Online adaptation to internal and external anatomical changes in Stereotactic Radiosurgery (SRS) of L-Spine Tumors using Cone Beam CT and TMR ratios

Irfan Ghaffar, MS¹,
Salim Balik, Ph.D.², Tingliang Zhuang, Ph.D. ², Samuel Chao, MD²,
Ping Xia, Ph.D².

¹Cleveland State University, ²Cleveland Clinic
Purpose

Spine SRS treatment is usually given in single fraction making dosimetric and setup accuracy critical.

To investigate the feasibility of an online adaptive radiotherapy strategy to minimize the dosimetric variations due to internal and external anatomical changes in stereotactic radiosurgery (SRS) of L-spine tumors using Cone Beam CT and TMR ratio correction factors.
IGRT for Spine SRS

• Spine SRS patients are setup using cone beam CT image acquired before the treatment.
• CBCT is registered to planning CT image using target area (vertebral body) as the alignment focus.
• Shifts applied.
• Treatment
External Anatomical Variations

Planning CT

Pre-treatment Planning CT

Magenta: Planning CT external contour
Yellow : CBCT external contour

Difference between planning and delivery up to 4.8%
Internal Anatomical Variations

Planning CT

Pre-treatment Planning CT

Magenta: Planning CT external contour
Yellow : CBCT external contour

Difference between planning and delivery ~ 3.2%
Internal and External Variations

Magenta: Planning CT external contour
Yellow: CBCT external contour

Difference between planning and delivery up to 5%
How can we minimize errors?

• Plan wisely
  • Choose beam directions that will likely to cause minimum variation between plan and delivery
• Online adaptation using CBCT to re-plan or modify existing plan.
  • Simple (TMR ratios)
  • Complex (More difficult and time consuming)
Planning Strategies

Three coplanar treatment plans were made to deliver 16 Gy to 90% of GTV in one fraction

1) IMRT with 9 posterior beams every 20 degree,
2) IMRT with 9 beams equally distributed around the patient,
3) VMAT with 360 degrees full arcs.
Delivered Dose Estimation

Modified CT: Combination of Planning CT and CBCT contours

Bowel gas in CT

Bowel gas in CBCT

CT-CBCT

CBCT-CT

Density Overrides

CT-CBCT to 0
CBCT-CT to 1
Bowel gas in CT to 1
Bowel gas in CBCT to 0
Results

Conclusion:

Even though the results varied across patients, overall the posterior plans were less influenced dosimetrically in tumor coverage by variations in abdominal anatomy but were not superior in terms of cauda-equina dose.

Online adaptive treatment may be beneficial for patients with large anatomical variations.

The difference was statistically significant for the posterior vs. VMAT plans ($p = 0.049$) but not significant for the posterior vs. uniform plans ($p=0.174$).
TMR Correction

• Obtained the effective depth values from Pinnacle for planning CT and Modified CT.
• Obtained the corresponding TMRs for this two effective depths
• Correction Factor (CF) = TMR (Modified CT)/TMR (planning CT).
• Calculate new MUs by multiplying planning CT MUs with CF.
• Calculate the new delivered dose, Adaptive Dose, with the corrected MUs on the Modified CT.

In Summary

Planning CT
Planning MU

Modified CT
Planning MU

Modified CT
New MU

Planning
Delivery
Adaptive

Penn-Ohio AAPM Fall Symposium 2015
The New MUs is put into the Pinnacle to get new values (Adaptive Values)

**Posterior**

<table>
<thead>
<tr>
<th></th>
<th>Planning</th>
<th>Delivery</th>
<th>Adaptive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tumor</td>
<td>V16Gy</td>
<td>90.12</td>
<td>93.35</td>
</tr>
<tr>
<td>Cauda Equina</td>
<td>Dmax (cGy)</td>
<td>1472.7</td>
<td>1506.7</td>
</tr>
<tr>
<td></td>
<td>V12 Gy</td>
<td>5.7</td>
<td>7.45</td>
</tr>
</tbody>
</table>

**Uniform**

<table>
<thead>
<tr>
<th></th>
<th>Planning</th>
<th>Delivery</th>
<th>Adaptive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tumor</td>
<td>V16Gy</td>
<td>90.04</td>
<td>92.96</td>
</tr>
<tr>
<td>Cauda Equina</td>
<td>Dmax (cGy)</td>
<td>1537.2</td>
<td>1588.9</td>
</tr>
<tr>
<td></td>
<td>V12 Gy</td>
<td>6.22</td>
<td>9.01</td>
</tr>
</tbody>
</table>

**VMAT**

<table>
<thead>
<tr>
<th></th>
<th>Planning</th>
<th>Delivery</th>
<th>Adaptive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tumor</td>
<td>V16Gy</td>
<td>90.06</td>
<td>93.26</td>
</tr>
<tr>
<td>Cauda Equina</td>
<td>Dmax (cGy)</td>
<td>1406.4</td>
<td>1453.4</td>
</tr>
<tr>
<td></td>
<td>V12 Gy</td>
<td>2.6</td>
<td>3.9</td>
</tr>
</tbody>
</table>

All plans were made to deliver 16 Gy to 90% of the Tumor and sparing cauda-equina such that $V_{12Gy} < 10\%$ and $D_{max} < 16$ Gy.
Results

The mean absolute differences (MAD) between planning and estimated delivery without adaptation (P-D) and with adaptation (P-A) for $V_{16Gy}$ of the target (percentage of target volume covered by 16Gy); for Dmax and $V_{12Gy}$ of Cauda were evaluated.

<table>
<thead>
<tr>
<th>Source</th>
<th>TUMOR (V16Gy)</th>
<th>Cauda (Dmax)</th>
<th>Cauda (V12Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P-D (%)</td>
<td>P-A (%)</td>
<td>p</td>
</tr>
<tr>
<td>Posterior</td>
<td>1.8±1.4</td>
<td>0.9±1.1</td>
<td>0.190</td>
</tr>
<tr>
<td>Uniform</td>
<td>2.4±1.3</td>
<td>0.8±0.7</td>
<td>0.006</td>
</tr>
<tr>
<td>VMAT</td>
<td>2.6±1.3</td>
<td>1.0±0.9</td>
<td>0.0007</td>
</tr>
</tbody>
</table>
Conclusion

• The online adaptive strategy using correction factors based on TMR ratios calculated using pre-treatment CBCT information was feasible for the patient plans in this study.

• IMRT with uniform beam arrangement and VMAT plans benefited more than the posterior beam IMRT.
<table>
<thead>
<tr>
<th></th>
<th>Posterior</th>
<th>Uniform</th>
<th>VMAT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Planning</td>
<td>Delivery</td>
<td>Adaptive</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>90.02</td>
<td>88.42</td>
<td>89.81</td>
</tr>
<tr>
<td>2</td>
<td>90.16</td>
<td>89.87</td>
<td>89.98</td>
</tr>
<tr>
<td>3</td>
<td>90.12</td>
<td>93.35</td>
<td>90.4</td>
</tr>
<tr>
<td>4</td>
<td>90.18</td>
<td>85.3</td>
<td>89.99</td>
</tr>
<tr>
<td>5</td>
<td>90.08</td>
<td>88.72</td>
<td>90.92</td>
</tr>
<tr>
<td>6</td>
<td>90.23</td>
<td>88.12</td>
<td>88.95</td>
</tr>
<tr>
<td>7</td>
<td>90.26</td>
<td>91.59</td>
<td>89.32</td>
</tr>
<tr>
<td>8</td>
<td>90.11</td>
<td>90.61</td>
<td>85.93</td>
</tr>
<tr>
<td>9</td>
<td>90.14</td>
<td>86.47</td>
<td>89.93</td>
</tr>
<tr>
<td>10</td>
<td>90.02</td>
<td>90.25</td>
<td>90.05</td>
</tr>
<tr>
<td>11</td>
<td>90.25</td>
<td>91.29</td>
<td>88.75</td>
</tr>
</tbody>
</table>

Mean: 90.142727 89.45364 89.45727 90.11273 89.94182 89.61818 90.13091 89.86364 89.49909

Std Dev: 0.0798966 2.232053 1.261407 0.054621 2.746323 0.873237 0.085115 2.876125 1.263656

T TEST: 0.351067 0.121197 0.846452 0.104578 0.775286 0.133587