External Beam Radiotherapy (EBRT) and Internal Radiotherapy (Brachytherapy)

Introduction
Radiotherapy is a cancer treatment that uses ionizing radiation (photons, electrons, or protons) to damage the DNA of malignant cells, preventing them from replicating and causing cell death.1 It is broadly classified into two modalities based on the position of the radiation source relative to the patient: External Beam Radiotherapy (EBRT) and Internal Radiotherapy (Brachytherapy).2

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1. External Beam Radiotherapy (EBRT)

EBRT is the most common form of radiotherapy where the radiation source is located outside the patient's body.[3]

A. Principle

The fundamental principle of EBRT is **differential repair**. The radiation beam (usually high-energy X-rays or electrons generated by a Linear Accelerator or LINAC) is directed through the body to the tumor.[4]

- **Mechanism:** Ionizing radiation creates free radicals that damage DNA (double-strand breaks).[5] Normal cells have efficient repair mechanisms to fix this damage, whereas cancer cells have defective repair pathways and die.
- **Fractionation:** The total dose is divided into small daily doses (fractions) over several weeks.[6] This allows normal tissues to repair sublethal damage between sessions while cumulative damage kills the tumor.
- **Geometric Precision:** The beam is shaped to match the tumor's profile to maximize tumor dose and minimize dose to Organs At Risk (OAR).[7]

B. Procedure

The EBRT workflow involves distinct engineering and clinical steps:

1. **Simulation (Sim):**
   - **Immobilization:** The patient is positioned on a simulator table.[8] Custom molds, thermoplastic masks (for head/neck), or vacuum cushions are created to ensure the patient stays in the exact same position for every treatment.[9]
   - **Imaging:** A CT scan (CT-Simulation) is performed in this treatment position.[10] Reference marks (tattoos or fiducials) are placed on the skin to align the patient later.[11]
2. **Treatment Planning (TPS):**
   - **Contouring:** Radiation oncologists outline the **Gross Tumor Volume (GTV)** and adding margins for microscopic spread (**Clinical Target Volume - CTV**) and setup uncertainties (**Planning Target Volume - PTV**).[12] Normal organs (OAR) are also contoured.
   - **Dosimetry:** Medical physicists/dosimetrists use Treatment Planning Systems (software) to calculate beam angles and intensity.[13] Techniques like **3D-CRT** (Conformal) or **IMRT** (Intensity Modulated Radiotherapy) are used to sculpt the dose distribution.[14]
3. **Verification:**
   - Before the first dose, a "dry run" is often conducted using on-board imaging (OBI) or Cone Beam CT

(CBCT) to verify the target alignmnet matches the plan.[15]

4. **Treatment Delivery:**
    - The patient is positioned on the LINAC couch using the immobilization devices.[16]
    - The LINAC gantry rotates around the patient, delivering radiation from calculated angles.[17]
    - The process is painless and typically takes 15–20 minutes per session (beam-on time is only a few minutes).[18]

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2. Internal Radiotherapy (Brachytherapy)

Brachytherapy (from the Greek *brachys*, meaning "short") involves placing radioactive sources directly inside or immediately adjacent to the tumor.[19]

A. Principle

The core physical principle is the **Inverse Square Law**, which states that radiation intensity creates a massive dose very close to the source but falls off rapidly as distance increases.[20]

- **High Local Dose:** This allows a very high (ablative) dose of radiation to be delivered to the tumor.[21]
- **Rapid Fall-off:** The radiation dose drops sharply millimeters away from the source, sparing the surrounding healthy tissues more effectively than external beams.[22]

B. Classification

- **Intracavitary:** Source placed in a body cavity (e.g., Cervix, Uterus).[23]
- **Interstitial:** Source implanted directly into tissue via needles/catheters (e.g., Prostate, Breast).[24]
- **Intraluminal:** Source placed inside a tube/vessel (e.g., Esophagus, Bronchus).[25]
- **Surface:** Molds placed on the skin (e.g., Skin cancer).[26]

C. Procedure

The procedure varies by timing (LDR vs. HDR):[27]

1. **Applicator Insertion:**
    - Under anesthesia (spinal or general), hollow tubes, catheters, or applicators are inserted into the tumor site.[28]
    - Example: For cervical cancer, a "tandem and ovoid" applicator is placed in the uterus/vagina.[29]
2. **Imaging and Planning:**
    - CT or MRI images are taken with the applicators in place to ensure correct geometry.[30]
    - The physicist calculates the "dwell positions" (where the source stops) and "dwell times" (how long it stays) to achieve the required dose coverage.[31]
3. **Source Loading (Afterloading):**
    - **High Dose Rate (HDR):** A remote afterloader machine pushes a high-activity source (usually

Iridium-192) into the catheters.[32] It travels to the programmed positions, delivers radiation for a few minutes, and then retracts back into the safe.[33] This is often an outpatient procedure.[34]

- **Low Dose Rate (LDR):** Sources (like **Cesium-137**) are manually or remotely loaded and stay in the patient for 1–2 days. The patient must stay in a shielded hospital room.[35]
- **Permanent Implants:** Tiny radioactive seeds (e.g., **Iodine-125**) are implanted permanently (common in prostate cancer) and decay over months.[36]

4. **Removal:**
   - For HDR and LDR, the applicators and catheters are removed after treatment.[37] For permanent implants, they remain in the body.[38]

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3. Comparison: EBRT vs. Internal Radiotherapy

Feature	External Beam Radiotherapy (EBRT)	Internal Radiotherapy (Brachytherapy)
Source Position	Outside the body (usually 100 cm away).	Inside or very close to the tumor (< 1-2 cm).
Dose Distribution	Homogeneous dose; beam passes through normal tissue to reach tumor.	Non-homogeneous; very high central dose with rapid fall-off.
Treatment Duration	Long course: Daily fractions for 4–7 weeks.	Short course: 1–5 days (or single session).
Invasiveness	Non-invasive.	Minimally invasive (requires anesthesia/surgery for applicator).
Radioactivity	Patient is **never** radioactive.	Patient may be radioactive during LDR/Permanent implant.
Common Uses	Brain, Lung, Breast, Head & Neck, Deep tumors.	Cervix, Prostate, Skin, localized accessible tumors.

Conclusion

EBRT and Brachytherapy are complementary techniques.[39] EBRT is excellent for treating large tumor volumes and regional lymph nodes, while Brachytherapy is ideal for delivering a "boost" dose directly to the tumor core with high precision, sparing adjacent critical organs due to the rapid dose fall-off.