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JOINT AAPM | COMP MEETING

Applying a Proton Procedure of Optimizing Spot Weight and Ridge Filter to Single-Energy Carbon Pencil Beam

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Objective

To apply a proton procedure of optimizing spot weight and Ridge Filter (RF) to single-energy carbon pencil beam and evaluate it in a water phantom with a square-shape target in the center (prescription dose 50 Gy).

INTRODUCTION

Flash effect was extensively studied for electron [1], photon [2] and proton beam [3]. This effect was also observed during cell/animal experiments in carbon FLASH beam recently [4, 5]. Transmission method and Bragg-Peak irradiation are two different techniques to deliver particle FLASH beam. The Bragg-Peak technique provides both high dose-rate and high LET benefits.

We developed a procedure to optimize beam scanning spot weight and ridge filter dimension for single energy proton pencil beam with a fast Monte Carlo (FDC) and in-house developed optimizer based on the L-BFGS algorithm. This optimization procedure was proved to be efficient for proton pencil beam in a water phantom by one of our projects. In this project we verified it for carbon pencil beam.

The first two steps of this 3-step procedure are important. We creatively generated a dummy IMPT plan, in which different energy layers in a standard IMPT plan are simulated by the same energy but including different thickness of PMMA in the beam path. We modified our dose engine to make particles go through different thickness of PMMA when it gets to different layers in the dummy IMPT plan. Another special thing for this dummy plan is that all layers are with the same spot map. After spot weights were obtained from the dummy IMPT optimization, the spot weights can be converted to RF because the spot weight is proportional to the ladder area in the ridge filter. The summary of the spot weights at the same spot across different layers are the weight for a real IMPT plan with a single layer.

METHODS AND MATERIALS

A 3-step optimization procedure to optimize plan spot weight and RF dimension was developed for proton pencil beam recently. The procedure was based on a fast Monte Carlo dose engine (FDC) and L-BFGS algorithm.

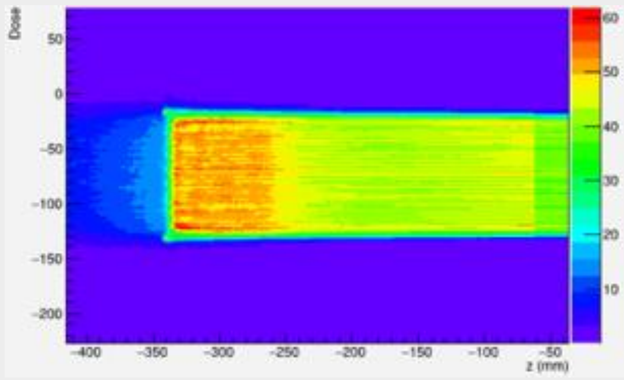
The 3 steps included (1) obtaining spot weight and RF dimension information from optimizing a dummy IMPT plan; (2) Converting spot weights of the optimized dummy IMPT plan to RF dimensions and spot weights for a real IMPT plan with a single-energy layer; and (3) reoptimizing the single layer IMPT plan with the ridge filter in the beam path. We applied this procedure to single-energy carbon pencil beam.

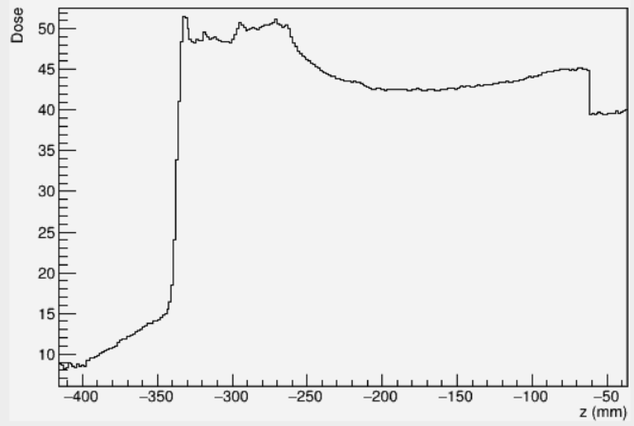
Table 1. DVH metric value for the optimized plan.

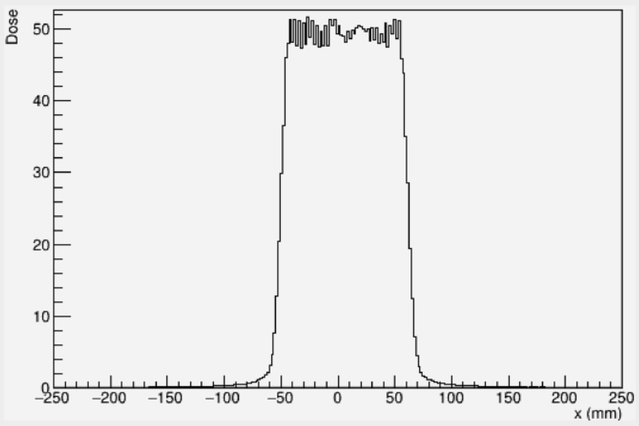
Indices	D98	D95	D5	D2	HI
Value (Gy)	46.1	47.2	54.0	55.4	1.14
Value (%)	92.2%	94.4%	108%	111%	

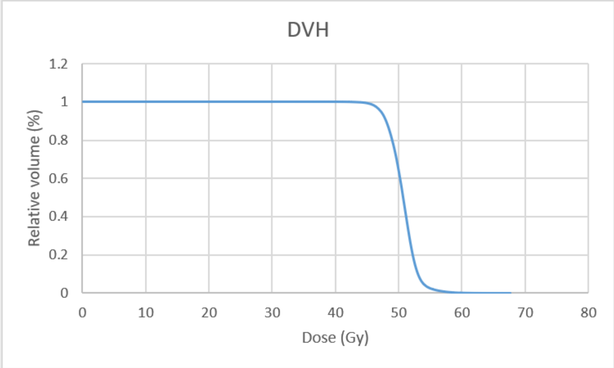
RESULTS

For the water phantom, the single layer plan used 404.5 MeV beam with a spot distance of 4 mm. The ridge filter was composed of 729 pyramids, and each pyramid had a base size of 3.826×3.826 mm^2, a total thickness of 66 mm and 22 ladders. The DVH indices for the target are 46.1 Gy (92.2%) for D98, 47.2 Gy (94.4%) for D95, 54.0 Gy (108 %) for D5, 55.4 Gy (111%) for D2. The Homogeneity Index is 1.14.









DISCUSSION

Compared with proton, carbon has much higher LET which can cause more double-strand breaks for DNA. At the same time, the carbon beam is less scattered and generates narrow beam in lateral direction and sharp Bragg-Peak in longitudinal direction. Because the beam is narrower, more spots are required to cover the entire volume.

The lateral dose profile shows fluctuation which is not due to fewer histories but large spot distance. This can be fixed by reducing spot distance. However, the current optimization used one pyramid for each spot. Too small size of pyramid will make RF printing less practical. Different strategy should be applied, for example, 1 pyramid for 4 beam spots.

There is a little peak at the end of the longitudinal dose profile. This is due to the energy selection. A higher energy is promising to fix this peak.

For proton therapy, 1.1 is used as the RBE in clinic. However, a constant RBE is not a good approximation for carbon therapy. Variable RBE model has to be used during carbon plan optimization.

The current optimization is still based on physical dose. With the variable RBE in the optimization, similar method can be applied for the RF and plan optimization. No decrease in plan quality is expected with variable RBE optimization using the same optimization method.

CONCLUSIONS

For single-energy carbon beam, this optimization procedure does not work as good as proton beam according to plan parameters. One of the reasons is that carbon beams are narrow in lateral direction which requires small spot distance and small size of pyramids in the procedure. It causes the conversion from spot weight to RF less accurate. We expected plan improvement for shallower target for which lower carbon energy will be used and lower energy has wider beam.

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