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Current Research Status of Laser Wakefield Accelerator for Cancer Treatment

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Laser wakefield accelerators have recently emerged as a promising alternative to conventional radio-frequency (RF) accelerators for generating high-energy electron beams.[1] Their compactness and ability to deliver ultrashort, high-intensity pulses make them attractive for various medical and scientific applications. In particular, the medical advantages of very high-energy electron (VHEE) beams—such as deep penetration, low dose at air interfaces, easy steering with magnetic fields, and small penumbra—are being studied as ways to overcome the limitations of conventional radiation therapy.[2,3] However, the medical dosimetric characteristics of VHEE beams from laser wakefield accelerators, such as percentage depth dose (PDD) and relative biological effectiveness (RBE), require thorough evaluation to ensure clinical suitability

In this study, we used a laser wakefield accelerator to generate VHEE beams and measured their dosimetric properties. A 20 TW laser with a pulse duration of 40 fs was focused onto a gas target using a parabolic mirror (f/# = 17) to accelerate electrons.[4] Since plasma characteristics are crucial for electron acceleration, shadowgraphy and interferometry were used to measure plasma structure and density. An integrated current transformer measured the bunch charge after the plasma, and a 1T dipole magnet with a scintillator screen was used to determine the beam energy. To enhance electron beam energy, a linearly increasing plasma density profile was employed, resulting in more than 30% higher electron energies compared to uniform plasma, achieving 170 MeV and 10–40 pC electron beams.

To assess medical applicability, we measured the properties of these VHEE beams. A solid phantom made of water-equivalent plastic simulated human tissue. Depth-dependent dose measurements were performed by adjusting the phantom thickness. Dose distribution was measured using Gafchromic™ EBT3 films, calibrated with a reference-class ion chamber (PTW Farmer-type) for linearity and accuracy. Percentage depth dose (PDD) curves were generated by irradiating the phantom at various depths, normalized to the maximum dose at the reference depth. RBE was evaluated using in vitro cell survival assays, benchmarked against conventional electron sources.

Figure 2 shows the experimental results. Before and after the dose experiments, electron beam parameters (energy, pointing stability, and spatial profile) were measured, confirming stable accelerator operation. The dose distribution, measured with Gafchromic films, showed a pencil beam shape with a divergence of about 7 mrad. The PDD curve demonstrated deep penetration, consistent with VHEE beams, but deviated from simulations due to a low-energy tail in the laser-accelerated electron spectrum. Nevertheless, the dose profiles retained clinical relevance, supporting the medical potential of VHEE beams. RBE, quantified via clonogenic survival assays in tumor cells, ranged from 1.1 to 1.4 compared to conventional X-rays, consistent with previous clinical electron studies.

These results demonstrate that VHEE beams generated by LWFAs exhibit PDD and RBE characteristics comparable to those of conventional electron beams, suggesting that laser-accelerated electron beams could be integrated into medical applications such as radiation therapy without significant changes to current dosimetric protocols or biological risk assessments. Further research is needed to explore the scalability and clinical implementation of laser-driven electron sources.

References

[1] T. Tajima and J. Dawson, Phys. Rev. Lett. 43, 267 (1979).
[2] K. R Hogstrom and P. R Almond, Phys. Med. Biol. 51, 455 (2006).
[3] W. P. Levin, H. Kooy, J. S. Loeffler and T. F. DeLaney, Br. J. Cancer 93, 849 (2005).
[4] J. Kim et al. Plas. Phys. Cont. Fus. 60 034008 (2018).

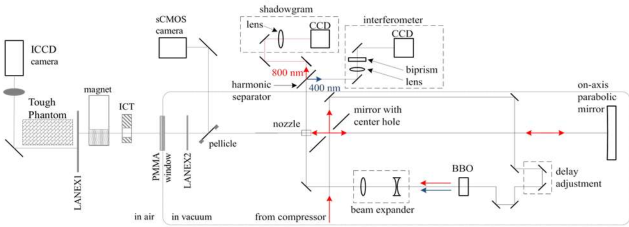

Figure 1. Experimental setup

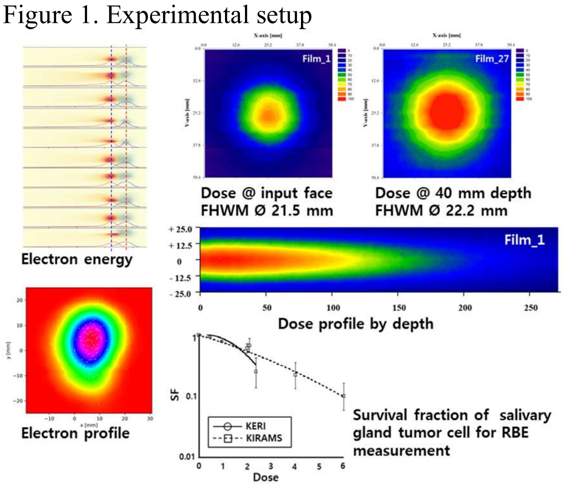

Figure 2. Experimental results. Electron beam energy and shape. Measured dose profile and dose by depth. Measured survival rate of tumor cell for RBE