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The Dosimetric Characteristics between Proton Pencil Beam Scanning Single-Energy Transmission IMPT and Conventional Multiple-Energy IMPT in Lung Cancer Treatment

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Abstract
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Abstract

Objective: The conventional multiple-energy IMPT cannot have sufficient dose rate for FLASH radiotherapy (RT), therefor using single-energy transmission beams were proposed for proton ultra-high dose rate treatment planning. However, the plan quality of the transmission FLASH plans is not clear. This work aims to evaluate transmission proton pencil beam scanning (PBS) FLASH RT radiotherapy (RT) planning for lung cancer patients. The dosimetry characteristics of the FLASH plans were quantified in comparison to conventional intensity-modulated proton therapy (IMPT)-stereotactic body radiation therapy (SBRT) plans.

Methods: Proton transmission plans of 34Gy in 1 fraction for a cohort of 7 lung cancer patients were optimized with 5 fields multiple-field-optimization (MFO) using an in-house developed tool. 400 minimal MU/spot with a spot peak dose rate (SPDR) of 670Gy/s was used for planning. The 3D average dose rate (ADR) and dose-averaged dose rate (DADR) distributions were calculated to assess if 40Gy/s FLASH dose threshold is reachable for OARs. RTOG0915 dose metrics were used to compare the FLASH and clinically approved lung IMPT plans.

Results: FLASH IMPT The FLASH plans result in slightly worse CTV uniformity compared to the conventional IMPT plans, as 114.7±4.6% vs 107.7±2.1%. The lung V7.0Gy and V7.4Gy are 717.5±378.0cc and 667.8±359.2cc compared to 488.2±245.5cc and 464.5±231.2cc between FLASH and IMPT plans ($p<0.01$). The FLASH plans yield significantly higher ($p<0.05$) D5cc and Dmax for esophagus as 13.9±7.2Gy and 20.9±13.6Gy vs 6.7±11.5Gy and 17.1±13.1Gy of the IMPT. Similar trends can be observed in the other OARs but do not achieve statistical significance due to the variation of target location and small cohort size. The average ADR V40Gy/s of the OARs is 79.0±3.5%, lower than that using the DADR which is 97.0±0.9%.

Conclusion: Transmission FLASH IMPT plans result in inferior plan quality to conventional IMPT due to the nature of transmission beam and lack of optimization flexibility. A 400 minimal minimum MU/spot can ensure 80-100% OAR FLASH dose rate coverage for both ADR and DADR. The biological effect of FLASH RT on the irradiated volume is unknown. To better spare OARs beyond the target, nNew planning strategies and delivery techniques are needed to deliver quality FLASH RT. The dosimetric characteristics between proton pencil beam scanning single-energy transmission IMPT and conventional multiple-energy IMPT in lung cancer treatment Dosimetry and dose rate evaluation of transmission proton pencil beam scanning FLASH treatment planning for hypofractionation lung cases: a comparison study with intensity modulated proton therapy.