An overview of compensated and intensity modulated proton therapy

Overview of presentation
1. Proton interactions with matter
2. Treatment delivery
3. Clinical experience and applications
4. The future of proton therapy

Proton interactions with matter.
1. Energy loss
   E.g. Depth-dose curve for 177 MeV protons

2. Multiple Coulomb scattering
   A proton pencil beam

R.R. Wilson, Radiology 47(1946), 487-491
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Tony Lomax, AAPM Summer School, Colorado Springs, June 2003

PROSCAN

Making protons useful 1. Passive scattering: in practice

Single passively scattered fields

Three passively scattered fields

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

Making protons useful 2. Active scattering

Magnetic scanner

Proton pencil beam

Range shifter plate

Target

Making protons useful 2. Spot scanning: in practice

Spot definition

Incident field

Spot selection

Selected spots

Initial dose distribution

Dose calculation

Spot weight optimisation

Optimised dose distribution

A final plan is then the linear combination of multiple, individually homogeneous single field doses

Treatment delivery – spot scanning in practice
## Treatment delivery

### Passive and scanning delivery – a comparison.

<table>
<thead>
<tr>
<th>Passive</th>
<th>Scanning</th>
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<tbody>
<tr>
<td>Mature technology</td>
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<td>Smaller gantries</td>
</tr>
<tr>
<td>required</td>
<td>can be used</td>
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- **Passive**
  - Mature technology
  - Insensitive to organ motions
  - Lateral fall-off
  - Inflexible
  - Field specific
  - Hardware required
  - Large gantries required

- **Scanning**
  - New technology
  - Very sensitive to organ motions
  - Lateral fall-off
  - Very flexible
  - No field specific
  - Hardware required
  - Smaller gantries

### Nominal dose – no motion

- Using a double scanning system (currently under development at PSI) 11 times rescanning could be implemented in similar time to current delivery times (~ 2-3 minutes for 1 litre volume per field).

(Thanks to Christian Hilbes)

### Treatment delivery – scanning and organ motion

- Nominal dose – no motion
- Dose with +/- 1 cm motion
- Dose with +/- 1 cm motion and 11x rescanning

### Treatment delivery – scanning and lateral fall-off

- Lateral fall-offs (80-20%) at 12 cm depth
  - IPS(σ) = 3mm
  - 6MV photons
  - PSI, 1cm air gap
  - PSI, 17cm air gap

- Lateral fall-offs (80-20%) at 20 cm depth
  - IPS(σ) = 3mm
  - 15MV photons

### Treatment delivery – IMPT vs spot scanning

- IMRT (9 fields)
- Protons (2 fields)

### Protons vs. Photons. Non-IM protons against IMRT

- Breast and regional node irradiation

### Treatment delivery – IMPT vs spot scanning

- IMPT
- Spot scanning

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The application of many optimised, individually inhomogenous proton fields which together provide a homogenous coverage of the target volume.
IMPT provides excellent conformity and sparing of spinal cord and lung.

Patient treated in 1999
> 3 years follow-up, locally controlled and no side-effects

IMPT provides excellent conformity and sparing of spinal cord and lung.

2D CCD dosimetry of posterior field

D(w) = 4.3cm
D(w) = 7.8cm

Calculation
Measurement

The CCD dosimetry system
The CCD dosimetry system

4 cases treated. First in 1999, 3 more in 2002.

Two examples

2 fields
3 fields

Treatment delivery – clinical experience with IMPT

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Clinical experience and applications
Example results for deep seated tumours (passive scattering)

Prostate cancer (Loma Linda, >300 Patients)
Stage T1-T2b
5 year disease free survival – 97 and 88% respectively

Skull base sarcomas (Harvard, 622 Patients)
Chondrosarcomas: 98% tumour free after 5 years.
95% tumour free after 10 years.
Chordomas: 65% tumour free after 10 years (m)
42% tumour free after 10 years (f)

Hepatocellular carcinomas (Tsukuba, >120 Patients)
Local Control Rate > 90%

Clinical experience and applications
Initial clinical experience with spot scanning at PSI
99 patients treated by end 2001 (129 by end 2002)

Initial clinical follow-up (-2001)

99 Patients treated
Curative 78, Palliative 21,
82 Local control,
61 surviving after 8 – 69 months.

Initial clinical follow-up (-2001)

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Curative 78, Palliative 21,
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Clinical experience and applications.

An example case - Sacral chordoma

4.5Y. after therapy (72 CGE) LC, no toxicity, back at work.

Clinical experience and applications.

Cranio-spinal irradiations (in collaboration with Beate Timmerman).

The plan
(Calculated for and delivered to an Alderson phantom)

Subfield 1 Subfield 2 Subfield 3 Subfield 4 Subfield 5

The irradiation

Volume – 2400ml
Length – 84cm
Fields – 1
Patches – “automatic” patching of 5 parallel sub-fields
Spots – 30000
Time – 10-15 Mins

Clinical applications – IMRT vs IMPT

Sarcoma – 12 year old boy

Delivered single field plan
9 field IMRT = second try

Factor 6 lower integral dose for protons

Clinical applications – conformal avoidance?

IMRT (9 fields)
IMPT (9 fields)
IMPT-IMXT

Mean doses (Gy/CGE)

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<th>Right lung</th>
<th>Heart</th>
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<tr>
<td>IMRT</td>
<td>14.5</td>
<td>23.4</td>
<td>18.2</td>
</tr>
<tr>
<td>IMPT</td>
<td>15.3</td>
<td>20.9</td>
<td>18.1</td>
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<tr>
<td>IMPT-IMXT</td>
<td>0.7</td>
<td>-2.6</td>
<td>0.9</td>
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Total dose to additional CTV region (CTV2-CTV1) increased by factor 1.4
CTV volume increased 1.8 times

When may protons be useful?

A brief (and probably incomplete) history of radiotherapy

- Ortho-voltage
- Co60
- LINACs
- 3D-planning
- IMRT
- P+IMPT

Improved dose distributions

Protons can simply be considered to be the next logical step in the advancement of radiotherapy

However, Protons are NOT necessarily competitive to conventional radiotherapy –
They could simply provide an additional treatment modality for those cases that can’t be satisfactorily treated using other techniques.
When may protons be useful?

- Factor 2 or more reduction of integral dose to normal tissues
- 3D modulation of Bragg peaks provides great flexibility in conforming dose, even in very challenging situations.
- Protons have the ability to reduce doses to critical structures in comparison to IMXT, whilst preserving target homogeneity.
- Possible applications:
  - Pediatric patients
  - Large treatment volumes (conformal avoidance?)
  - Patients with concomitant treatments
  - Pre-irradiated patients
  - Patients with co-morbidity

Proton therapy in the future.

Current estimates against IMRT
- Protons 2.4 times more expensive
- 1.7 times with likely improvements in efficiency and production facilities
(C.f. Chemotherapy)
(Estimates courtesy of Mike Goitein and Martin Jermann)

The PSI gantry – diameter 4 meters

Hospitals currently supplying or developing proton therapy equipment

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<td>Accel (Siemens)? (Germany)</td>
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Hospital based facilities as of end 2002

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<td>Plus 4 in Japan</td>
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Probable new hospital facilities in the near future

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>25 facilities worldwide, mostly in research institutes.

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Why protons in Switzerland?

The PSI proton therapy team.

Acknowledgements