WP9: Advanced beam delivery

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GSI HELMHOLTZ CENTER FOR HEAVY ION RESEARCH

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101008548
Overview

- **Task 9.1**: A modular patient chair and imaging design
- **Task 9.2**: Particle arc therapy for fixed beam lines
- **Task 9.3**: Clinical scenarios for particle arc therapy on sitting patients
- **Task 9.4**: Particle arc therapy at high dose rates

Milestones/deliverables:

- **Deliverable 9.1 (M9)**: Conceptual design report for a modular patient chair and vertical imaging
- **Deliverable 9.2 (M30)**: Particle arc therapy delivery to a small scale demonstrator of a rotational patient positioning system for gantry-free delivery with a position feedback integrated to the DDS
- **Deliverable 9.3 (M48)**: Patient identification and Experimental validation of arc therapy treatment plans through patient QA-like procedures
- **Milestone 9 (M18)**: Finished simulation environment for particle arc therapy
Task 9.2: Particle arc therapy for fixed beam line

Carbon arc TPS:
- Field setup
- Pre-selection of energy band and spot positions
- A-priori energy selection
- Raster point setup
- Iterative energy optimization
- Rob. bio. optimization and plan refinement

Small scale demonstrator:
- Beam nozzle
- Dose delivery system
- Rotating stage
Task 9.2: First experiments at GSI

- Arc simulator running at GSI
- Rotation controlled by (our research version of) the CNAO dose delivery system
  - Step & shoot with multiple angles per spill – synchroniziation of delivery and rotation by gating
  - 180 control points with single energies to small targets

Laila El Ouali
Task 9.2: First experiments at GSI - results

➢ Several issues identified, a.o. gating system at GSI is not sufficient, upcoming beam time in 2025 will use one spill per angle – delivery still within 5-10 min

➢ Outcome: synchronization was successful; ready for next experiments
Task 9.3: Clinical scenarios for particle arc therapy on sitting patients

- Datasets of upright patient treatment
  - arc simulations on energy selection in 6 patients from SPHIC (presented last year, now published)
    Volz et al, Health and Technology 2024, https://doi.org/10.1007/s12553-024-00877-0
  - 6 lung patients scanned upright and supine:
    - developed method for co-registration (ready for submission)
    - investigated dosimetric differences, will be extended to 14 pax
  - dataset on multiple metastases in the brain: comparison of photon hyper arcs, proton and carbon ion arc therapy
Ion-based LET boost by particle arc irradiation (LEOPARD)

Idea: boost hypoxic core with dose and LET
Boost delivered by arc vs. by conventional SIB
and because we can: multi-ion combinations
to further concentrate LET where it matters

tested in H&N patient cases,
with hypoxic target volume (HTV) defined as GTV minus 1…5 mm

courtesy of
Guangru Li
LEOPARD simulations in TRiP98

Figure 1. Dose volume histogram (DVH) and LET$_d$ volume histogram (LVH).

Figure 2. $D_{RBE}$ and LET$_d$ maps, depicted VOIs: CTV (red), HTV (black), brainstem (yellow), right eye (green), left eye (blue).

courtesy of Guangru Li
Spot-scanning hadron arc (SHArc) for stereotactic radiosurgery of multiple brain metastases
L. Volz¹, P. Liu², T. Tessonnier³, M. Durante¹, A. Mairani³, X. Ding², T. Li⁴ and S. Mein³,⁴

oral presentation at ESTRO 2024

use case: recurring metastases in the brain

Stereotactic radiosurgery (SRS), esp. Hyper-Arc VMAT (HA-VMAT)¹

Single dose SRS effective²

Recurrences are common, re-irradiation leads to challenging brain exposure

protons (non-coplanar SPArc, RayStation) or carbon (SHArc, FROG, TRiP98) for lower dose volume
  • robust optimization to 1mm / 2.5%

³Milano et al. (2021) IJROBP; ⁴Atkins et al. (2018) IJROBP
Patient case with 3 metastases

<table>
<thead>
<tr>
<th>Modality</th>
<th>D99%</th>
<th>D1%</th>
<th>V2Gy</th>
<th>V12Gy</th>
</tr>
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<tbody>
<tr>
<td>HA-VMAT</td>
<td>25 Gy</td>
<td>32 Gy</td>
<td>342 cc</td>
<td>9 cc</td>
</tr>
<tr>
<td>SPArc</td>
<td>25 Gy</td>
<td>35 Gy</td>
<td>123 cc</td>
<td>12 cc</td>
</tr>
<tr>
<td>SHArc^{12}C</td>
<td>21 Gy</td>
<td>29 Gy</td>
<td>89 cc</td>
<td>11 cc</td>
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</table>

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Patient case with 5 metastases

<table>
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<th>D1%</th>
<th>V2Gy</th>
<th>V12Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td>HA-VMAT</td>
<td>25 Gy</td>
<td>28 Gy</td>
<td>776 cc</td>
<td>12 cc</td>
</tr>
<tr>
<td>SP Arc</td>
<td>22 Gy</td>
<td>31 Gy</td>
<td>331 cc</td>
<td>15 cc</td>
</tr>
<tr>
<td>SH Arc$^{12}$C</td>
<td>22 Gy</td>
<td>27 Gy</td>
<td>190 cc</td>
<td>14 cc</td>
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</table>

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Patient case with 10 metastases and resection cavity

<table>
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<th>D99%</th>
<th>D1%</th>
<th>V2Gy</th>
<th>V12Gy</th>
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<tbody>
<tr>
<td>HA-VMAT</td>
<td>23 Gy</td>
<td>28 Gy</td>
<td>1278 cc</td>
<td>93 cc</td>
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<tr>
<td>SPArc</td>
<td>22 Gy</td>
<td>29 Gy</td>
<td>565 cc</td>
<td>58 cc</td>
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<tr>
<td>SHArc(^{12}\text{C})</td>
<td>21 Gy</td>
<td>28 Gy</td>
<td>488 cc</td>
<td>60 cc</td>
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UPLIFT Doctoral Network coordinated by GSI

Strong interest in upright particle therapy enabled us to assemble DN consortium
- 14 institutes across Europe to host 19 ESR (15 EU, 2 CH, 2 UK) ~ 5 M€
- spanning industry, particle and photon centers
- from clinical & technical to health economics and patient empowerment

Funding granted in April 2024, project start is Oct 1, 2024:
we need excellent students – please send us yours!

GA awaits signature, details still in embargo
Summary and contributions

- Research platform for particle arc established & exploited for new approaches
- Continuation funding secured
- Upright therapy project developed into a large international collaboration
  - Lennart Volz co-organizer of Upright Research Consortium
- Publications & Talks:
  - 2 Talks (Volz, Li) on arc therapy at ESTRO2024, upcoming proffered posters at PTCOG
  - PT review including WP9 topics (Graeff et al, PPNP 2023); arc strategy (Volz et al, Health & Technology 2024)
  - Particle arc review (Mein et al, Green Journal) in revision
  - Manuscripts ready to be submitted for upright therapy strategies & arc boost therapy.
THANK YOU