The Heidelberg Ion Therapy Center
and
PARTNER

Thomas Haberer
Heidelberg Ion Therapy Center
Goal

The key element to improve the clinical outcome is **local control!**

**entrance channel:**
- low physical dose
- low rel. biol. efficiency

**tumour:**
- high physical dose
- high rel. biol. efficiency

275 MeV/u $^{12}$C in Water, 3mm FWHM
Standard Approach

- Facilities being built at existing research accelerators
- Fixed energy machines with moderate flexibility (if at all)
- Dose delivery not exactly tumor-conform
Carbon Ion Therapy at NIRS

(June 1994-August 2004)

Total 2,297

- Lung 245 (18.9%)
- Head & Neck 207 (16.0%)
- Prostate 190 (14.6%)
- Liver 145 (11.2%)
- Bone/soft tissue 121 (9.3%)
- Uterus 78 (6.0%)
- Brain 74 (5.7%)
- Esophagus 23 (1.8%)
- Base of skull 20 (1.5%)
- Pancreas 18 (1.4%)
- Rectum 15 (1.2%)
- Eye 13 (1.0%)
- Miscell. 148 (11.4%)
Carbon Ion Therapy @ GSI

Fig. 4.4a: The GSI Accelerator Facility
Rasterscan Method

scanning of focussed ion beams in fast dipole magnets

active variation of the energy, focus and intensity in the accelerator and beam lines

utmost precision via active position and intensity feed back loops

intensity-controlled rasterscan technique @ GSI
Haberer et al., NIM A, 1993
Key Developments @ GSI

• Scanning-ready pencil beam library (25,000 combinations): 253 energies (1mm range steps) x 7 spot sizes x 15 intensity steps
• **Rasterscan method** incl. approved controls and safety
• **Beammonitors** follow the scanned beams (v <= 40 m/s) in real-time
• **Biological interaction model** based on 25 years of radiobiological research
• Physical beam **transport model**
• **Planningsystem** TRiP
• **In-beam Positron Emission Tomography**
• **QA system**
• ...

Th. Haberer, Heidelberg Ion Therapy Center
Results

Pre OP

Post OP

chondro sarcoma

rasterscanned carbon ions

dose [%]
FSRT / IMRT vs FSRT / IMRT+C12 at the locally advanced adenoid-cystic carcinoma

Schulz-Ertner, Cancer 2005

- acute toxicity acceptable
- late toxicity > CTC Grad 2 < 5%

Th. Haberer
Heidelberg Ion Therapy Center

- compact design
- full clinical integration
- rasterscanning only
- low-LET modality: Protons (later He)
- high-LET modality: Carbon (Oxygen)
- ion selection within minutes
- world-wide first scanning ion gantry
- > 1000 patients/year
  > 15,000 fractions/year

Th. Haberer, Heidelberg Ion Therapy Center
Some Facts

• Effective area 5.027 m²
• Concrete 30,000 tons
• Constructional steel 7,500 tons
• Capital Investment 100 M€

Start of construction: November 2003
Completion of building and acc.: June 2006
First patient planned: early in 2009

Project Partners:
• University pays, owns and operates the facility
• GSI built the accelerator
• Siemens supplies all components related to patient environment
• GSI, DKFZ, ... are research partners
HIT / General Requirements

- **ions**: p, $^3\text{He}^{2+}$, $^{12}\text{C}^6$, $^{16}\text{O}^{8+}$

- **energies (MeV/u)**: 48, 72, 88, 102 (255 steps)
  - -220, -330, -430, -430

- **beam spot size**: 4 - 10 mm (2d-gaussian) (4 steps)

- **treatment caves**: 3 (2 horizontal, 1 iso-centric gantry)

- **QA and research**: 1 (1 horizontal)

Th. Haberer, Heidelberg Ion Therapy Center
H, Li, C, N, O ?

RBE for fractionated RT of gut crypt cells of mice (Berkeley)

Which Ion is optimal: Li, C, N, O ?
And: for which clinical indication?
high energy beam transport

synchrotron

Th. Haberer, Heidelberg Ion Therapy Center
Identical patient positioning systems
- fixed beam
- gantry

Workflow optimization
- automated QA procedures
- automated patient hand over from shuttle
- treatment chair

Inroom position verification
- 2D
- 3D Cone beam CT

Open for future applications and workflows

Th. Haberer, Heidelberg Ion Therapy Center
Patient Positioning
Status & Next Steps

preliminary scanner commissioning result
Protons@maximum energy recorded in a verification film
no feedback loops for beam intensity or position
(courtesy S.O. Grözinger et al., Siemens Medical Solutions)
Motivation

Gantry

Advantage of a rotating beamline

Pancreas, supine position via gantry advantageous
Scanning Ion Gantry

- optimum dose application
- world-wide first ion gantry
- world-wide first integration of beam scanning
- 13m diameter
  25m length
  600to overall weight
  0,5mm max. deformation
- prototype segment tested at GSI

Th. Haberer, Heidelberg Ion Therapy Center
Mounting
Gantry / Medtech

Patient Gantry Room November 2007

Tilt floor, pending on Gantry position

Nozzle
Bumber mats
Patienttable, Roboter
Gantry: first beam at the isocenter
<table>
<thead>
<tr>
<th>15-M1</th>
<th>Customisation and integration of the FLUKA MC code in the UKL-HD (HIT) research planning platform for dose calculations of scanned ion beams in water and patient- or phantom-CTs</th>
<th>M6</th>
<th>Milestone: Integration of the FLUKA Monte Carlo code in the research planning platform for scanned ion beams at UKL-HD (HIT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-D1</td>
<td>Development of workflow-efficient analysis tools for comparison of MC and analytical treatment plan calculations</td>
<td>M18</td>
<td>Deliverable: Report</td>
</tr>
<tr>
<td>15-D2</td>
<td>Intercomparison between MC and analytical treatment plan calculations in a representative number of challenging real clinical situations (e.g., in the presence of tissue/air interfaces and metallic implants, dose to water/tissue...)</td>
<td>M24</td>
<td>Deliverable: Report</td>
</tr>
</tbody>
</table>
Calculations done with TRiP98 and TRiP98Beam (S. Brons, K. Parodi)
### PARTNER: Clinical Studies, Epidemiology and Patient Selection

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Milestone</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-M1</td>
<td>Effectiveness of carbon ions therapy</td>
<td>m3</td>
<td>Specification</td>
</tr>
<tr>
<td>2-M2</td>
<td>Correct definition of treatment volumes &amp; precise patient setup</td>
<td>m6</td>
<td>Report</td>
</tr>
<tr>
<td>2-D1</td>
<td>Preliminary results: LC and early toxicity</td>
<td>m6</td>
<td>Report</td>
</tr>
<tr>
<td>2-M3</td>
<td>Target definition for treatment</td>
<td>m12</td>
<td>Protocol</td>
</tr>
<tr>
<td>2-M4</td>
<td>Technique for data analysis selected</td>
<td>m21</td>
<td>Protocol</td>
</tr>
<tr>
<td>2-D2</td>
<td>Experimental data analysed</td>
<td>m24</td>
<td>Report</td>
</tr>
<tr>
<td>2-D3</td>
<td>Preliminary results: LC, DFS, OS, and late toxicity and relationship with dose fractionation and Final Report</td>
<td>m24</td>
<td>Report</td>
</tr>
<tr>
<td>2-D4</td>
<td>Clinical validation of biological input parameters</td>
<td>m30</td>
<td>Report</td>
</tr>
<tr>
<td>2-D5</td>
<td>Cost-effectiveness analysis</td>
<td>m36</td>
<td>Report</td>
</tr>
</tbody>
</table>

*Courtesy S. Combs*
PARTNER: Clinical Studies, Epidemiology and Patient Selection

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Task Description</th>
<th>Milestone</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-M1</td>
<td>Refine epidemiological data for indication for ion therapy</td>
<td>m6</td>
<td>Milestone</td>
</tr>
<tr>
<td>2-D1</td>
<td>Comparison of data on photon proton and ion therapy</td>
<td>m12</td>
<td>Report</td>
</tr>
<tr>
<td>2-M2</td>
<td>Develop clinical trial of specific indication</td>
<td>m18</td>
<td>Protocol</td>
</tr>
<tr>
<td>2-D2</td>
<td>Report on the analysis of the data on P2-M2</td>
<td>m36</td>
<td>Report</td>
</tr>
</tbody>
</table>

Courtesy S. Combs
Preparatory Work

carbon ion therapy for chondrosarcomas at the base of the skull

local control 96.2% / 89.8% at 3 / 4 years, n=54

failure: n=1 in-field
n=1 border

5-year OS 98.2%

Schulz-Ertner, IJROBP 2007

Courtesy S. Combs
Goals of this planned trial:

Optimized therapy of chordomas and chondrosarcomas at the base of the skull

Comparison: high-dose proton vs carbon ion treatment, monitor local control, overall survival and toxicity (phase III trial)

Establish a common protocol

Other trials are under way (pancreas, prostate, …)

Courtesy S. Combs, J. Debus, K. Herfarth, M. Münter
Organ motion and beam scanning

4DCT lung tumor

Organ motion + with beam scanning leads to *interplay* effects

*Courtesy by E. Rietzel (MGH) and C. Bert (GSI)*
Thank you for your attention!