Tony Lomax, Mayneord-Phillips Summer School, July 2009

**Overview of presentation**

1. Passive scattering, discrete scanning and IMPT
2. Protons vs photons
3. Clinical results from PSI
4. Summary

**Why protons?**

R.R. Wilson, Radiology 47(1946), 487-491

A mono-energetic proton Bragg peak is not very useful for treating anything other than the smallest tumours. To make protons useful, we need to spread out the dose laterally and along the beam direction.

The problem of lateral field size and coverage in depth

A mono-energetic proton Bragg peak is not very useful for treating anything other than the smallest tumours.

To make protons useful, we need to spread out the dose laterally and along the beam direction.

Dynamic lateral scanning, also called lateral scanning in the Bragg peak (LSBP) and dynamically scanned Bragg peak (DSBP) therapy,

The Bragg peak

E.g. Depth-dose curve for 177 MeV protons

Dose concentrated in small volume in Bragg peak.

Extending the dose in depth

The 'Spread-Out-Bragg-Peak'

FWHM=6.11mm

σ=5.8mm

σ=3.5mm

Target volume

Dose peak where protons slow down and stop

Width of peak dependent on range straggling in medium and initial energy spectrum.

Peak-to-plateau ratio 4.5 (depending on width of energy spectrum)
Extending the dose in depth

The range shifter wheel

A rotating wheel with varying thickness

The range shifter wheel in action...

RS wheel rotates continuously in beam at ~3000 rpm

Passive scattering in practice

The collimator

Field specific aperture (collimator) matching projected shape of target

• Each delivered field (incident direction of irradiation) requires specific collimator and compensator
• No range shifter in upstream beam path

Computer-milled compensators (examples from Orsay)

Example collimator

Eye irradiation

Generally, a compensator and collimator are required for every field in the passive scattering approach.

Fixed extent SOBP leads to poor sparing of normal tissue proximal to target

Conformation of dose can be improved through the use of multiple fields

Discrete scanning

Discrete scanning – a treatment planning example

Proton pencil beam

Range shifter plate

Magnetic scanner

Spot selection

Optimised dose

Dose calculation

Discrete scanning – a treatment planning example
Note, each individual field is homogenous across the target volume.

Discrete scanning:
Single Field, Uniform Dose (SFUD) mode

Combined distribution

Passive scattering
1 field
3 fields

Passive scattering and discrete scanning compared

3 fields

Discrete scanning:
Intensity Modulated Proton Therapy (IMPT) mode

The simultaneous optimisation of all Bragg peaks from all incident beams.

The three ‘orders’ of proton therapy compared

Sources of protons for therapy

Example clinical IMPT plans delivered at PSI

Skull-base chordoma
3 field IMPT plan to an 8 year old boy

4 fields

3 fields
Treatment gantries for proton therapy

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1. Medulloblastoma (5 year old boy)
   - Single posterior 160MeV proton field, 80cm long
   - No patching of divergent fields required
   - Irradiation time ~ 10-15 minutes
   - No comparison necessary!...

2. Desmoid tumor (12 year old boy)
   - Delivered single field plan
   - 9 field IMRT – second try
   - Factor 6 lower integral dose for protons

4. Complex head and neck (IMPT vs Tomotherapy)
   - Tomotherapy 3 field IMPT
   - Widesott et al, IJROBP 2008
4. Complex head and neck (IMPT vs Tomotherapy)

<table>
<thead>
<tr>
<th></th>
<th>Tomotherapy</th>
<th>IMPT</th>
<th>Ratio (Tomo/IMPT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contralateral parotid(^1)</td>
<td>21.7%</td>
<td>4.8%</td>
<td>4.52</td>
</tr>
<tr>
<td>Ipsilateral parotid(^1)</td>
<td>41.5%</td>
<td>14.3%</td>
<td>2.9</td>
</tr>
<tr>
<td>Larynx(^2)</td>
<td>1.4%</td>
<td>1.9%</td>
<td>0.73</td>
</tr>
</tbody>
</table>

\(^1\) End point – flow rate <25% after 1 year
\(^2\) End point - grade 2 enema after 15 months

Widesott et al. IJROBP 2008

5. Pediatric cases (protons/IMPT vs IMXT)

Anesthesia equipment is mounted on the patient table and monitored by video during the treatment.

A close collaboration between PSI (PD Dr. Beate Timmermann) and KiSpI, Zurich (PD Dr. Markus Weiss)

5. Pediatric cases (protons/IMPT vs IMXT)

9 patients treated with protons at PSI compared to IMXT plans calculated retrospectively

Average fields used:
- Protons: 1.9
- X-rays: 7.2

Average EUD (overlapping)

Average EUD (<25mm)

Average EUD (>25mm)

Critical organ EUD’s as function of distance from PTV

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Average reduction in integral dose - 2.03 (1.5-2.7)
1. Skull base chordomas and chondrosarcomas

Prescription dose:
- Brainstem surface: 63CGE
- Brainstem centre: 54CGE
- Optical structures: 60CGE

Debus et al. submitted to IJROBP 2008

Local control probability (n=42 Chordoma, n=22 Chondrosarcoma)

2. Extracranial chordomas and chondrosarcomas

Prescription dose:
- Spinal cord surface: 60CGE
- Spinal cord centre: 54CGE

3. Other indications from PSI...

<table>
<thead>
<tr>
<th>Publication</th>
<th>Indication</th>
<th>n</th>
<th>Median dose</th>
<th>Local control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weber et al. (2007)</td>
<td>Adult Sarcomas</td>
<td>13</td>
<td>69.6</td>
<td>74% (4 yrs)</td>
</tr>
<tr>
<td>Rutz et al. (2009)</td>
<td>Pediatric and adolescent Chordomas</td>
<td>10</td>
<td>74 (66)</td>
<td>100% (30 months)</td>
</tr>
<tr>
<td>Timmermann et al. (2007)</td>
<td>Pediatric patients</td>
<td>16</td>
<td>50</td>
<td>91% (1.5 yrs)</td>
</tr>
</tbody>
</table>
Summary

- Proton therapy is a mature technique, with more than 50,000 patients treated worldwide.
- Spot scanning/IMPT provides improved flexibility and conformality in comparison to passive scattering.
- IMPT is being delivered routinely at PSI with about 40% of all patients receiving IMPT as part of their therapy.
- Initial clinical results with scanning are very favourable, and most new proton facilities will include scanning component.
- Proton therapy is experiencing a "boom" period in Japan, US and (continental!) Europe.

Gay et al: 65% PFS at 5 years
46 chordoma patients
- 67% (n=31) had total or near-total surgical resection
- 33% (n=15) had partial or sub-total resection

Ares et al: 81% PFS at 5 years
42 chordoma patients
- 0% (n=0) had total or near-total surgical resection
- 100% (n=42) had partial or sub-total resection

Gay et al: "Radiotherapy with high-energy particles, or by focussed radiation, is recommended if the tumour cannot be totally removed."