pencil beam scanning (PBS). PBS plans were obtained to ensure appropriate target coverage (90% 50 Gy(RBE) prescription dose to the 90% breast) and heart-lung sparing. Different planning objectives for skin were used (Table 1) and two different beam set-ups were tested. The proton plan body DSHs were extracted and the corresponding NTCP values calculated.

<table>
<thead>
<tr>
<th>OAR</th>
<th>Parameter (mm)</th>
<th>IMRT</th>
<th>IMPT</th>
<th>IMRT</th>
<th>IMPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kidney left</td>
<td>V10 Gy</td>
<td>11.3</td>
<td>13.1</td>
<td>8.3</td>
<td>11.1</td>
</tr>
<tr>
<td>Kidney right</td>
<td>V10 Gy</td>
<td>10.1</td>
<td>11.3</td>
<td>0.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Spinal cord</td>
<td>Emax (Gy)</td>
<td>16.5</td>
<td>18.5</td>
<td>22.3</td>
<td>23.9</td>
</tr>
</tbody>
</table>

**Purpose or Objective:** Proton beam therapy represents a promising modality for left breast irradiation due to negligible dose to non-target volume, as heart and lung. However skin toxicity and poor cosmesis inherent to protons physical properties are of major concern. Radiation-induced skin toxicity (RIST) is a side effect impacting on the quality of life in breast cancer patients treated with radiation therapy. Purpose of the present study is twofold: a) to develop a normal tissue complication probability (NTCP) model of severe acute RIST in BC patients treated with conventional three-dimensional conformal radiotherapy (3DCRT) and b) to use the implemented skin NTCP model to guide breast proton therapy plan optimization.