From Laser-Driven Particle Beams to Clinical Translation: Progress and Challenges

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Advanced radiation oncology is undergoing rapid technological transformation, driven by innovations in beam delivery, imaging, and data-driven optimization. This talk provides an overview of the current status of modern radiotherapy, including hypofractionation and simultaneous integrated boost strategies, adaptive and motion-managed treatments, and the increasing use of AI-assisted approaches. Advances in hadron therapy will be discussed, including recent clinical results, emerging concepts such as upright proton therapy facilities, and current research directions at clinical hadron therapy centers—such as LET painting and biologically guided treatment planning. In addition, the renewed interest in boron neutron capture therapy will be briefly addressed.

Innovative irradiation modalities explored at large-scale accelerator facilities, including FLASH radiotherapy and spatially fractionated radiation therapy, will then be introduced. Examples from infrastructures such as CERN and DESY illustrate how unconventional beam characteristics may open new therapeutic windows, while simultaneously posing significant technical and radiobiological challenges.

Beyond these efforts to improve the therapeutic index using conventional radiation sources, the unique characteristics of laser-accelerated particle beams offer promising potential for future clinical applications. Key milestones in the development of laser-driven proton and neutron beams are reviewed, with emphasis on beam control, stability, repetition rate, dose delivery, and beam transport—parameters that are critical for any path toward clinical relevance. Finally, advances in radiobiological research using laser-driven beams will be presented, from early proof-of-principle studies to biologically meaningful experimental achievements. Particular attention is given to identifying the most promising developmental directions aligned with the requirements of radiotherapy.