Proton Therapy
Dosimetry & Clinical Implementation

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Department of Radiation Medicine
Outline

» Proton Therapy Basics
» Why Proton Therapy? (Dosimetric Superiority)
» Clinical Implementation
» Sample Proton Plans
» Loma Linda Experience
» Summary
BASICS
Radiation Therapy: Basic Facts

» Radiation kills tumor cells
  Higher the dose to the tumor ⇒ Better tumor control

» Radiation also kills normal cells
  Higher dose to normal cells ⇒ More complications
Radiation Therapy: Basic Goals

- Deliver high dose to tumor cells
  - maximal tumor cell kill
  - better tumor control

- Minimize dose to the normal surrounding tissue
  - minimize complications
  - maintain viability and function

All improvements in radiation treatment delivery have been driven by these goals
Why Protons?

High energy protons have ideal properties for radiation therapy:

Well defined range ⇒ A proton beam stops

As protons traverse the body, initially, rate of energy loss is low ⇒ Low entrance dose and low dose to tissue proximal to the tumor

Near the end of the range, proton deposit all their energy over a very small volume, (Bragg Peak) ⇒ Maximal dose to tumor

No energy is deposited beyond the Bragg Peak ⇒ No dose to normal tissues distal to the tumor
Why Protons?...

“Just using the **intrinsic properties** of high energy protons, we can, in principle, deliver **maximal dose to a tumor** in the body, at the same time **spare tissues proximal (upstream)** to the tumor, and deliver no dose to structures **distal (downstream)** to the tumor.”

These exactly are the basic goals of radiation therapy
Proton Therapy: Concept

Depth in Water [mm]

Relative Dose

SOBP
Tumor
Bragg Peak
Protons Vs. X-rays: Depth Dose Profiles

![Graph showing depth dose profiles for 23 MV X-Rays and 225 MeV Protons. The graph compares the absorbed dose at various depths, highlighting the tumor volume with the higher dose delivered by protons compared to X-rays.](image-url)
### To Summarize: Protons Vs. X-rays

<table>
<thead>
<tr>
<th><strong>Protons</strong></th>
<th><strong>X-rays</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bragg Peak (fixed range)</td>
<td>Exponential dose fall-off</td>
</tr>
<tr>
<td>Low entrance dose</td>
<td>Higher entrance dose</td>
</tr>
<tr>
<td>Almost no distal dose</td>
<td>Distal dose an issue</td>
</tr>
<tr>
<td>No exit dose</td>
<td>Finite exit dose</td>
</tr>
<tr>
<td>Less integral dose</td>
<td>Integral dose an issue</td>
</tr>
</tbody>
</table>

Protons are an ideal modality to treat cancer.
This is where it all began...

Radiological Use of Fast Protons

ROBERT R. WILSON
Research Laboratory of Physics, Harvard University
Cambridge, Massachusetts

Radiology, 47: 487-491 (1946)

Above: Curve I Range, Curve II: Ions/cm

Right: Hyperbolic Obelisk by Robert Wilson
Radiation Biology Considerations

» Protons are low LET radiation
  ⇒ Experience with photons is relevant to proton therapy

» Adopted Proton RBE value is 1.1

» Dose Specification (current convention)
  Cobalt Gray Equivalent Dose
  \[ \text{CGE} = 1.1 \times \text{(Proton Physical Dose)} \]

» Dose Specification (ICRU Report 78 Recommendation)
  RBE-weighted proton absorbed dose
  \[ D_{RBE}^{\text{(Gy)}} = 1.1 \times D^{\text{(Gy)}}, \text{D is proton absorbed dose} \]
Radiation Biology Considerations...

» Proton LET is depth dependent, maximum near Bragg Peak

» Superior energy deposition patterns

» RBE is depth dependent, Maximum near the Bragg Peak
   Higher effective dose near the distal edge
   An issue for distal organ sparing
IMPLEMENTATION
Loma Linda Proton Treatment Facility Layout

- Synchrotron
- Beam Transport System
- Treatment Gantry 1-3
- Fixed Beamline
- Research Beamline
James M. Slater, MD, Proton Therapy & Research Center, LLUMC

World’s first hospital based proton treatment facility (1990)

Protons accelerator: a synchrotron
Treatment Machines
  three isocentric gantries
  one fixed horizontal beam line
  one fixed eye beam line
  one research room (3 fixed beams)
Clinical Energies (MeV): 250, 225, 200, 186, 155, 126, 100

140-160 patients treated with protons everyday
Patient Immobilization

A Whole-body Pod

A Face Mask
Immobilization: Proton Radiosurgery

Vacuum assisted dental & table fixation device
Imaging
Devices: 3D-Conformal Therapy with Protons
Compensator Bolus
3D-Conformal Therapy with Protons...

Bolus: Dose conformity in the distal aspect of tumor

Aperture: Dose conformity in the lateral aspect of the tumor

Modulator Wheel: Dose conformity in the proximal aspect

A single proton beam can deliver 3-D conformal dose distribution to a tumor!
## Proton Therapy Facilities in Operation in the USA

<table>
<thead>
<tr>
<th>Institution</th>
<th>Max Clinical Energy (MeV)</th>
<th>Start Date</th>
<th>Patients Treated</th>
<th>Date of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>JMS-PTRC Loma Linda, CA</td>
<td>250</td>
<td>1990</td>
<td>13500</td>
<td>March-2009</td>
</tr>
<tr>
<td>MPRI Bloomington, IN</td>
<td>200</td>
<td>1993</td>
<td>220</td>
<td>Sept-2006</td>
</tr>
<tr>
<td>NPTC, MGH Boston, MA</td>
<td>235</td>
<td>2001</td>
<td>3000</td>
<td>July-2008</td>
</tr>
<tr>
<td>MDACC Houston, TX</td>
<td>250</td>
<td>2006</td>
<td>700</td>
<td>July-2008</td>
</tr>
<tr>
<td>FPTI Jacksonville, FL</td>
<td>230</td>
<td>2006</td>
<td>500</td>
<td>July-2008</td>
</tr>
</tbody>
</table>
Proton Centers Under Construction in the USA

The Northern Illinois Proton Treatment and Research Center at Northern Illinois University
West Chicago

HU Proton Therapy Institute

PraCure Proton Therapy Center
Oklahoma City, OK
located at the INTEGRIS Cancer Center

LOMA LINDA UNIVERSITY
MEDICAL CENTER
Proton Treatment Gantry Structure

- 35 feet diameter (3-story tall!)
- Weighs 90 tons
- Isocentric, SAD=250-285 cm
- Isocentric Accuracy = 1 mm
A Typical Proton Patient Treatment
Proton Eye Treatment
Proton Stereotactic Radiosurgery Treatment
Gantry Upgrade to Robotic Positioner System

• Increased degrees of freedom
• Better real time imaging
• More treat-through areas
• Increased patient throughput
Treatment Room with the Robotic Positioner
Dose Distributions (X-rays Vs. Protons)
X-rays Vs. Protons : Breast Treatment

X-rays

Protons
Proton Patch Fields: Simple and Elegant
Proton Stereotactic Radiosurgery (AVM)
So, Why Protons? (Medulo Blastoma: PNET)

Treatment with X-rays  Treatment with Protons
Treatment Planning With Protons

Dosimetry Planning

Distal margins
Proximal margins
Bolus design
Distal Blocking and Distal Edge Patching

Powerful tools unique to proton planning

More parameters available to optimize a dose distribution
Proton planning is quite challenging
Treatment Planning with Protons…

Distal Blocking and Distal Edge Patching

Shoot Through Beam

Patching Beam
Treatment Planning with Protons...

Dosimetry Planning...

RBE issues

Noticeable increase in RBE near the distal edge

Extra care needed in setting up distal margins

This fact can be exploited in treatment planning
## Treatment Planning with Protons: Uncertainties

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Uncertainty</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>0.035 x depth</td>
<td>Distal margins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Proximal margins</td>
</tr>
<tr>
<td>Position</td>
<td>Pod: 0.5 cm</td>
<td>Lateral margin</td>
</tr>
<tr>
<td></td>
<td>mask: 0.3 cm</td>
<td>Bolus smear</td>
</tr>
<tr>
<td>Motion</td>
<td>Measure/Estimate</td>
<td>Lateral margin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bolus smear</td>
</tr>
<tr>
<td>Range</td>
<td>0.3 cm</td>
<td>Distal &amp; proximal margins</td>
</tr>
<tr>
<td>Penumbra</td>
<td>Measured</td>
<td>Lateral margin</td>
</tr>
<tr>
<td>Scatter</td>
<td>0.03 x Range</td>
<td>Bolus smear</td>
</tr>
</tbody>
</table>
We treat many kinds of cancers...

Prostate 66%

Choroidal Melanoma 1.5%
Pituitary 0.8%
Acoustic Neuroma 0.7%
Meningioma 1.5%
Astrocytoma 1.3%
Other Brain 3.4%
Craniopharyngioma 0.2%
Head & Neck 6.0%
Other Pelvis 0.9%
Orbital 0.5%
Paraspinal Tumors 1.1%
Chordoma/Chondrosarcoma 4.3%
Sarcoma 1.1%
Other Chest 3.9%
AVM 1.5%
Other Abdominal 1.3%
SNVM 3.9%

13,500 Patients treated through 03/2009
Patients from all over the world...

Other Countries with <0.08%
Africa, Argentina, Austria, Bahamas, Bermuda, Bolivia, Cayman Islands, Chile, Curacao, Dominica, Greece, India, Indonesia, Ireland, Jamaica, Japan, Korea, Kuwait, Lebanon, Malaysia, Netherlands, Nevis, New Zealand, New Zealand, Peru, Philippines, Poland, Russia, Singapore, Spain, Switzerland, Thailand, Turkey, Venezuela

International: 3%
Summary

» Proton therapy is an established form of radiation therapy

» It offers clear advantages in terms of conformal dose delivery to tumors and conformal avoidance of normal structures

» For the same tumor control, proton therapy offers clear advantage in terms of reduced normal tissue complications

» Proton therapy is financially viable

» Focus should shift from “justifying proton therapy” to reducing start up costs
Loma Linda University Medical Center
Loma Linda, California
Thanks