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Introducing a new Spot-Scanning Proton Arc optimization algorithm with a Variable Tolerance Window to improve plan quality for bilateral breast cancer

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Abstract

This study aims to introduce a new SPArc algorithm with a variable tolerance window (SPArc$_{\text{-variable}}$) to further improve plan quality for patients receiving bilateral breast and regional nodal irradiation, by allowing extra energy layers across specific arc trajectories.

Introduction

Breast cancer is the most common cancer in women, and 12% of all women in the United States are estimated to be diagnosed with breast cancer over their lifetime. With state-of-the-art Intensity Modulated Proton Therapy (IMPT), it remains challenging to achieve satisfactory performance in terms of multi-lymph node coverage and dose to the heart and lungs, though significant improvement is witnessed compared to intensity-modulated radiation therapy(IMRT). Recently, the emerging technology, Spot-scanning Proton Arc (SPArc) therapy, has shown potential clinical benefits compared to IMPT; however, it has been challenged in the energy layer selection in the even distributed control point, which results in unfavorable plan quality. We hypothesize that giving the optimizer more degrees of freedom by allowing extra energy layers across specific arc trajectories, which might be particularly important and help in the optimization of complicated target geometries, e.g., bilateral breast cancer patient population. Therefore, we introduce a new SPArc algorithm with a variable tolerance window (SPArc$_{\text{-variable}}$) to further improve the quality of life for patients with bilateral breast cancer.

Methods and Materials

The SPArc$_{\text{-variable}}$ optimization algorithm is based on a 0-1 knapsack problem in dynamic programming (DP). Starting with the multifield-IMPT plan with 20 degrees apart, the algorithm iteratively selects a subset of energy layers with decreasing energy layer filtration factor. Then it resamples the energy layers based on the gantry's movement and irradiation sequence. Finally, spot weighting optimization is applied. Five cases with bilateral breast and lymph nodes treatment are retrospectively selected. Three treatment planning groups were generated, including IMPT with 2 isos, SPArc planning with a fixed distance of 2.5 degrees between adjacent control points(SPArc$_{\text{-original}}$), and SPArc planning with non-fixed distance(SPArc$_{\text{-variable}}$), with a prescription of 5000cGy(RBE). DVH metrics are included to evaluate performance over OARs and targets, and dynamic delivery is simulated via a published dynamic arc system controller.

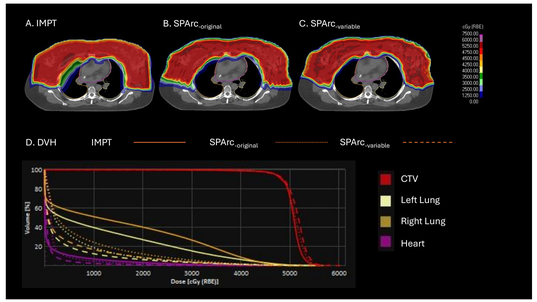

Figure 1. Dosimetric comparison between IMPT, SPArc-original, and SPArc-variable.

Results

Both SPArc$_{\text{-original}}$ and SPArc$_{\text{-variable}}$ plans showed slightly better target coverage than IMPT plans, but the difference was not statistically significant. In addition, SPArc$_{\text{-variable}}$ showed significantly better performance than IMPT and SPArc$_{\text{-original}}$ in sparing the heart($P<0.01$ for D1%) and significantly better performance in sparing the left and right lungs($P<0.01$ for V20Gy and V5Gy) than both IMPT and SPArc$_{\text{-original}}$. In terms of delivery efficiency, the SPArc$_{\text{-variable}}$ shows a slightly longer treatment delivery time than SPArc-original and is superior to IMPT(SPArc$_{\text{-variable}}$:434.99±52.95sec, IMPT: 506.47±14.65sec, P=0.02, SPArc$_{\text{-original}}$:382.11±49.31sec, P=0.01).

Table 1. Dosimetric analysis of IMPT, SPArc-original, and SPArc-variable

	Evaluation Metrics	IMPT	SPArc$_{\text{-original}}$	SPArc$_{\text{-variable}}$
CTV	D95%(cGy)	4582.80±182.59	4596.96±194.46	4695.14±258.63
	CI	0.73±0.10	0.74±0.13	0.74±0.13
Heart	V5Gy(%)	10.67±5.91	7.59±4.90(-28.87%)	3.28±3.75(-69.29%)
	Mean(cGy)	185.56±119.43	153.59±128.17(-17.23%)	72.34±70.06(-61.02%)
	D1%(cGy)	2196.89±1129.16	1965.61±1209.91(-10.53%)	1193.34±1144.12(-45.68%)
Left Lung	V20Gy(%)	23.33±5.90	15.19±4.49(-34.89%)	7.96±2.20(-65.89%)
	V5Gy(%)	48.13±4.05	38.40±4.50(-20.22%)	22.81±3.86(-52.61%)
	Mean(cGy)	1062.31±183.37	798.18±129.86(-24.86%)	460.77±84.57(-56.63%)
Right Lung	V20Gy(%)	26.08±3.92	15.12±5.49(-42.03%)	8.17±3.74(-68.68%)
	V5Gy(%)	50.91±2.19	37.52±7.72(-26.29%)	24.10±7.45(-52.65%)
	Mean(cGy)	1142.60±88.88	798.05±216.42(-30.15%)	481.45±168.35(-57.86%)

Discussion

This work is the very first study to provide an algorithm for optimizing over variable tolerance window in SPArc scenarios in bilateral breast cancer scenario. This study provides insight for further evaluation into variable tolerance window for potential dosimetric benefit while maintaining non-inferior delivery efficiency. While the algorithm presented being evaluated in bilateral breast scenario, the investigation of other disease sites are also of potential improvements, which will be covered in future work.

Conclusions

This study introduces a novel SPArc optimization algorithm with a variable window to enhance dosimetric performance for bilateral breast cancer patient population. More specifically, it reduces the dynamic delivery time compared to IMPT, while achieving equivalent target coverage and significantly superior heart and lungs sparing compared to IMPT and SPArc$_{\text{-original}}$.

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