Physics and technology allied against cancer

Presented By: Dr. Tataridou Eftychia

Department of Radiation Oncology : Theagenio anti Cancer hospital of north Greece

Physics and technology :

Governs radiation interactions with tissues.

Ensures precise dose delivery to tumors.

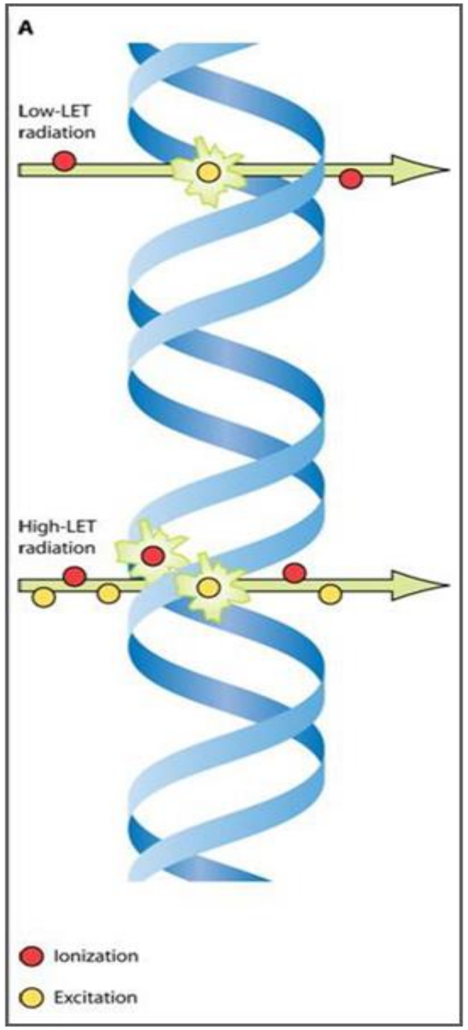
Minimizes damage to healthy tissues.

Determines how photons, protons, and heavy ions deposit energy.

Combined Impact:

Integrates physics and AI for unprecedented accuracy.

Enables cutting-edge techniques like proton therapy, adaptive radiotherapy, and FLASH therapy.



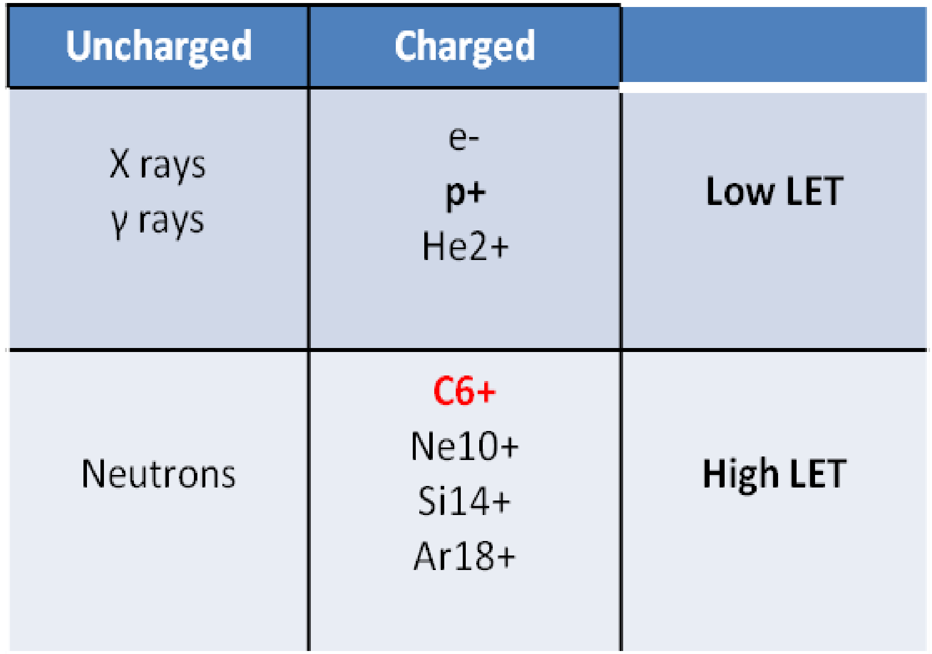
How radiation interacts with tissues

low LET " Photons vs. Protons"

low LET vs high LET

High LET particles (e.g. carbon ions) create complex DNA damage

Linear Energy Transfer (LET):



Uncharged	Charged	
X rays γ rays	e- **p+** He2+	**Low LET**
Neutrons	**C6+** Ne10+ Si14+ Ar18+	**High LET**

Higher LET particles cause more damage to cancer cells.

Useful for radioresistant tumors.

Precise Dose Calculation:

Ensures accurate dose delivery.

Physics-based algorithms conform dose to tumor shape, minimizing exposure to healthy tissue.

Beam Shaping and Modulation:

Modern physics allows for 3D dose shaping (IMRT, SBRT).

Allows us to sculpt the radiation dose to fit the tumor precisely.

Artificial Intelligence (AI) in Radiotherapy:

Optimizes treatment planning, automating tumor contouring and dose optimization.

Enhances personalized treatment approaches by analyzing large datasets.

Supports real-time adaptive radiotherapy, adjusting based on tumor response.

AI
in Treatment Planning Radiotherapy

Automates tumor contouring.

Optimizes dose calculations.

Saves time and increases accuracy.

AI-based models analyze large datasets to optimize dose calculations for individual patients.

Improves precision in dose delivery and reduces side effects.

AI for Predicting Outcomes:

Machine learning models predict how tumors will respond.

Personalizes treatment based on individual patient data.

AI in Real-Time Adjustments:

Adaptive radiotherapy: AI adjusts treatment based on daily imaging.

Ensures accurate delivery even with patient movement or tumor changes.

Cutting-Edge Techniques in Radiotherapy

- FLASH Therapy
- MRI-Guided Linear Accelerator System
- Biology-Guided Radiotherapy (BgRT)
- Proton Therapy
- Proton FLASH Therapy
- Synthetic CT from MRI

1. FLASH Therapy

Ultra-high dose rate delivery: Exceeds 40 Gy/s, significantly higher than conventional radiotherapy (~0.1 Gy/s).

Reduced normal tissue toxicity: Hypothesis of oxygen depletion at high dose rates leading to a protective effect on normal cells.

Short treatment times: Radiation delivered in milliseconds, offering potential for single-session treatments.

Current status: Under preclinical and early clinical trials to validate its therapeutic index.

2. MRI-Guided Linear Accelerator System

Real-time soft tissue imaging: Continuous MRI guidance allows for precise visualization of tumors and surrounding anatomy during radiation delivery.

Adaptive radiotherapy capabilities: Facilitates on-the-fly adjustment of treatment plans based on daily anatomical changes (e.g., tumor shrinkage, patient motion).

Integration of 1.5T MRI and linear accelerator: Achieves simultaneous imaging and treatment, improving accuracy in moving tumors.

Use cases: Particularly advantageous for abdominal, pelvic, and thoracic tumors where organ motion is a challenge.

3. Biology-Guided Radiotherapy (BgRT)

PET-guided real-time adaptation: Utilizes PET imaging to monitor metabolic activity of tumors, providing biological guidance for radiation targeting.• Tumor heterogeneity targeting: Radiotherapy delivered based on functional information (e.g., glucose metabolism), allowing for dose painting strategies.

Dynamic tumor response adaptation: Treatment modified in real-time based on tumor biological changes during radiation sessions.

Potential application: Suitable for radioresistant and heterogeneous tumors such as head and neck cancers or high-grade gliomas.

4. Proton Therapy

Bragg peak phenomenon: Protons deposit maximal energy at a specific depth, minimizing exit dose and sparing normal tissues beyond the tumor.

High precision dose escalation: Allows for higher doses to the tumor with reduced collateral damage to adjacent tissues, especially in pediatric and sensitive regions.

Optimal for deep-seated tumors: Frequently used for skull base tumors, pediatric cancers, and spinal tumors where precision is crucial.

Treatment planning: Requires complex 3D modeling for beam path planning, accounting for tissue heterogeneity and proton range uncertainties.

5. Proton FLASH Therapy

Ultra-high dose rate proton delivery: Combines proton therapy’s precision with FLASH therapy’s ultra-high dose rates (>40 Gy/s).

Sparing of normal tissues: Hypothesized to achieve a protective effect on normal tissues while maintaining high tumoricidal efficacy.

Potential to further reduce side effects: Early preclinical results show promise in reducing acute and chronic toxicity.

Ongoing research: Currently in early clinical trials, with focus on exploring therapeutic index improvements over conventional proton therapy.

6. Synthetic CT from MRI

MRI-based synthetic CT generation: Converts MRI scans into synthetic CT images for accurate dose calculations in MRI-only workflows.

Advantages in soft tissue contrast: MRI offers superior soft tissue contrast compared to CT, improving tumor delineation for treatment planning.

No ionizing radiation: Eliminates the need for additional CT scans, reducing cumulative radiation exposure during treatment planning.

Applications: Beneficial in head and neck, brain, and prostate cancers where soft tissue contrast is critical for accurate tumor targeting.

The FUTURE of radiotherapy

Hadrotherapy

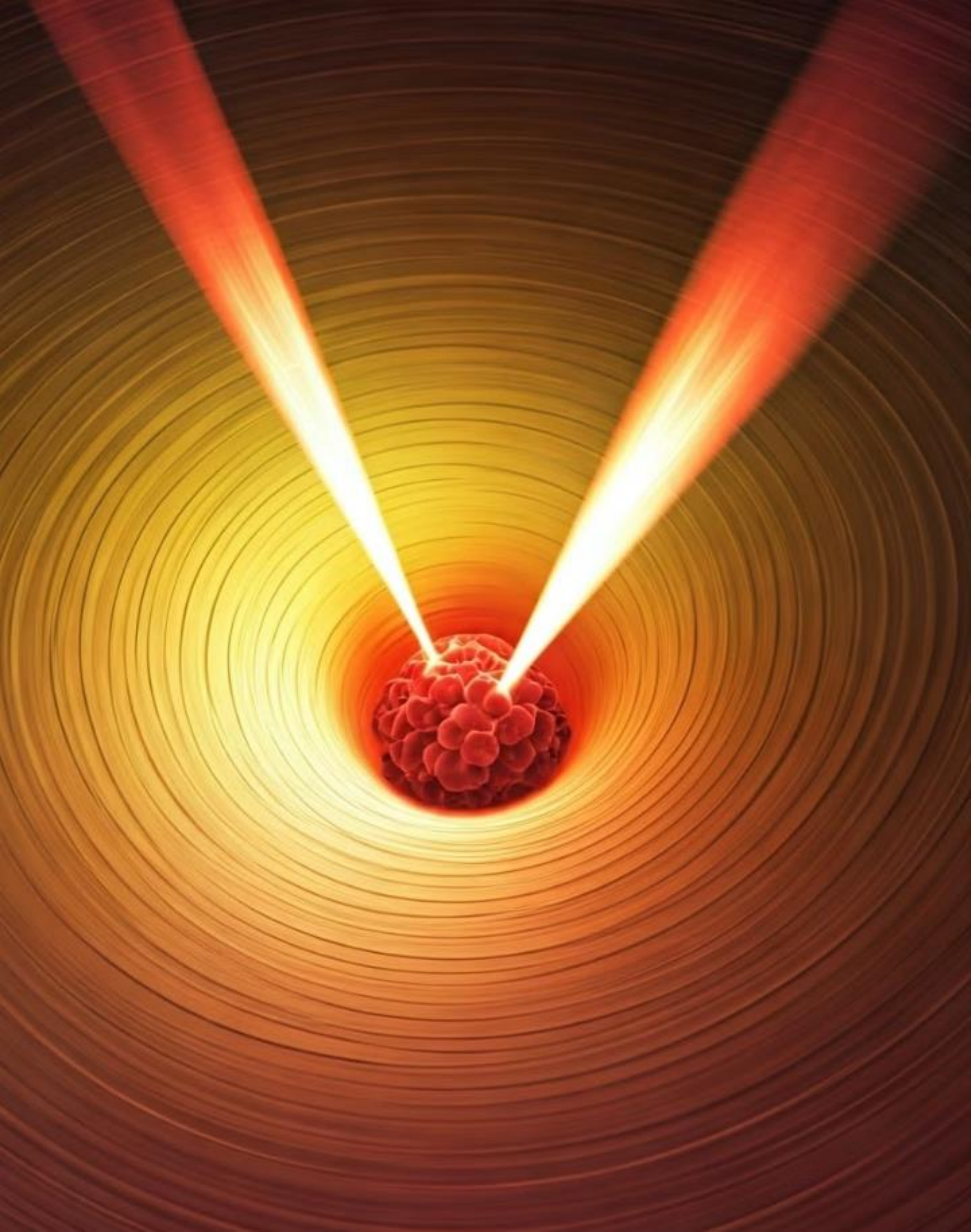
Carbon ions with high LET: Induces complex DNA damage beyond repair in radioresistant tumors.

Increased relative biological effectiveness (RBE): Particularly suited for deep-seated or hard-to-treat cancers (e.g., sarcomas, pancreatic cancers).

Superior dose conformity: Enhanced precision in energy deposition at tumor sites.

AI-Driven Adaptive Radiotherapy:

- :• Real-time tumor tracking: AI monitors tumor response and adjusts treatment plans dynamically during the course of therapy.
- • Enhanced personalization: Treatment evolves continuously with tumor size, position, and biological changes, improving outcomes.
- • Clinical decision support: AI-based algorithms enhance oncologist decision-making through data-driven insights.



Proton FLASH Therapy:.

- Combines proton therapy with ultra-high dose rates: Delivers doses at >40 Gy/s, minimizing normal tissue damage through the FLASH effect.
- • Sparing of normal tissues: Reduced normal tissue toxicity while maintaining therapeutic efficacy for radioresistant tumors.
- • Current status: Under clinical investigation with promising early preclinical and clinical data

Challenges and Limitations

Cost and Accessibility:

- High costs of equipment (e.g., proton centers, heavy ion facilities).
- Limited availability of advanced technologies globally.

Technological Barriers:

- Proton range uncertainties and adaptive technology challenges.
- MRI-metallic artifact challenges in MRI-guided RT.

Long-term Data:

- Need for more clinical trials and long-term outcomes data for new techniques like FLASH therapy.

Research and DevelopmentClinical Trials:

Ongoing trials in FLASH and proton FLASH therapy (e.g., Phase I/II studies).

Heavy ion therapy trials focusing on radioresistant tumors.

AI in Radiotherapy:

AI-driven adaptive radiotherapy algorithms under development.

Exploring AI’s role in predicting radiotoxicity and tumor response.

Radiogenomics:

- Integrating genetic markers into treatment planning to personalize doses.

Wrap-up and Acknowledgments

Physics & Technology with AI are driving advancements in precision.

Cutting-edge technologies like FLASH, MRI-guided RT, and personalized therapies are shaping the future.

Continued research and collaboration are key to realizing these innovations.

Thank you