Intensity Modulated Radiation Therapy of Medulloblastoma using Helical TomoTherapy: Initial Experience from planning to delivery

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Aim

• To establish feasibility of Intensity Modulated Radiation Therapy (IMRT) for craniospinal irradiation (CSI) using Helical TomoTherapy (IMRT_Tomo)

• To report initial experience of its implementation in the clinic.

• Dosimetric comparison of IMRT_Tomo with conventional Linear Accelerator based 3DCRT (3DCRT_LA), and IMRT (IMRT_LA) plans
Materials and Methods:

Phase I: Dosimetric comparison of 3DCRT, IMRT_LA and IMRT_Tomo

- Selected CT datasets of 4 previously treated patients (5-14 yrs) of medulloblastoma having spinal lengths up to 48 cm

- Delineated Target and OARs on Coherence dosimetrizist VSim Workstation

- For each patients, 3DCRT and IMRT_LA plan were generated on Eclips TPS (V 7.3.1) configured with millennium 120 MLC from Varian
• IMRT_Tomo plans were generated using the same patient datasets on TomoPlanning System (V 2.2.4).

• All plans were generated using 6 MV X-rays

• A dose of 35 Gy in 21 fractions was prescribed to planning target volume (PTV) of Brain and Spine.

• Planning Goal :
  – At least 95% volume of target (PTV_brain and PTV_spine) received at least 95% of the prescription dose while restricting the maximum dose limit to 107%  
  – Reduced dose to OARs
3D CRT Plan.

- Fixed Geometry approach
- Bilateral Half beam block cranial fields collimated to match with the divergence of direct posterior field.
- One or two Posterior direct fields depending on spinal length
- Spinal & Cranial fields shaped on PTV using MLC
IMRT_LA Plan

- Spinal PTV planned first using inverse planning strategy
  - 5 fields/Isocenter using gantry 0, ±20 and ±50 deg.
- Cranial field plan similar to 3DCRT
- Dose prescribed and normalized to geometrical center of PTV_brain and isocenter for PTV_Spine.
IMRT_Tomo Plan.

- Fan Beam Thickness (FBT) - 2.5cm.
- Pitch - 0.3.
- Modulation Factor - 3.
- Directional block used for eyes and kidneys.
- Both PTV_Brain and PTV_Spine was planned together.
Plan Evaluation for Target

- Target Volume coverage (TC)

\[ TC = \left( \frac{V_{T,\text{Pi}}}{V_T} \right) \times 100\% \]

- Dose Uniformity Index (DHI) = D95/D5

- Conformity index (CI)

\[ CI = \left\{ \frac{V_{T,\text{Pi}} \times V_{T,\text{Pi}}}{V_T \times V_{\text{Pi}}} \right\} \]

VT, Pi - volume of target enclosed by the prescription dose
V Pi - volume of tissues including target covered by the prescription dose
VT - volume of target; D95 and D5 - dose to 95% and 5% volume of the PTV
Plan Evaluation for OARs

• Volume of each OARs receiving various dose range
  – high $\geq 80\% \ (V_{80\%})$,
  – intermediate $\geq 50\% \ (V_{50\%})$ and
  – low $\geq 30\% \ (V_{30\%})$ and $\geq 10\% \ (V_{10\%})$

• Integral dose (ID) of target & OARs

\[ ID_j = \rho_j V_j D_j, \]

where $\rho_j$, $V_j$ and $D_j$ are the density, volume, and mean dose of the organ respectively for sub-volume $j$
Figure 2: Dose distributions resulted from a) 3DCRT, b) IMRT.LA and c) IMRT.Tomo Plans for one of the representative cases having large spinal length of 48 cm. Magenta – 95% isodose line; Red – 50% isodose line; Blue – 30% isodose line
Dose-volume indices for the three different treatment techniques.

All values represent the mean of the four patients.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>PTV_Brain</th>
<th>PTV_Spine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3D-RT</td>
<td>IMRT</td>
</tr>
<tr>
<td>$D_{\text{max}}$</td>
<td>37.4</td>
<td>38.6</td>
</tr>
<tr>
<td>$D_{\text{min}}$</td>
<td>18.52</td>
<td>22.57</td>
</tr>
<tr>
<td>$D_{\text{mean}}$</td>
<td>35.45</td>
<td>35.52</td>
</tr>
<tr>
<td>$V_{95%}$</td>
<td>98.22</td>
<td>98.28</td>
</tr>
<tr>
<td>$V_{107%}$</td>
<td>0</td>
<td>0.07</td>
</tr>
<tr>
<td>DHI</td>
<td>0.93</td>
<td>0.93</td>
</tr>
<tr>
<td>$V_{\text{pi}}$</td>
<td>1713</td>
<td>1715</td>
</tr>
<tr>
<td>CI</td>
<td>0.86</td>
<td>0.86</td>
</tr>
</tbody>
</table>
Maximum (Dmax) and mean (Dmean) doses in Gy to various OARs for 35 Gy to whole craniospinal axis in the 3 treatment techniques.

*All values are the mean of four patients*

<table>
<thead>
<tr>
<th>OARs</th>
<th>$D_{\text{max}}$ in Gy</th>
<th>$D_{\text{mean}}$ in Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2D-RT</td>
<td>IMRT</td>
</tr>
<tr>
<td>Lt. Eye</td>
<td>36.31</td>
<td>36.31</td>
</tr>
<tr>
<td>Rt. Eye</td>
<td>36.3</td>
<td>36.30</td>
</tr>
<tr>
<td>Heart</td>
<td>33.12</td>
<td>17.10</td>
</tr>
<tr>
<td>Rt. Lung</td>
<td>35.71</td>
<td>24.5</td>
</tr>
<tr>
<td>Lt. Lung</td>
<td>32.23</td>
<td>26.73</td>
</tr>
<tr>
<td>Thyroid</td>
<td>32.91</td>
<td>17.37</td>
</tr>
<tr>
<td>Rt. Kidney</td>
<td>28.13</td>
<td>17.7</td>
</tr>
<tr>
<td>Lt. Kidney</td>
<td>29.22</td>
<td>19.15</td>
</tr>
<tr>
<td>Liver</td>
<td>30.91</td>
<td>17.35</td>
</tr>
<tr>
<td>Esophagus</td>
<td>33.13</td>
<td>27.87</td>
</tr>
</tbody>
</table>

Note: The values for Lt. Eye in 2D-RT and Rt. Lung in TOMO are highlighted for emphasis.
Integral dose in Gy-Kg to the targets and various OARs resulting from 3DCRT, IMRT_LA and IMRT_Tomo.

All values represent mean of the 4 patients’ data

<table>
<thead>
<tr>
<th>Volumes</th>
<th>3DCRT</th>
<th>IMRT_LA</th>
<th>IMRT_Tomo</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV_brain</td>
<td>60.08</td>
<td>60.20</td>
<td>60.86</td>
</tr>
<tr>
<td>PTV_spine</td>
<td>6.00</td>
<td>5.89</td>
<td>5.82</td>
</tr>
<tr>
<td>Left eye</td>
<td>0.13</td>
<td>0.13</td>
<td>0.05</td>
</tr>
<tr>
<td>Right eye</td>
<td>0.11</td>
<td>0.11</td>
<td>0.05</td>
</tr>
<tr>
<td>Heart</td>
<td>3.93</td>
<td>1.65</td>
<td>1.10</td>
</tr>
<tr>
<td>Right lung</td>
<td>0.95</td>
<td>1.03</td>
<td>1.33</td>
</tr>
<tr>
<td>Left lung</td>
<td>0.97</td>
<td>1.03</td>
<td>1.21</td>
</tr>
<tr>
<td>Thyroid</td>
<td>0.18</td>
<td>0.07</td>
<td>0.05</td>
</tr>
<tr>
<td>Right kidney</td>
<td>0.20</td>
<td>0.34</td>
<td>0.29</td>
</tr>
<tr>
<td>Left kidney</td>
<td>0.21</td>
<td>0.39</td>
<td>0.31</td>
</tr>
<tr>
<td>Liver</td>
<td>3.49</td>
<td>2.57</td>
<td>1.87</td>
</tr>
<tr>
<td>Esophagus</td>
<td>0.25</td>
<td>0.14</td>
<td>0.07</td>
</tr>
</tbody>
</table>
The mean volume of each PTV receiving at least 95% of prescribed dose ($V_{95\%}$) was $>98\%$ in all plans.

Comparable dose homogeneity index (DHI) for PTV_Brain from all plans.

For PTV_spine, IMRT_Tomo achieved highest mean DHI of 0.96 as compared to 0.91 for IMRT_LA and 0.84 for 3DCRT.

The best dose conformity index (CI) was achieved by IMRT_Tomo for PTV_brain (0.96) and IMRT_LA for PTV_spine (0.83).
• Integral dose to both PTVs was comparable in all 3 techniques.

• IMRT_Tomo plan reduced ID to the majority of OARs including eyes, heart, thyroid, liver and oesophagus as compared to 3DCRT and IMRT_LA.

• IMRT_Tomo plan was superior in terms of
  – reduction of maximum and mean doses to almost all OARs.
  – It also reduced volume of each OAR irradiated to various dose levels, except for the lowest dose volume.
Phase II: Clinical Implementation

- Selected 3 patients treated on an ongoing prospective protocol of Helical TomoTherapy,
- Patient Immobilization and Set-Up
  - Supine Position
  - using base plate,
  - thermoplastic mould,
  - knee rest all incorporated in vacuum cradle
• TomoPlanning
  – 5 mm Planning CT acquired from vertex to coccyx
  – Delineation of target and OARs
  – IMRT plan based on Helical TomoTherapy (IMRT_Tomo)
  – Fan beam thickness (FBT) of 2.5 cm, pitch of 0.3 and a modulation factor of 3 was used during optimization and dose computation.

• A total dose of 35 Gy was prescribed to both PTV_brain and PTV_spine

• Patient specific QA using Cheese Phantom
  – Point dose verification
  – Fluence verification
DVH and Dose distribution in a TOMO CSI patient
• Patient specific QA using Cheese Phantom
  – Point dose verification
  – Fluence verification

Acceptable criteria is 3% for pt dose measurement and 3mm for Gamma analysis.
PreTreatment MV-CBCT and image Co-registration with reference CT dataset (Image)

Application of Final Shifts.

- MVCT scans taken at three levels and differential shifts noted.
- Preference given to the cranial shifts because of proximity of surrounding vital structures.
- CTV coverage at different levels assured within application of final shifts.
- If not possible then repositioning and rescanning done.
Conclusion

• Craniospinal irradiation remains one of the most challenging processes in radiation planning, delivery, and verification.

• IMRT_Tomo for CSI is technically easier and dosimetrically favorable as compared to IMRT_LA and 3DCRT in terms of
  – target volume coverage,
  – dose homogeneity, conformity,
  – OAR sparing and
  – reduction of integral doses to non-target tissues.

• The In-build image-guidance allows precise patient positioning and accurate dose delivery.

• In case of non-availability of TomoTherapy, IMRT for CSI can be realized on conventional linear accelerator even for spinal lengths exceeding maximum allowable field sizes using appropriate intensity feathering techniques.
• Although time and labor intensive, challenges in successful implementation of IMRT_Tomo for CSI can be circumvented provided they are preempted during the planning phase.

• During clinical implementation, practical issues that arose included
  – challenges in whole body immobilization,
  – areas to be imaged daily with MVCT,
  – co-registration efficiency,
  – Longer beam-on time.
  – intrafraction motion, and impact of differential shifts of different parts of the body, which were handled using appropriate methodology resulting in increased daily time on the machine