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Study on the LET distribution as a function of different treatment planning approaches in proton beam therapy

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Introduction

The **constant RBE value of 1.1** commonly applied within the proton therapy community may not sufficiently describe biological effects in all clinical situations. In a mixed particle beam, a **dose-averaged LET** (LET_d) over the entire particle spectrum is a quantity to correlate to biological effect. In this work, LET_d to water calculation using the Monte Carlo (MC) in the TPS RayStation[1] (RS v5.99.50) was benchmarked against GATE8.0/Geant4.10.3 MC simulations. The aim was to set up a **validated tool to evaluate LET_d distributions** resulting from **different optimization strategies** for cases with critical beam incidences.

Material & Methods

For the **LET_d benchmarking** two plans with a target of 5x5x5 cm^3 centred at a depth of 6 and 30 cm in water and one 160 MeV pencil beam (range in water: 17.4 cm) were optimized in RayStation (RS) and recalculated with GATE/Geant4. Different dose grids ((0.1x0.1x0.1) cm^3, (0.2x0.2x0.2) cm^3 and (0.3x0.3x0.3) cm^3) were used to investigate the **voxel size dependence**. A (2x2x2) cm^3 and a (10x10x10) cm^3 water target were centered at 8 cm, 18 cm and 28 cm depths in a water phantom to assess **depth and field size dependence**. Two SFO fields separated by 0° to 180° in steps of 10° for a spherical target with 4 cm diameter centered in a cylindrical water phantom and subsequent analysis of Dose-Volume Histograms (DVHs) and LET_d-Volume Histograms (LET_d-VHs) in concentric shells around the target enabled to study the **angular dependence**. Finally, 2-field plans were generated for **three clinical cases** (two paediatric head tumors and one superficial tumor) in RS using **different optimization strategies**. The effect of varying the number of distal energy layers, limiting of maximum spot weights and the combination of both strategies in single field plans was tested. In the case of 2-field plans Single Field Optimization (SFO) was compared with Multiple Field Optimization (MFO) for two orthogonally arranged beams (*Figure 1*).

Patient 1 Patient 2

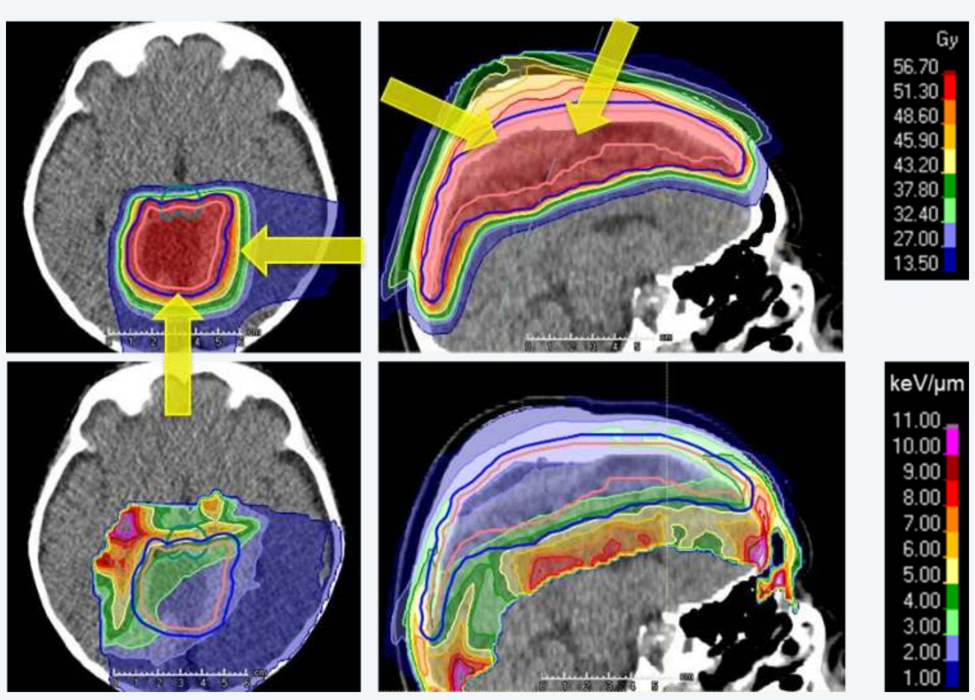

Figure 1: Orthogonal beam arrangement of two fields for two clinical cases for the planning strategy: SFO, one distal layer, no maximum spot weight limitation. Dose distributions (two images on the top) vs. LET_d distributions (two images on the bottom). For patient 3 the same beam arrangement was applied as for patient 1 because of similar geometric/anatomic target location and size.

Results

LET_d values calculated with **RS agreed with GATE/Geant4** within ± 5% for all profiles (*Figure 2*). Moreover, no voxel size dependence was observed. Analysis of the depth and field size found the highest maximum LET_d for **small superficial targets** (*Figure 3*). **Increasing the angle** separating two SFO beams lead to a decrease of maximum LET_d around the PTV as shown in *Figure 4*. The evaluation of the LET_dVHs within the PTV and in a 0.5 cm shell structure around the PTV in one paediatric case showed the maximum LET_d value of the single-beam plan is almost double if compared to the **2-beams plan** approach. A better balance between LET_d and integral dose outside the target compared to single-beam plans was offered by the 2-field plans. *Table 1* summarizes the maximum LET_d values for the three clinical cases and all different optimisation strategies.

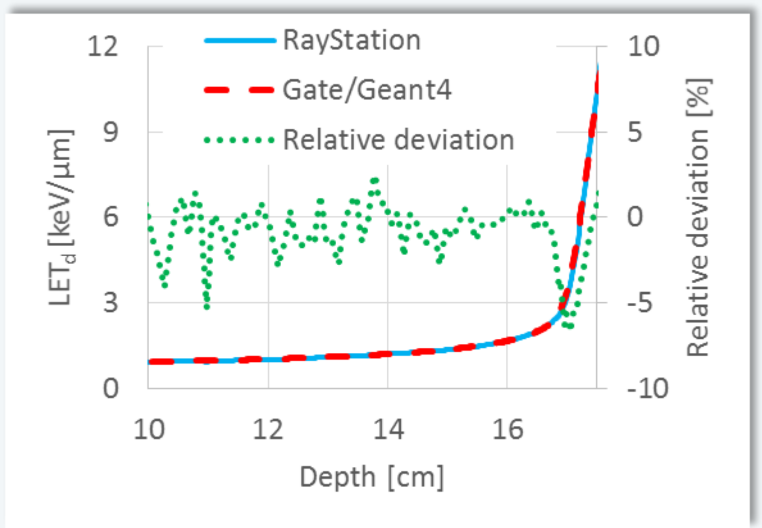

Figure 2: Depth LET_d profile computed with RS (solid line) and with GATE/Geant 4 (dashed line) as function of depth for a 160 MeV pencil beam (range in water: 17.4 cm). The relative deviation of the LET_d computed with RS from the LET_d computed with GATE/Geant4 is also shown (dotted line).

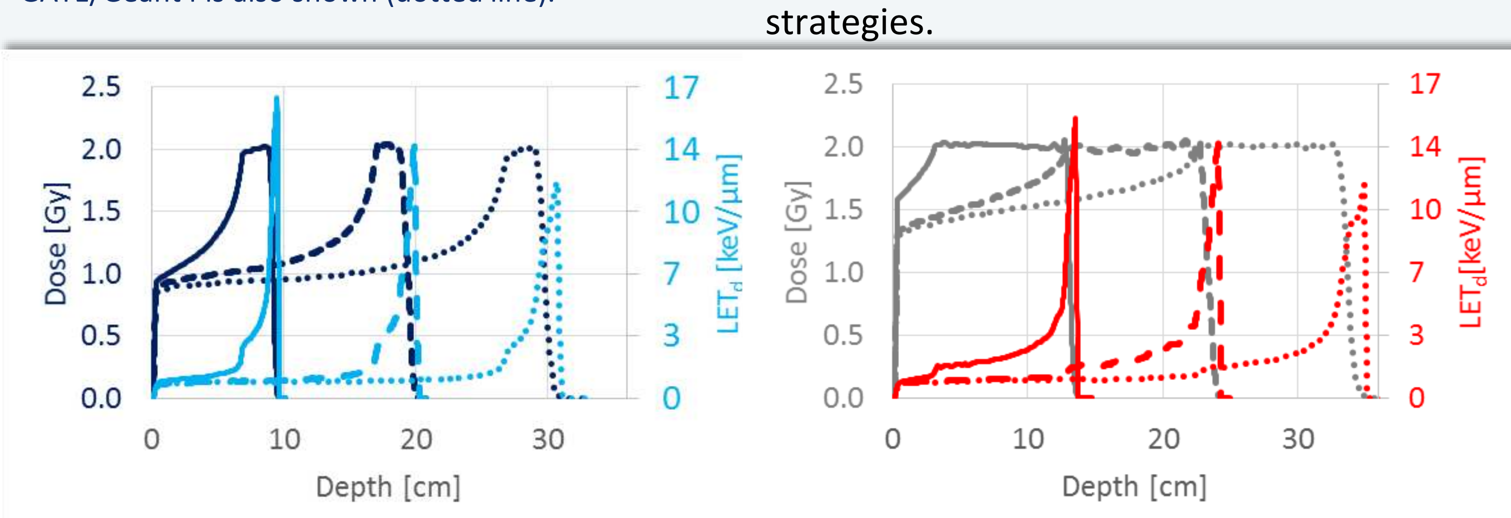

Figure 3: Dose profiles (dark blue lines resp. grew lines) and LET_d profiles (light blue lines resp. red lines) of water targets with two different sizes ((2x2x2) cm^3 (left image) and (10x10x10) cm^3 (right image)) at a depth of 8 cm (solid line), 18 cm (dashed line) and 28 cm (dotted line).

Figure 4: DVHs (upper lines) and LET_dVHs (lower lines) with varying angle separating two SFO beams (angle varies from 0° to 180° in steps of 10°) in a shell from 0.0 to 0.5 cm around the PTV.
The green colored lines represent angles above 90° and the red colored lines represent angles below 90°.

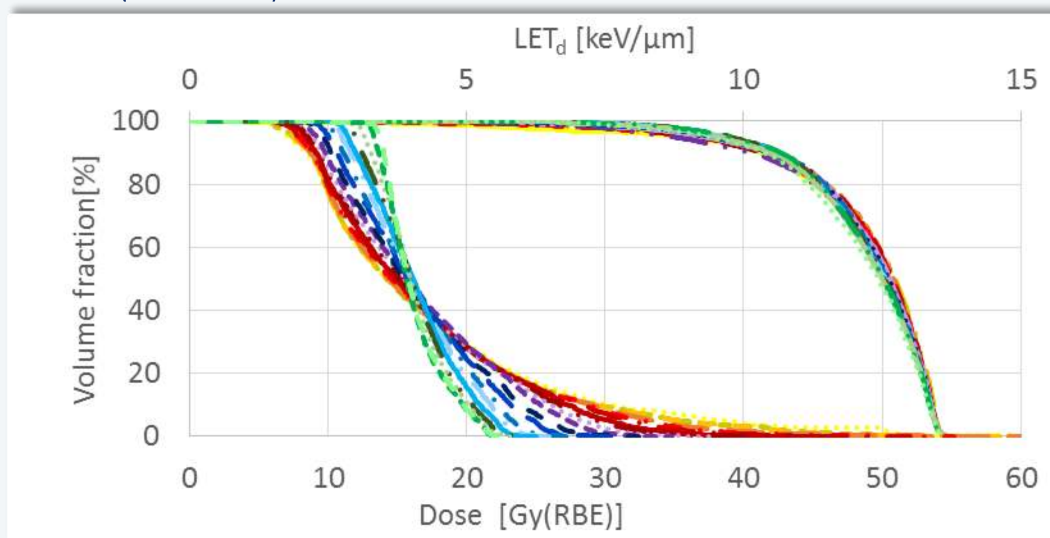

Table 1: Maximum LET_d to 2% of a shell from 0.0 to 0.5 cm around the PTV averaged over three patients. The values in brackets are the corresponding minimum and maximum values.

Optimisation strategy	Max LET_d [keV/µm]
Single beam 1 distal layer	10.6 (8.7, 13.2)
Single beam 1 distal layer & max. spot weight limitation	10.1 (8.7, 11.7)
Single beam 3 distal layers	10.2 (8.2, 12.7)
Single beam 3 distal layers & max. spot weight limitation	8.8 (8.1, 9.2)
SFO 1 distal layer	7.2 (6.9, 7.6)
MFO 1 distal layer	7.6 (7.1, 8.0)

Conclusions

The LET_d distributions calculated by RS were in **good agreement with GATE/Geant4**. RS is therefore a reliable tool for LET_d distribution display. **Increasing the number of beams** and using **orthogonal** to **contralateral** beams had the highest impact on the reduction of max. LET_d, whereas decreasing the target´s **depth** and the **field size** led to a raise of max. LET_d. In the **LET_dVHs only small differences between two beam SFO vs MFO** were noticed for the three investigated cases. The integral doses were only slightly higher for SFO. In cases where the number of available beam incidences is low a **limitation of maximum spot weight** resulted in a **reduction** of volume receiving high and medium LET_d values **when combined with the addition of distal energy layers**. At the same time the change in integral dose was minor.

References:

1. Traneus, E., & Ödén, J. (2018). Introducing Proton Track-End Objectives in Intensity Modulated Proton Therapy Optimization to Reduce Linear Energy Transfer and Relative Biological Effectiveness in Critical Structures. International Journal of Radiation Oncology • Biology • Physics. 103(3), pp. 747-757.

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