Re-Evaluation of Beam Energy and Field Size Limits for Clinical Proton Beam Therapy and Related Machine Requirements

Richard A. Amos[1], Erik Traneus[2], and Stefan Schmidt[3]

[1]University College London, London, UK, [2]RaySearch Laboratories AB, Stockholm, Sweden, [3]Particle Therapy Consultant, Overath, Germany

Objectives

Proton beam therapy (PBT) is an increasingly well-established radiotherapy modality with more than 100 facilities currently in operation worldwide and many more under development. However, the large financial investment required to build a new PBT facility, even for compact single-room systems, hampers more widespread adoption of this technology, thus limiting access to cancer patients who may benefit. The objective of this study is to re-evaluate the technical requirements for clinical PBT systems and to suggest potential solutions for equipment cost-savings.

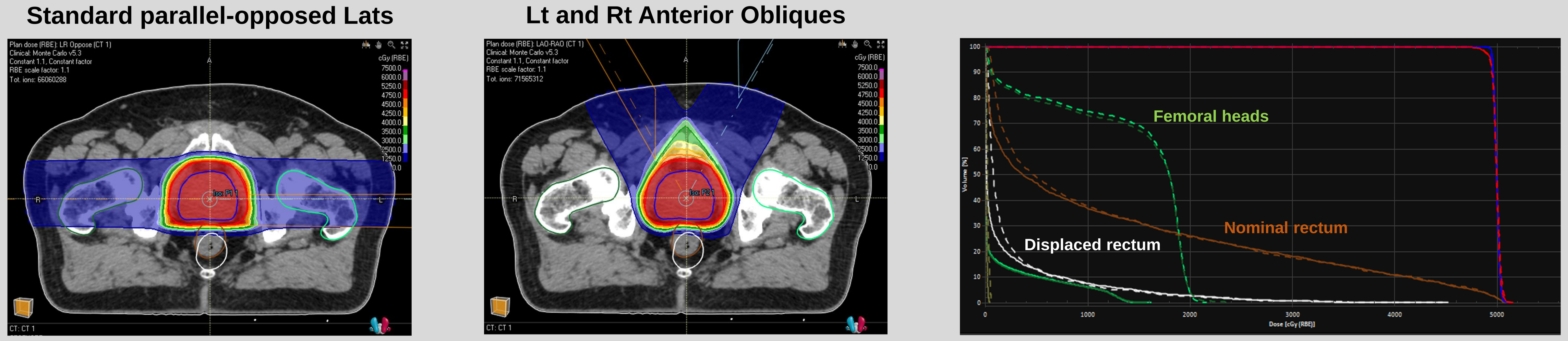
Materials and Methods

Since the 1990s the design of most clinical PBT systems has been based on a similar set of technical requirements that are generally recognized by the PBT community. This study challenges those requirements and attempts to re-establish a new baseline by examining: (a) relevant examples of tumor/target locations for proton irradiation; (b) pencil beam scanning (PBS) treatment techniques used for these indications; (c) related proton beam field parameters. LET_d re-distribution methods were also applied and considered when evaluating treatment planning techniques*.

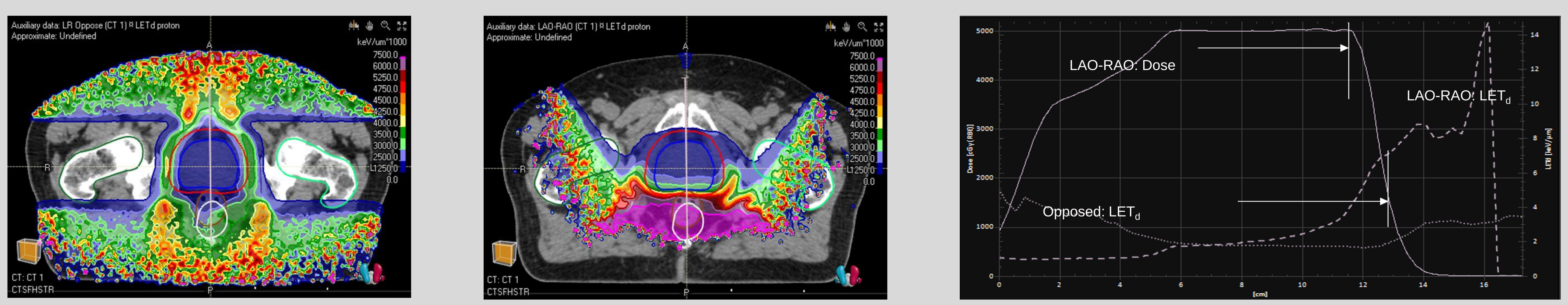
Results

Prostate – with rectal volume displaced posteriorly to simulate the use of the SpaceOAR™, or similar device, for rectal sparing.

Standard parallel-opposed Lats | **Lt and Rt Anterior Obliques**



Highest beam energy = **205 MeV** | Highest beam energy = **171 MeV** | —— LAO-RAO - - - - Opposed Lats

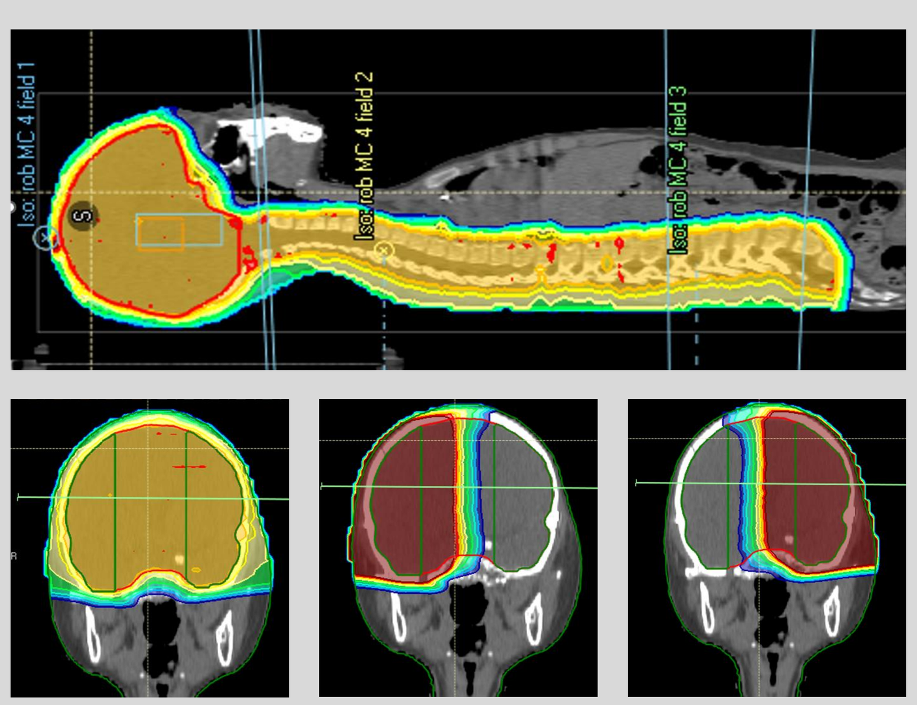


LET_d distribution | LET_d distribution

Dose and LET_d data along central AP axis:

- Higher LET_d in rectum for LAO-RAO plan, but at onset of dose fall-off (25% of Rx).

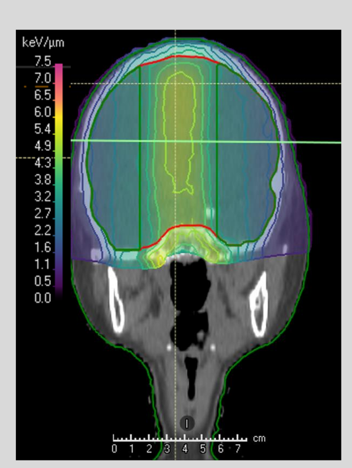
Cranio-spinal irradiation (CSI)



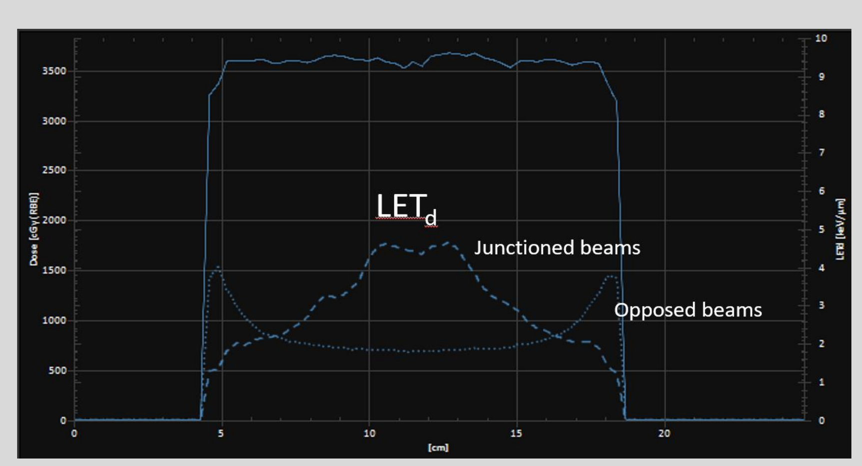
CSI with standard matched PA fields for the spine, and Rt and Lt lateral "junctioned" fields for whole brain by use of LETd penalty functions. The junctioned fields match distally at mid-plane.

- Max. beam energy: spine fields = **150 MeV**
- Max. beam energy: brain fields = **165 MeV**

Standard opposed brain fields were 187 MeV



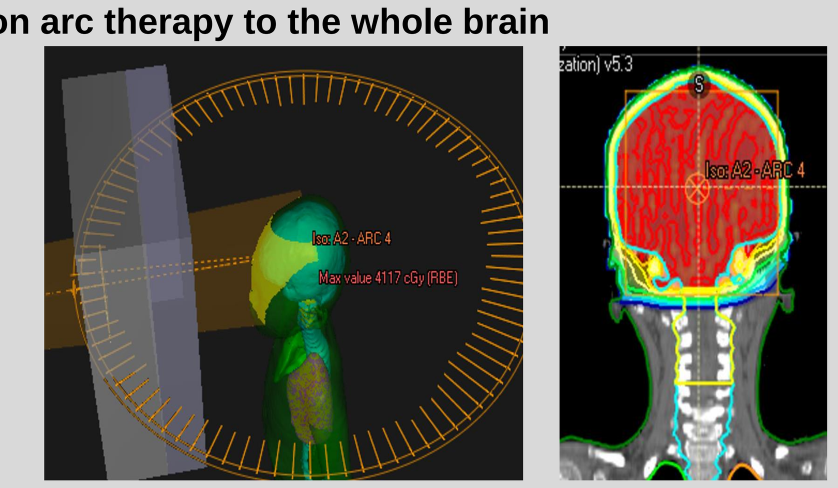
LET_d for junctioned fields



Comparison of LET_d across whole brain for standard parallel opposed fields and lateral junctioned fields.

Alternative approach: **Proton arc therapy to the whole brain**

- Single 360° arc
- Max. energy = **159 MeV**
- Homogeneous LET_d



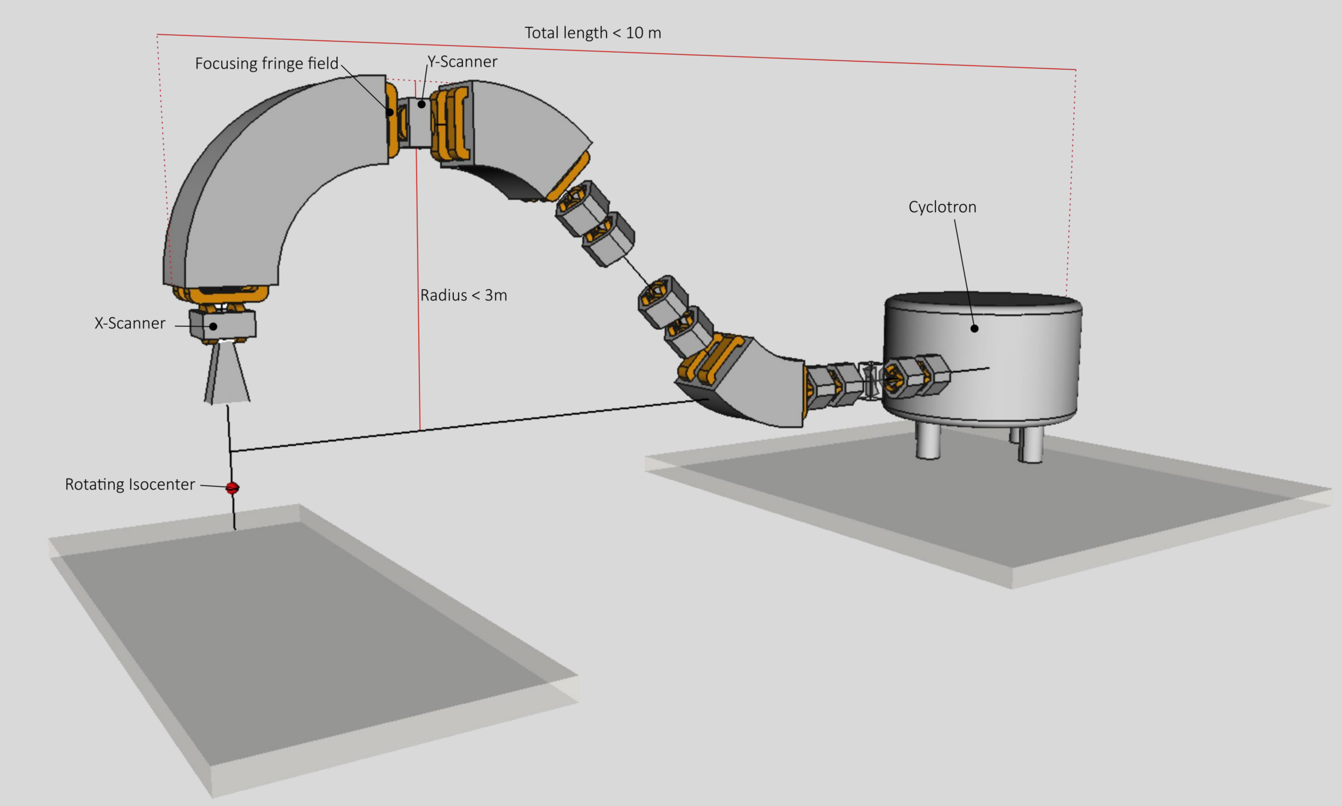
Effect on Machine Requirements

The investigations of typical treatment scenarios show that especially the requirement on the maximum energy for proton therapy systems may be significantly reduced with respect to the values around 230 MeV that are commonly used, today, without significantly decreasing the number of cases that can be treated. This is especially true for cases that are particularly suitable for proton therapy, because the advantages of protons over X-rays (dose concentration in tumor, sharp distal fall-off) dominate at low energies. At higher energies, as required for large and deep-seated tumors, these advantages are considerably reduced.

Combined X-ray/proton irradiations are therefore proposed for optimum treatment of such cases. Low-energy PT systems can be significantly more compact and cheaper than today's standard systems. They also require significantly less shielding with smaller footprint. This enables installations of such machines close to linacs in the same building, so that combined X-ray/proton treatments are easily possible in the same facility.

Proposed PT System Configuration and Specification (patent pending)

- Conventional (non-superconductive) cyclotron with beam energy of 180 MeV or less
- Degrader without a downstream energy selection system (not required due to small distal fall-off already at maximum energy)
- Lightweight 360° non-isocentric gantry (non-isocentricity reducing the gantry radius)
- Scanning system with one scanner before the last bending magnet (reducing the gantry radius)
- Bending magnet with focusing entrance fringe field (enabling compactness of magnet)
- Small maximum field size (e.g. 20 × 10 or 10 × 10 cm²), reducing cost of scanning magnets and power supplies and enabling scanning through the last bending magnet; larger fields can be irradiated using automated field patching)



Main Advantages of Proposed System

- System/equipment **cost greately reduced** (estimated to be below 10 million $)
- Gantry radius < 3 m and total length < 10 m ⇒ **Significant reduction of building cost** (not included in above figure)
- Low energy requiring much less shielding of secondary radiation ⇒ further reduced building cost
- Combination with conventional linacs (several options of level of integration) ⇒ **better economics** due to easier patient referral ⇒ **improved accessibility of proton therapy in general**.
- Low maximum energy enabling high beam currents ⇒ **FLASH compatible**
- **Proton arc compatible**

Conclusions

Pencil beam scanning (PBS) treatment planning techniques were investigated for two sites commonly treated with PBT with the view of reducing beam energy and field size requirements where possible. Such reductions in the technical requirements for clinical PBT could translate into equipment cost-savings for selected clinical applications. A comprehensive investigation of all PBT indicated clinical targets is required. The opportunity to develop cost-saving design concepts may enable further help the democratization of PBT for eligible patients.

*Treatment planning was done in research version 11B-IonPG(12.0.130) of RayStation, RaySearch Laboratories AB, Sweden