A comparative treatment planning study of IMPT and IMXT for cervical cancer

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Introduction

- The aim of this work was to compare intensity modulated proton therapy (IMPT) planning with intensity modulated photon therapy (IMXT) planning for patients with cancer of the cervix.

- All the treatment planning were optimized with a new software, ORBIT Workstation, developed by RaySearch Laboratories AB.

- IMPT has been investigated for various tumour sites, but the use of this technique in treatment of cervical cancer is rather unexplored.

- IMPT for cervical cancer has potential benefits due to large target volumes and organs at risk adjacent to the tumour.
Materials and Methods: Patient data

**Patient data**

- 4 patients were selected from a clinical database.

- Contours for each dataset:
  - PTV (based on a 1.5 cm margin to the CTV)
  - Bladder and rectum
  - Small bowel
  - Femoral heads

- The small bowel was grossly estimated and the other OARs were delineated according to generally accepted clinical practice by an oncologist.

- In average 64% of the bladder and 59% of the rectum were overlapped by the PTV.
Materials and Methods: Research software

- ORBIT Workstation is a stand-alone Windows-based software, developed in C++.

- Runs on a standard PC or high performance laptop.

- ORBIT Workstation is not used clinically and is intended to serve as an environment for research and development.
The software has functionality within the following fields:

- **standard IMXT optimization**
  - direct optimization of step-and-shoot segments (DSS)
  - gantry angle optimization
- **adaptive radiation therapy**
  - 4D architecture and GUI
  - deformable dose accumulation
  - replanning based on accumulated dose and organ motion prediction
- **biological optimization**
  - Poisson-LQ TCP models
  - Poisson-LQ and LKB based NTCP models
  - EUD
- **proton beam scan patterns**
Materials and Methods: Treatment planning software

Optimization graph

DVH view

Patient views

Fluence view
Materials and Methods: Planning

46.8 Gy or CGy were delivered in 26 fractions

- **IMXT planning**
  - 7 equispaced beams
    - (0°, 51°, 103°, 154°, 206°, 257°, 308°)
  - 90 segments in total.
  - Direct optimization of step-and-shoot segment shapes and weights.

- **IMPT planning**
  - 4 equispaced beams
    - (45°, 135°, 225°, 315°)
  - 25 energy levels for each beam
Materials and Methods: Evaluation criteria

- Target dose homogeneity criteria to PTV was defined as: $D_{100} > 95\%, D_{95} > 100\%, D_{\text{max}} < 107\%$ of prescribed dose.

- Irradiated volume, defined as $V_{50}$

- Treated volume, defined as $V_{95}$

- RTOG0418-specified evaluation parameters
  - Bladder $D_{60}$
  - Rectum $D_{35}$
  - Small bowel $D_{30}$
  - Femoral heads $D_{15}$

- All patients were planned so that target coverage was achieved.

- Comparison was made based on OAR protection.
Results: Min, Mean and Max dose differences

The min, mean and max dose differences between IMXT and IMPT, normalized to the photon plans.

<table>
<thead>
<tr>
<th>Volume</th>
<th>Dose level</th>
<th>Min</th>
<th>Mean</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectum-PTV</td>
<td>D$_{60}$</td>
<td>10%</td>
<td>26%</td>
<td>45%</td>
</tr>
<tr>
<td>Bladder-PTV</td>
<td>D$_{35}$</td>
<td>7%</td>
<td>16%</td>
<td>24%</td>
</tr>
<tr>
<td>Small Bowel</td>
<td>D$_{30}$</td>
<td>45%</td>
<td>49%</td>
<td>54%</td>
</tr>
<tr>
<td>Femoral heads</td>
<td>D$_{15}$</td>
<td>53%</td>
<td>61%</td>
<td>70%</td>
</tr>
</tbody>
</table>

The entire bladder and rectum volume did not exhibit any major difference in D$_{60}$ and D$_{35}$, respectively.
## Results: Min, Mean and Max dose differences

The min, mean and max dose differences normalized to the photon plans.

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<tbody>
<tr>
<td>Treated volume</td>
<td>$V_{95}$</td>
<td>15%</td>
<td>22%</td>
<td>32%</td>
</tr>
<tr>
<td>Irradiated volume</td>
<td>$V_{50}$</td>
<td>37%</td>
<td>43%</td>
<td>48%</td>
</tr>
<tr>
<td>PTV-surrounding tissue</td>
<td>$D_{mean}$</td>
<td>39%</td>
<td>43%</td>
<td>48%</td>
</tr>
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</table>
## Results: Equivalent Uniform Dose (EUD)

The relative min, mean and max EUD differences.

<table>
<thead>
<tr>
<th>Volume</th>
<th>a-value</th>
<th>Min</th>
<th>Mean</th>
<th>Max</th>
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</thead>
<tbody>
<tr>
<td>PTV</td>
<td>-10</td>
<td>-0.06%</td>
<td>0.05%</td>
<td>0.10%</td>
</tr>
<tr>
<td>Bladder&lt;sup&gt;1&lt;/sup&gt;</td>
<td>2</td>
<td>3%</td>
<td>7%</td>
<td>13%</td>
</tr>
<tr>
<td>Femoral Heads&lt;sup&gt;1&lt;/sup&gt;</td>
<td>4</td>
<td>50%</td>
<td>60%</td>
<td>68%</td>
</tr>
<tr>
<td>Rectum&lt;sup&gt;1&lt;/sup&gt;</td>
<td>8.33</td>
<td>0%</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>Small bowel&lt;sup&gt;1&lt;/sup&gt;</td>
<td>6.67</td>
<td>29%</td>
<td>32%</td>
<td>37%</td>
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## Results: Equivalent Uniform Dose (EUD)

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<tr>
<td>Bladder$^1$</td>
<td>2</td>
<td>3%</td>
<td>7%</td>
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<td>Femoral Heads$^1$</td>
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Results: DVH

Accumulated dose for photons (solid) and protons (dotted)
Summary and discussion

Summary

- Research software for IMPT treatment planning has been developed and cervical cancer has been studied.

- The IMPT plans exhibited significant dose reduction to the small bowel and femoral heads compared to IMXT, with preserved target coverage.

- IMPT gives, with same target dose homogeneity, significantly lower irradiated and treated volumes compared to the photon techniques.

- Results from this study suggest that the IMPT technique is suitable for tumors of the cervix.

Further work

- Clinically accurate dose calculation, using beam model from Nucletron
- Biology-based fractionation schedule optimization
- Adaptive PT strategies
- Carbon ions