Protons Can Be Delivered as Easily as Photons

Thomas Rockwell Mackie
Emeritus Professor, University of Wisconsin
Madison WI
Proton therapy needs further technological development to fulfill the promise of becoming a superior treatment modality (compared to photon therapy)

Daniel E. Hyer1 | Xuanfeng Ding2 | Yi Rong3

1 Department of Radiation Oncology, University of Iowa, Iowa City, Iowa, USA
2 Department of Radiation Oncology, William Beaumont Hospital, Royal Park, Michigan, USA
3 Department of Radiation Oncology, Mayo Clinic Arizona, Phoenix, Arizona, USA

Correspondence
Yi Rong, Department of Radiation Oncology, Mayo Clinic Arizona, Phoenix, AZ.
Email: rongyi@gmail.com

Daniel E. Hyer and Xuanfeng Ding contributed equally to the manuscript.
Disclosure and Potential Conflicts of Interest Statement

I am the Co-founder, Chief Innovation Officer and Chairman of the Board and have financial interest in Leo Cancer Care which is developing an upright radiotherapy system.

I am a Board Member and have financial renumeration by Cosylab which provides and maintains control software to science laboratories and radiation therapy equipment worldwide.
Overview

- Eliminate complex building projects and high costs
- Reduce proton beam commissioning
- Use a fixed horizontal beam with an upright positioning system
- Upright positioning may be better much of the time
- Patients prefer to be upright
- High-quality CT scan needed in the upright treatment position
- Similar QA used in photon radiotherapy
- Planning more like photon radiotherapy
- Intensity-modulated arc therapy (IMAT)
- What about other imaging systems?
- Eliminate the need for specialty proton medical physicists
Multi-room Construction Projects Are Massive
Heidelberg Particle Beam Facility Has Rotating and Fixed Beams

<table>
<thead>
<tr>
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<th>Rotating Beam</th>
<th>Fixed Beam</th>
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<tbody>
<tr>
<td>Patient Recumbent</td>
<td>✓</td>
<td>Clumsy?</td>
</tr>
<tr>
<td>Patient Upright</td>
<td>Not Necessary</td>
<td>✓</td>
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Coplanar Photon Beam Radiotherapy Systems

- TomoTherapy (MVCT)
- Varian Halcyon (CBCT)
- Elekta Unity (MRI)
- Reflexion (PET)
- Aurora (MRI)

Note: All These Systems Have Built-in IGRT
Most Proton Radiotherapy is Coplanar

- Vast majority coplanar only
- You can treat all cases with a carefully designed beam delivery and an upright patient positioning system
The Beam Magnet System Has to be Tweaked for Every Gantry Angle

- For mechanical variation
- To adjust for changing direction from Earth’s magnetic field

\[ \vec{F} = q(\vec{v} \times \vec{B}) \]
MeVion S250i-FIT Treatment Room

MeVion 250 MeV Synchrocyclotron

Compact MeVion 250 MeV Synchrocyclotron

Conventional Linac Vault

Patient Positioner and Upright CT
Rendering of MEVION FIT (Stanford University)
How Small is it Really?

VARIAN TrueBeam

MeVion Accelerator +
LEO System
= MeVion S250i FIT

VARIAN TrueBeam
MeVion S250i FIT

From Niek Schreuder, Leo Cancer Care
It Would Fit in the "Paint" of a Basketball Court
One Hitachi Gantry + One Upright Room with Hitachi Synchrotron (UW-Madison)
Enablers for Upright Proton Radiotherapy

Upright CT at the Isocenter
A Dual-Energy CT Capable Of Imaging Head & Neck, Breast & Lung, Prostate

Upright Positioning
An Upright Positioning System Capable of Treating Head & Neck, Breast & Lung, and Prostate
Designed for a Variety of Upright Postures

1. Postures we need to be able to position the patient to treat <95% of cancer cases

2. Develop a patient positioner that can do that
Multi-Axis Patient Positioner

1. Patient Posture
   *Not DICOM parameters Yet*
   **Above Floor Motorized**
   - Seat Height
   - Seat Pan Angle
   - Shin Rest
   - Heel Stops
   **Non-Motorized**
   - Indexed Backrest angle
   - Arm rests

2. Patient Setup
   **Standard DICOM Parameters**
   **Below Floor Motors**
   - Z - Elevation
   - X - Left-Right
   - Y – Front-Back
   - Yaw
   - Pitch
   - Rotation

Necessary Immobilization
   - Vac Lock Bag
   - Abdominal Belt
   - Face Mask

Upright Positioner at Lyon France
Medical Pediatric Upright Seats are Available

TransMotion Medical Child Seat with Belt
• Plastic coated foam construction
• Claims nontoxic with anti-microbial protection, washable, and odor, urine, and stain resistant
• 4 inches of vertical adjustment of the shoulder straps for large size
• 2 year warrantee

Multicamera System for Setup and Surface Registration
Intra-fraction Shifts Over 20 Minutes of Simulated Helical Treatments

~80% of patients have shifts of < 1 mm

Boisbouvier et al. TIPSRO 24: 124-130 (2022)
Patient Stability and Comfort Questionnaire Results from 15 Patients

- Patients felt stable: 87% Upright, 67% Supine
- Patients found it comfortable to breathe: 100% Upright, 87% Supine
- Patients felt it easy to get out of the system: 88% Upright, 70% Supine
- Patients felt comfortable: 87% Upright, 73% Supine

Boisbouvier et al. TIPSRO 24: 124-130 (2022)
Diagnostic Quality CT Scanner for Planning and Adaptive Radiotherapy

CT Balanced Along Translation

Counterweight

Scanning Parallel with the Chair Back
Phantom CT Scan

Scan Parameters

- 140 kV, 100 mAs
- 1 s rot speed
- 32 row detector
- pitch = 0.93
- 2 mm Al filter
- Large focal spot
Scanning Workflow

Imaging Sequence – CT SIM

CT Data Sent to Treatment Planning

Imaging Sequence + Treatment Sequence

From Niek Schreuder, Leo Cancer Care
Indications for Upright – Head and Neck

Head & Neck
10 % of Cancer Cases

- Already used for eye treatments
- More stability and accuracy
- Easier to swallow
- Less gastric reflux issues

https://www.who.int/news-room/fact-sheets/detail/cancer
Indications for Upright - Lung

LUNG
22% of Cancer Cases

- Lung more inflated
- Less lung movement

https://www.who.int/news-room/fact-sheets/detail/cancer
Indications for Upright- Breast

- Control of skin folds
- More reliable positioning

https://www.who.int/news-room/fact-sheets/detail/cancer
Indications for Upright - Liver

- No systematic organ drift

LIVER
9% of Cancer Cases

https://www.who.int/news-room/fact-sheets/detail/cancer
Indications for Upright - Prostate

- Prostate is more stable
- No bladder filling needed

PROSTATE
13% of Cancer Cases

https://www.who.int/news-room/fact-sheets/detail/cancer
Incidences for Upright

Head & Neck
10% of Cancer Cases

LUNG
22% of Cancer Cases

BREAST
22% of Cancer Cases

LIVER
9% of Cancer Cases

PROSTATE
13% of Cancer Cases

https://www.who.int/news-room/fact-sheets/detail/cancer
QA Test Fixtures Mounted on Upright Positioner

- Winston-Lutz Test Fixture
- General Upright Test Fixture
- 10 cm x 10 cm Scribe Lines
- Film Attachment Surface
- +/- 3 deg Scribe Lines

Table Fixture
RayStation Supports Upright Radiotherapy

RayStation 10A and beyond is 100% ready for upright treatment planning
Particle Beams Stop Thereby Providing More Degrees of Freedom for Avoiding Normal Tissue

Multiple paths to the distal edge of a tumor reduces uncertainty.
IMPT is Nearly Mature Technology

- Need to plan for robustness
- Affect of severe density heterogeneity is more important than for photon radiotherapy
- Effect of motion is more important than for photon radiotherapy

From Paganetti and Bortfeld, Proton Beam Radiotherapy – State of the Art
Spot Scanning and Arc Dose Distributions

Arc Distributions Can Limit the Path Through Tumor and Reduce Spots on the Periphery Directed Towards Sensitive Normal Tissues

From Ryan Flynn, University of Iowa
Dose Contrast Resolution

Apply Boost or Avoidance (Negative Boost) Dose to Regions of Varying Size

From Ryan Flynn, University of Iowa
Conformity and Normal Tissue Dose

From Ryan Flynn, University of Iowa
Comparison of Photon IMRT and Proton Arc IMPT

From Ryan Flynn, University of Iowa
Upright Proton Arc Therapy Rendered by RaySearch
Proton Radiotherapy Should Not Be a Specialization

Proton cancer therapy among areas threatened by skills shortage

by Cockcroft Institute
Take Home Messages

• Upright radiotherapy can:
  • Eliminate complex building projects and high costs
  • Eliminate proton gantry commissioning
  • Eliminate the need for specialty proton medical physicists
• High-quality upright CT scanner is required for upright radiotherapy
• QA and planning can be more similar
• IMPT and IMAT is nearly mature for upright radiotherapy

Thank You
Or Perhaps Children Should Be Forward Leaning?

Fabricated by Niek Schreuder and Featuring His 3 yr Old Granddaughter