Cancer Therapy using Proton Beams

Ewart Blackmore, TRI UMF

Topics
- Cancer treatment – quick summary
- Radiotherapy – electron, X-ray, proton
- How protons behave in matter?
- Why protons are good for cancer treatment?
- TRIUMF treatment of eye cancer
- Proton therapy around the world
- Commercial from Hitachi
Cancer Treatment

18,000 new cases each year in BC

1. Surgery – to remove the tumour
2. Chemotherapy – to kill the tumour with drugs
3. Radiotherapy – to kill the tumour with radiation
   External beam therapy – X-rays, gamma rays, protons
   Internal therapy – brachiotherapy (radioactive isotopes)

Success: Tumour control vs. complications
Destroy/remove tumour without damaging healthy or normal tissue nearby
Energy Scale – electron Volts

kilo (keV) = thousand, mega (MeV) = million

Battery ~ 1-10 eV

Television ~ 20 keV

Cyclotron ~ 100 MeV
What is a Photon (X-ray), Electron & Proton?

**Photon**
- quantum or packet of EM energy
- visible light (low E)
- X-ray ~ keV to MeV (atomic transition)
- gamma ray ~ MeV (nuclear decay)

**Electron**
- negatively charged light particle
- found in all atoms
- easily produced beams
- used to make X-rays

**Proton**
- much heavier than the electron x 1840
- nucleus of the hydrogen atom
- positively charged
- protons and neutrons make up all nuclei
Conventional Radiotherapy

Electron linac producing X-ray beam – 7500 units worldwide
Excellent for most cases of cancer

Cobalt Therapy Unit Co-60 produces a gamma ray beam

Invented by Dr. Harold Johns - Canadian 1915-1998
Connection to AECL (MDS-Nordion)
3000 in use worldwide (most made in Canada)
Protons in Matter - Some Basic Concepts

- protons have a well defined range in matter
e.g. 200 MeV proton, range 25 cm
- protons lose energy by ionizing electrons – more loss as they slow down (Bragg curve)
- protons stopping in living tissue produce damage to DNA causing cells to die.
A monenergetic proton beam stopping in matter produces a rapid increase in dose near the end of its range.

This dose can be spread out over a desired depth by modulating the energy of the proton beam - SOBP Spread Out Bragg Peak

Success of radiation therapy comes from delivering maximum dose to the tumour and minimizing dose to nearby sensitive structures.
Comparison of Treatment Planning using Protons vs. X-rays

- Highest dose: red
- Lowest dose: yellow

X-rays

Protons
BCCA/UBC/TRIUMF Collaboration on Proton Therapy

**BC Cancer Agency**
Dr. Tom Pickles, Oncologist
Dr. Roy Ma, Oncologist
Dr. William Kwa, Medical Physicist
Dr. Richard Lee, Medical Physicist

**UBC Department of Ophthalmology & Eye Care Centre**
Dr. Katherine Paton, Ophthalmologist
Dr. Jack Rootman, Ophthalmologist

**TRIUMF**
Dr. Ewart Blackmore, Physicist

Patients referred from Western Canada
Population base of ~ 10 million
Both Proton & $^{198}$Au Plaque Therapy
Cyclotron and Beam Line

\( E_{\text{max}} = 500 \text{ MeV} \)
\( I \sim 120-150 \mu\text{A} \)

Variable Energy Extraction by H\(^-\) stripping

Use of Pepperpot ÷40 intensity

“Patient Mode”

Treatment parameters

BL2C 74 MeV
6 nA

Delivers 12.5 Gy in 100 sec.
Layout of Eye Treatment Equipment
Diagram of the Eye
Ocular Melanoma - Uveal or Choroidal Melanoma

Frequency: 5-6 cases/year per million population

Treatment protocols:
- Radioactive plaque therapy
- Charged particle radiotherapy
- Enucleation

Uveal Melanoma before proton beam treatment

Uveal Melanoma after proton beam treatment
Treatment Planning for Ocular Melanoma
Patient in Treatment Position

Treatment Chair
6 motorized motions
Χ, Y, Z, Κ, θ, Φ
Xrays viewed with Polaroid/Lanex Screen
Modulator and Patient Collimator

Modulators: 10 mm to 25 mm in 1 mm increments
Brass collimators, Aluminum wedges
Monitor Chamber with T1 calibration chamber in plastic holder

3D scanning table for dosimetry in a water box
Beam Profiles – Depth/Transverse

Markus data, comparison of raw Bragg peak, 15 mm and 23 mm cal wheels SOBP, 2.0 cm coll.

- 15 mm wheel
- 23 mm cal wheel
- raw Bragg peak
- raw Bragg shifted in depth -2.4 mm

- Diamond Perpendicular
- Diamond Parallel
- Diode Parallel
- Diode Perpendicular
TRI UMF Proton Patient & Tumor Statistics

Total Patients: 104  99 choroidal or uveal melanoma, 3 iris, 2 hemangioma (benign)

Ages: 14 - 80, Median 57

Tumour Control - >95%
Vision improvement/ loss : depends on tumour location and size
Complications - 10% neovascular glaucoma (may require enucleation)
Survival rate (> 5 years) 80%
# World Wide Charged Particle Patient Totals

**January 2004**

<table>
<thead>
<tr>
<th>Who</th>
<th>Where</th>
<th>What</th>
<th>Date First RX</th>
<th>Recent Patient Total</th>
<th>Comments</th>
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<tbody>
<tr>
<td><strong>North America</strong></td>
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<tr>
<td>Harvard</td>
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<td>1961</td>
<td>9116</td>
<td>160 MeV synchrocycl.– many pt tech. developed</td>
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<td>NPTC, MGH</td>
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<td>hospital based – 230 MeV cycl. + gantries</td>
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<td>UCSF – CNL</td>
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<td>TRIUMF</td>
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<td>π</td>
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<td>367</td>
<td>phase III trials using pions – stopped in 1994</td>
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<td>89</td>
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<td>Switzerland</td>
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<td>France</td>
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<td><strong>Japan</strong></td>
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NOT A COMPLETE LIST

Total Patients Worldwide 41501 (36111 protons)
## Conditions treated with protons at Loma Linda

<table>
<thead>
<tr>
<th>Brain and spinal cord</th>
<th>Isolated brain metastases</th>
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<tbody>
<tr>
<td></td>
<td>Pituitary adenomas</td>
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<td></td>
<td>Arteriovenous malformations (AVMs)</td>
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<td>Base of skull</td>
<td>Meningiomas</td>
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<tr>
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<td>Acoustic neuromas</td>
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<td></td>
<td>Chordomas and chondrosarcomas</td>
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<tr>
<td>Eye</td>
<td>Uveal melanomas</td>
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<td>Head and neck</td>
<td>Nasopharynx</td>
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<tr>
<td></td>
<td>Oropharynx (locally advanced)</td>
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<tr>
<td>Chest and abdomen</td>
<td>Medically inoperable non-small-cell lung cancer</td>
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<tr>
<td></td>
<td>Chordomas and chondrosarcomas</td>
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<tr>
<td>Pelvis</td>
<td>Prostate</td>
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<tr>
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<td>Chordomas and chondrosarcomas</td>
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<tr>
<td>Tumors in children</td>
<td>Brain</td>
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<tr>
<td></td>
<td>Orbital and ocular tumors</td>
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<tr>
<td></td>
<td>Sarcomas of the base of skull and spine</td>
</tr>
</tbody>
</table>

Protons best for well-defined tumours located near sensitive/important structures or organs.
Beam Delivery - Gantry with Spot Scan

PROSCAN @ PSI

Dose delivered by scanning beam at different energies
Hitachi - Japan

Hospital Based Proton Therapy Facility

1. Proton accelerator (synchrotron or cyclotron) capable of 250 MeV
2. Beam delivery system with gantries
3. Patient positioning equipment
4. Very sophisticated control system
5. Treatment planning and imaging devices (CT, MRI, ultrasound etc)
6. Building
7. Cost $100 million