Energy Layer Filtering and Splitting in Breath Sampled Re-painting for Lung SBRT using Pencil Beam Scanning Proton Beams

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INTRODUCTION

The breath-sampled repainting (BSR) has been reported to be the most effective repainting scheme for a pencil beam scanning (PBS) proton therapy. However, it is hard to be efficiently and effectively implemented due to treatment time and machine delivery limitations. The purpose of this study is to develop an energy layer filtering and splitting technique to efficiently optimize energy layers and repaint each layer within a breathing cycle for reducing motion interplay effect in lung SBRT.

METHOD

An energy-layer filtering algorithm was developed to select the most effective layers with substantial contributions to the plans. Layer repainting was implemented by splitting the optimized layers into 4 adjacent layers (±0.2MeV). A 4D-CT scan (10 phases) of a CIRS lung motion phantom with 3cm insert was conducted with sinusoidal motion of 1.5cm and 2.0cm in the superior-inferior direction. Three plans were created: non-4D optimized plan, 4D optimized plan, and the proposed energy-layer selection repainting (ESRP) plan, all normalized to CTV V100=98%.

An interplay evaluation tool was used to calculate the dosimetric effect from motion period (4s vs 8s) and starting phases (phase 0 vs 50). Dosimetric parameters (CTV D99, V110, and D_{max}) were calculated. Gafchromic film was sandwiched in the phantom insert, and the plans were delivered on a PBS proton machine with corresponding parameters. Gamma analysis was performed using a 7%/7mm criteria.

RESULTS

- It was found that none of the plans showed dependence on starting phase nor breathing period.
- The interplay evaluation of CTV D99 for the corresponding three plans were calculated to be 42.7±1.9Gy vs. 47.3±0.5Gy vs. 48.0±0.2Gy ($p<0.05$), respectively.
- The corresponding V110 and Dmax were calculated to be 33.4±7.1% vs. 49.7±2.4% vs. 79.1±8.0% ($p<0.05$) and 60.5±0.4Gy vs. 62.6±0.9Gy vs. 59.3±0.5Gy ($p<0.05$), respectively.
- Gamma analysis passing rates from the measurements were found to be 59.7±3.9%, 70.4±5.5%, and 84.5±3.9% respectively.

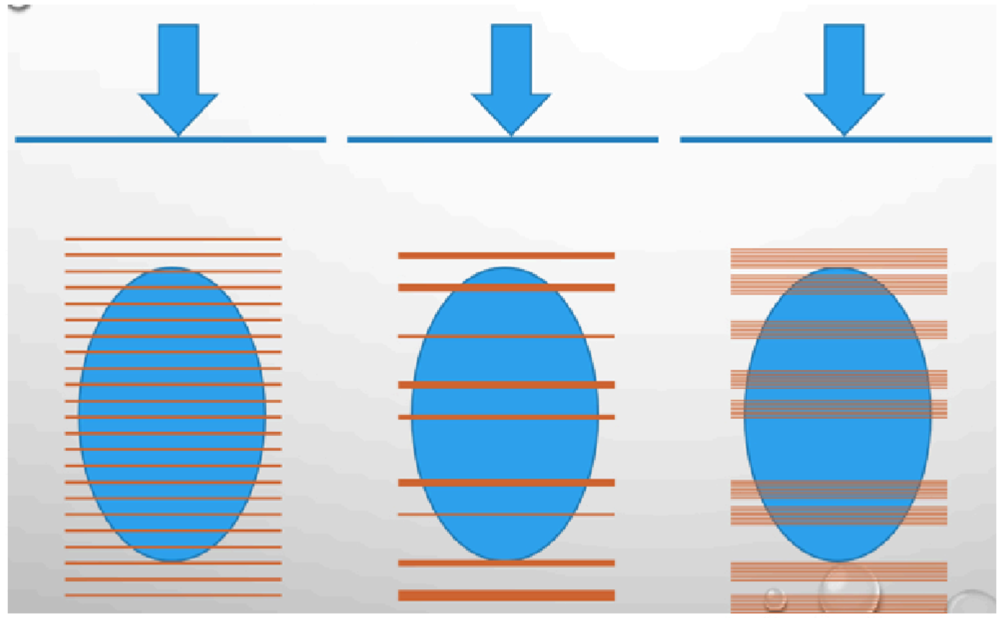

Figure 1: ESRP method for energy layer filtering and splitting. A fine layer spacing is initially placed (left), an energy layer filtering algorithm is used to optimize and select the most effective layers (center), and the selected layers are split into multiple adjacent layers for breath gated repainting

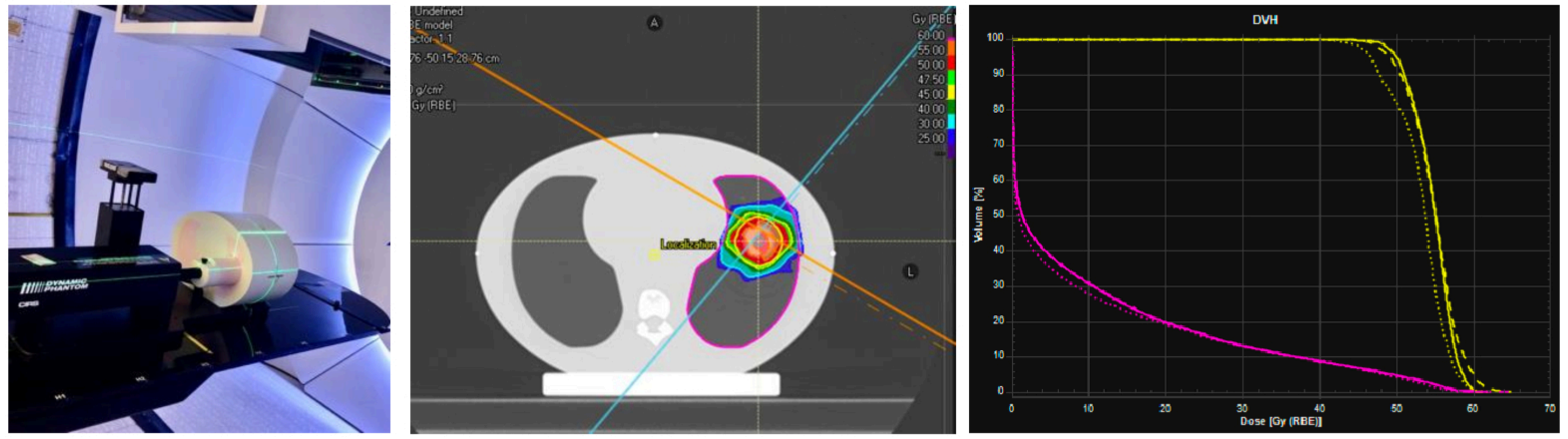

Figure 2: CIRS lung motion phantom setup (left), isodose distribution of a nominal plan (center), and CTV interplay evaluation for the non-4D optimized plan (dotted line), 4D optimized plan (dashed line) and the proposed energy selection repainting plan (solid line) (right). All nominal plans were initially normalized to V100 = 98% prescription (50Gy in 5 fractions)

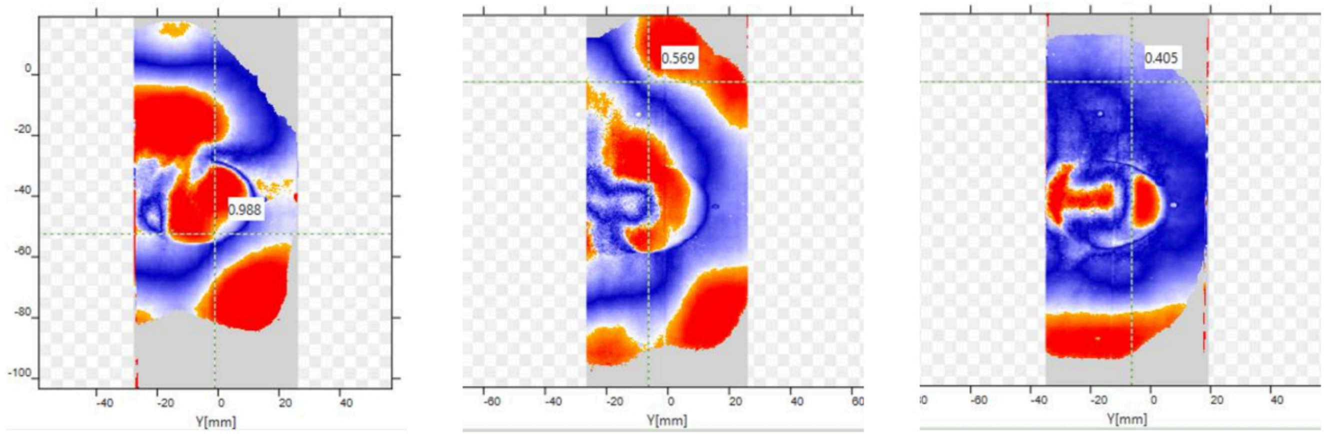

Figure 3: Gamma Heat Map for the nominal plan (left), 4D optimized (middle), ESRP (Right)

CONCLUSIONS

The evaluation tool validated that the ESRP method mitigated motion of the tumor better than 4D optimization. It was verified using film measurements. The evaluation overestimated the effect 4D optimization had on mitigating motion due to assumed set parameters of the beam. The evaluation tool can be improved by incorporating machine log files to better reflect the true mitigation.

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