Table I. Estimated Relative Risks, model parameters and input distributions

<table>
<thead>
<tr>
<th></th>
<th>Bladder</th>
<th>Rectum</th>
<th>CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR (VMAT/C-ion)</td>
<td>1.31 [0.65, 2.18]</td>
<td>0.58 [0.41, 0.89]</td>
<td>95%</td>
</tr>
<tr>
<td>RR (VMAT/IMPT)</td>
<td>1.73 [1.07, 2.85]</td>
<td>1.11 [0.79, 1.53]</td>
<td>95%</td>
</tr>
<tr>
<td>α (Gy²)</td>
<td>0.25 [0.075, 0.25 [0.075] Gaussian</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B (Gy²)</td>
<td>0.083 [0.005]</td>
<td>0.046 [0.007] Gaussian</td>
<td></td>
</tr>
<tr>
<td>RBCmax (C-ion)</td>
<td>1.25 [1.2, 1.3]</td>
<td>1.25 [1.2, 1.3] triangle</td>
<td></td>
</tr>
<tr>
<td>RBCmax (ion)</td>
<td>6 [5.7]</td>
<td>6 [5.7] triangle</td>
<td></td>
</tr>
<tr>
<td>RBCmax (proton)</td>
<td>1.03 [1.01, 1.05]</td>
<td>1.03 [1.01, 1.05] triangle</td>
<td></td>
</tr>
<tr>
<td>RBCmax (proton)</td>
<td>1.25 [1.2, 1.3]</td>
<td>1.25 [1.2, 1.3] triangle</td>
<td></td>
</tr>
</tbody>
</table>

Conclusion: Based on the modest variations in RR across the large spread in parameter values, the treatment modalities are not expected to have very different SC risk profiles with respect to these organs. The α value had the strongest influence on the RR and may change the RR in favour of one technique instead of another (particle vs photons).

OC-0554
Robustness recipe for minimax robust optimisation in IMPT for oropharyngeal cancer patients
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Purpose or Objective: Treatment plans for intensity-modulated proton therapy (IMPT) can be robustly optimized by performing ‘minimax’ worst-case optimization, in which a limited number of error scenarios is included in this optimization. However, it is currently unknown which error scenarios should be included for given population-based distributions of setup errors and range errors. The aim of this study is to derive a ‘robustness recipe’ describing the setup robustness (SR; in mm) and range robustness (RR; in %) settings (i.e. the absolute error values of the included scenarios) that should be applied in minimax robust IMPT optimization to ensure adequate CTV coverage in oropharyngeal cancer patients, for given Gaussian distributions of systematic and random setup errors and range errors (characterized by standard deviations Σ, α and p, respectively).

Material and Methods: In this study contoured CT scans of 6 unilateral and 6 bilateral oropharyngeal cancer patients were used. Robustness recipes were obtained by: 1) generating treatment plans with varying robustness settings SR and RR, 2) performing comprehensive robustness analyses for these plans using different combinations of systematic and random setup errors and range errors (i.e. different values of Σ, α and p), and 3) determining the maximum errors for which certain SR and RR settings still resulted in adequate CTV coverage. IMPT plans were considered adequately robust if at least 98% CTV coverage (V95% ≥ 98%) was achieved in 98% of the simulated fractionated treatments for a given SR and RR settings. Robustness analyses were performed using Polynomial Chaos methods, which allow for fast and accurate simulation of the expected dose in fractionated IMPT treatments for given error distributions. Separate recipes were derived for the unilateral and bilateral cases using one patient from each group. The robustness recipes were validated using all 12 patients, in which 2 plans were generated for each patient corresponding to Σ = α = 1.5 mm and p = 0% and 2%.

Results: The robustness recipes are depicted in Figure 1. We found that 1) systematic setup errors require larger SR than random setup errors, 2) bilateral cases are intrinsically more robust than unilateral cases, 3) the required RR only depends on p, and 4) the required SR can be fitted by second order polynomials in Σ and α. The formulas for the robustness recipes are: SR = -0.1527 + 0.2700i + 1.852 - 0.06α + 1.22 and RR = 0.07i + 0.190i + 1.34 - 0.07α + 1.17 and RR = 3% for p = 1% and 2% for unilateral cases, and SR = -0.07i + 0.190i + 1.34 - 0.07α + 1.17 and RR = 3% and 4% for p = 1% and 2%, respectively, for bilateral cases. The recipe validation resulted in 22 plans being adequately robust, while for the remaining two plans CTV coverage was adequate in 97.8% and 97.9% of the simulated fractionated treatments.

Conclusion: Robustness recipes were derived that can be used in minimax robust optimization of IMPT treatment plans to ensure adequate CTV coverage for oropharyngeal cancer patients.

Proffered Papers: RTT 6: Advanced radiation techniques in prostate cancer

OC-0555
Organ at risk dose parameters increased by daily anatomic changes in prostate cancer SBRT
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Purpose or Objective: Stereotactic body radiotherapy (SBRT) is increasingly used to treat low and intermediate stage prostate cancer (PC). In our institution, SBRT is delivered in 4-5 fractions of high dose using the CyberKnife system with marker-based tracking. Tracking accurately aligns the treatment beams to the prostate just prior and during the treatment fraction. However, surrounding organs at risks (OARs) may move relative to the prostate, causing the OAR dose to deviate from what was planned. The aim of this work is to quantify the daily dose to OARs in SBRT for PC, and compare it to the planned dose.

Material and Methods: For 9 patients, four to five repeat CT scans were acquired prior to each daily SBRT fraction and were analyzed. The bladder, rectum, anus, and urethra were contoured in the planning and repeat CTs. The urethra was divided in three parts: the cranial and the caudal part of the urethra prostacta (UP) and the membranous urethra (MU, 2 cm caudal to the prostate). The repeat CTs were aligned to the planning CT based on the four implanted markers. Subsequently, the planned dose distribution was projected on the aligned repeat CTs. For each patient, dose-volume parameters of the OARs were recorded, averaged over the 4-5 repeat CTs and compared to planning.

Results: The greatest deviation between the delivered and planned dose was seen for the MU. The planned mean dose of 24.0 Gy was exceeded in the repeat CTs by an average 59±17% (1 SD) and the D5% was increased by 7±3%, from 38.7 to 41.6 Gy (Fig. 1a). For the mean dose of the caudal and cranial UP the deviation from planning was limited: 1±1% and 5±5% respectively. The planned mean and V1cc (dose allowed to 1cc of the organ) rectum dose, 10.9 and 32.8 Gy respectively, was on average 5±5% and 12±11% higher in the repeat CTs (Fig. 1b). The mean dose of the anus increased as well, with 15±24% from 8.7 to 9.8 Gy. The planned V1cc bladder dose (40.2 Gy) was reproducible in the repeat CTs.
(difference: 1±1%). The planned mean bladder dose (18.4 Gy) was slightly reduced in the repeat CTs (-6±7%).

Conclusion: For the membranous urethra, rectum, and anus, the dose in the repeat CTs was higher than was planned. This warrants future research investigating whether increased dose leads to increased incidence of side effects and whether dose increases should be mitigated by treatment adaptations.

OC-0556
Early clinical outcomes of prostate SABR treated with VMAT-FFF
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Purpose or Objective: Endpoints for this ethically approved clinical study:
- Assess the feasibility of planning SABR for low-intermediate risk prostate cancer using flattening filter free volumetric arc therapy.
- Assess safety of treatment delivery by recording RTOG scoring criteria of acute gastro-intestinal (GI) and genito-urinary (GU) toxicity.

Material and Methods: 25 patients were included, each has 18 week toxicity data.
Inclusion criteria:
- Written informed consent, 18 - 80 years, T1- T2 stage, WHO performance status ≤ 2. Initial PSA ≤ 20 ng/ml. Gleason score ≤7 with histologically-proven prostate adenocarcinoma. No pathologic lymph nodes on CT/ MRI scans and no distant metastases. No previous prostate surgery, including transurethral resection of the prostate no TURP in past 6 months. No previous active malignancy within the last 10 years.
A prescription dose of 35Gy in 5 fractions was treated alternate days. This was planned using Rapidarc VMAT planning on Varian Eclipse (V.10), treated using a Varian Truebeam STX.
A clinically acceptable plan was determined by assessing the planned dose to GTV/PTV criteria and achieving dose constraints (table 1).

GI, GU and skin toxicity was scored using Radiation therapy oncology group (RTOG) criteria. Baseline data was recorded before treatment commenced (baseline), week 4 and week 18.

Results:
Results include first 25 patients.
Age range was 52-78, median 70, initial PSA median 4.3-29.2, median 10.8ng/ml. All patients were successfully planned and treated with VMAT-FFF with plans being deemed clinically acceptable for 100% of patients. GU and GI toxicity at baseline, week 4 and week 18 is detailed for each grade below, respectively.

GU toxicity:
Grade 0 - 44%, 12%, 48%
Grade 1 - 52%, 56%, 48%
Grade 2 – 4%, 28%, 4%
Grade 3 – 0%, 4%, 0%
For GU toxicity, a statistically significant increase in toxicity was observed from baseline to week 4 (p=<0.01) and a significant reduction from week 4 to week 18 (p=<0.01). No significant difference was observed between baseline and week 18, with toxicity reducing to similar levels as baseline.

GI toxicity (baseline, week 4, week 18):
Grade 0 – 96%, 52%, 72%
Grade 1 – 4%, 40%, 28%
Grade 2 – 0%, 8%, 0%
Grade 3 – 0%, 0%, 0%
GI toxicity significantly increased from baseline to week 4 (p=<0.01). From week 4 to week 18, toxicity had reduced (p=<0.05). A significant difference was observed between baseline and week 18 (p=<0.05) with toxicity having reduced, but not having returned to baseline grade.

Conclusion: Highly conformal plans were created for all patients. Toxicity was acceptable throughout, with toxicity at week 18 reducing to that of baseline for GU toxicity, and reducing significantly for GI toxicity. 1 patient experienced grade 3 GU toxicity at week 4, this resolved by week 10. Longer follow-up is required to assess late outcomes.

OC-0557
Feasibility of single fraction HDR brachytherapy in patients with prostate cancer: a planning study
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Purpose or Objective: To investigate the feasibility of single fraction High Dose Rate (HDR) brachytherapy (BT) as monotherapy for low risk prostate cancer.

Material and Methods: CT scans of 30 patients were selected from our prostate HDR database. Patients were divided in groups based on prostate volume (< 40cc, 40-70cc and >70cc) and the number of needles used (13-16 and 17-22).