Contribution ID: **30** Type: 海报展示

FLASH 闪疗关键技术及原理样机研制

摘要

FLASH 放疗以超高剂量率（≥40 Gy/s）在百毫秒内完成照射，可在杀灭肿瘤的同时显著保护正常组织，但现有 X 射线设备剂量率低、多角度切换慢，制约其临床转化。本研究针对上述瓶颈，研制一套静态多角度 FLASH-X 射线装置：通过紧凑型大流强（≥400 mA）驻波加速管与高转速韧致辐射旋转靶，实现单管剂量率 ≥40 Gy/s（80 cm 源皮距）；采用超级电容储能与固态脉冲调制技术，构建 300 kW 级瞬时大功率电源及 FPGA 多通道同步控制系统；创新设计五源环形集成的静态机架，配合一进五出微波分配网络，规避机械旋转速度限制。预期建成国际先进的原理样机，为 FLASH 放疗临床转化提供核心装备支撑，推动我国高端放疗设备自主创新。

关键词

FLASH 放疗；超高剂量率；多角度 X 射线装置；直线加速器；固态脉冲调制器

Abstract

FLASH radiotherapy delivers ultra-high dose rates (≥40 Gy/s) within hundreds of milliseconds, sparing normal tissues while effectively killing tumors. However, conventional X-ray devices suffer from low dose rates and slow multi-angle switching, hindering clinical translation. This study addresses these bottlenecks by developing a static multi-angle FLASH X-ray apparatus. Key innovations include: a compact high-current (≥400 mA) standing-wave accelerating tube and a high-speed rotating bremsstrahlung target, achieving a single-tube dose rate ≥40 Gy/s at 80 cm SSD; a supercapacitor-based solid-state pulse modulator providing 300 kW instantaneous power and an FPGA-based multi-channel synchronized control system; and a static gantry integrating five fixed X-ray sources with a 1-to-5 microwave power distribution network, eliminating the speed limitation of mechanical rotation. An advanced prototype is expected to be established, providing essential equipment support for clinical translation of FLASH radiotherapy and promoting independent innovation of high-end radiotherapy devices in China.

Keywords

FLASH radiotherapy; ultra-high dose rate; multi-angle X-ray apparatus; linear accelerator; solid-state pulse modulator

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Session Classification: 海报展示

Track Classification: 海报展示: 海报展示