Hadron Therapy: A Physicist’s View
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Prevention, Diagnosis, Treatment

Italian National Institute of Health
From service to value for-money

- **Hadron-therapy (proton and ions)**
  - ☺ has intrinsic physical properties to precisely target the tumors, reducing side effects
  - ☹ has remarkable biological effects on tumor cells
  - ☹ is relatively expensive

- **Continuously growing**
  - technologies development
  - improved physics and biological knowledge
  - extended cost/benefit and clinical outcomes analyses

Facilities in Clinical Operation and No. of Patients Treated (1955-2014)

Ref.: PTCOG, 2015
Clinical outcomes depend on how well we **know** and **control** the physics and the biological processes involved in the hadron therapy and how we make them happen.
Hadron-therapy facility

CNAO Layout

(Circular) Accelerator

Beam Trasport

Treatment Room

Beam/Dose Delivery

Beam Physics Characterization

Patient positioning and verification

Control System

Quality Assessment

Treatment planning

Patient Data Management

Costs analysis from A. Peeters et al., Rad. & Onc. 95 (2010) 45-53

<table>
<thead>
<tr>
<th>Costs (keuro)</th>
<th>Capital</th>
<th>Oper./year</th>
<th>Fraction</th>
<th>Treatment</th>
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</thead>
<tbody>
<tr>
<td>Carbon+Proton</td>
<td>140000</td>
<td>37000</td>
<td>1.1</td>
<td>10-30</td>
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<tr>
<td>Proton</td>
<td>95000</td>
<td>25000</td>
<td>0.7</td>
<td>12-39</td>
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<tr>
<td>Photon</td>
<td>23000</td>
<td>10000</td>
<td>0.2</td>
<td>4-18</td>
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</tbody>
</table>

Surgery: 14-57 kUSD
Pharmacologic: 1-120 kUSD
Note: cost/treatment strongly depends on tumor and modality
Current developments directions

Reducing system costs
- Lower power needs
- Smaller size
- Simpler procedures
- Smaller weight

Advancing therapeutic performances
- Improved planning
- Optimal dose delivery
- Accurate quality assurance
- Improved assessment

A dream device (single room facility)

New acceleration technologies: Linear Accelerator, Superconducting, FFAG, Laser Acceleration, Dielectric Wall Accelerator

Caporaso et al. (2009)
Artistic view
Linear Accelerator for Proton Therapy

- Compact and lightweight
- Radiation clean, reduced shielding
- Power efficient
- **Very Modular**: customizable according to needs; can be in operation during its construction

- **Performances**: all physics properties (energy, intensity, direction, …) of the particle beam can be varied quickly and actively offering improved precision and larger flexibility on dose delivery to the patient (e.g. optimal intrafraction motion control)

- Only single ion type can be accelerated

- Never used before for therapy (but physical modality similar to photon therapy)

Estimated Capital costs: 40-70 MEuro
LinAc for Proton Therapy becoming real

TOP-IMPLART facility

Enel
Italian National Agency for New Technologies, Energy and Sustainable Economic Development

IRE
Istituto Nazionale Tumori Regina Elena
Istituto di Ricostruzione e Curva a Carattere Scientifico

Italian National Institute of Health

Regione Lazio

Status:
Energy: 35 MeV
(150 MeV in 3 years)
Current/Pulse: 30 uA

Projects on LinAc for PT:
LIGHT, Erha, TOP-IMPLART

Already in operation for:
- Beam and diagnostics characterization
- Radiobiology studies
- Cultural heritage analyses
- New development (e.g., LiF dosimetry)
- Radioprotection optimization studies

Current development total costs: ~6 Meuro
Robust Treatment Planning

The optimal exploitation of a very accurate equipment needs to tackle all details of the involved processes and a careful plan.

**Physics Processes**
- Tracking particles in heterogeneous matter

**Biological Effects**
- Tumor and Normal Tissue Biological / Personalized Response

**Planning System**
- Decision support (AI)
- Monte Carlo methods
- Computing Power

- Accurate (few %) and extended low energy nuclear physics data
- Radiobiology data
- Anatomic and Functional Imaging of the patient
- Detailed and validated accelerator description

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F. Tommasino et al. Cancers, 2015

GPU: from games to crucial applications

8
Nuclear Science and Technologies

**play a major role** in many key aspects of hadron radiation therapies and their improvements are substantial for the ultimate benefit of the patients.

<table>
<thead>
<tr>
<th>System</th>
<th>Planning</th>
<th>Treatment</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerator</td>
<td>Quality Control</td>
<td>Delivery modality</td>
<td>Online Dose Delivered</td>
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<tr>
<td>Diagnostic Devices</td>
<td>Imaging</td>
<td>Delivery control</td>
<td>Verification</td>
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<td>Redundancy and Safety</td>
<td>Modeling</td>
<td>Intra-fractional Motion control</td>
<td>Montecarlo validation</td>
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<tr>
<td></td>
<td>MonteCarlo (computing)</td>
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Thank You