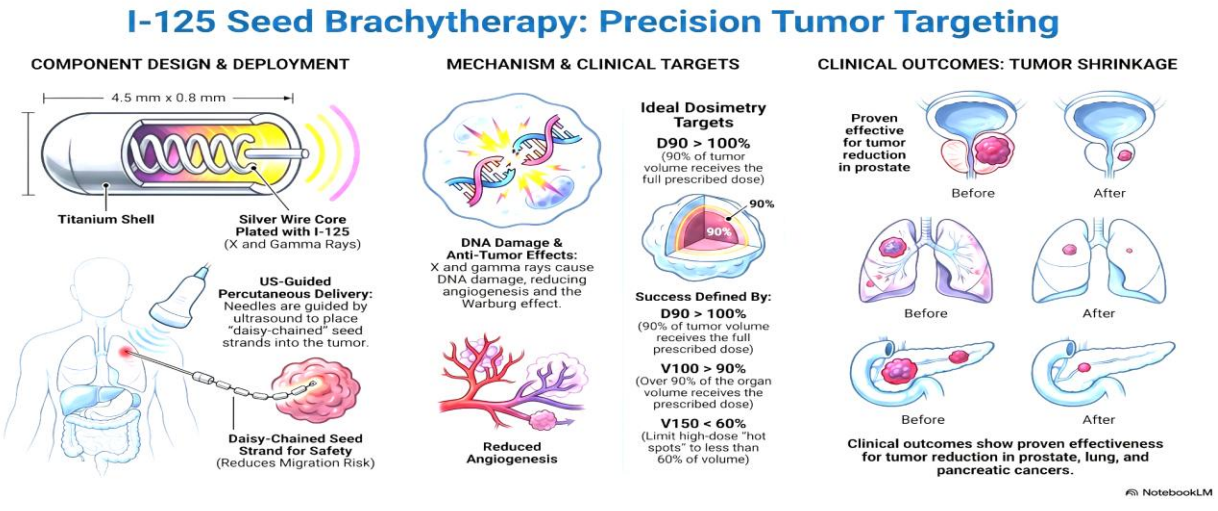
I-125 Seed Implantation: Principles, Dosimetry, and Clinical Applications in Interventional Oncology

[1]Dr. Sayantan Patra, [2]Dr. Reetoja Das, [3]Dr. Soumya Suvra Patra,
[4]Smt. Sima Patra (Bhandari)
[1,2,3,4] *Institute of Post Graduate Education and Research and Seth Sukhmal Karnani Memorial Hospital, Kolkata*

***Abstract*—I-125 seed implantation is a form of low-dose-rate (LDR) brachytherapy that has become a cornerstone of interventional oncology. Utilizing the radioactive decay of Iodine-125, these seeds provide highly localized radiation (0.7 cGy/hour) that induces DNA damage and inhibits angiogenesis within a clinical target volume. This review explores the dosimetry required for successful ablation, patient selection criteria, and specific use case scenarios ranging from standalone prostate cancer treatment to novel combination therapies and seed-integrated stents. By focusing on localized energy deposition, I-125 implantation minimizes collateral damage to healthy tissues, offering a viable alternative for patients with recurrent tumors or those ineligible for major surgery.**

***Index Terms*—Brachytherapy, Iodine Radioisotopes, Neoplasms, Radiotherapy Dosage, Radiotherapy, Image-Guided**



I. INTRODUCTION AND PHYSICAL PRINCIPLES OF I-125 ISOTOPE

I-125 seed implantation is a specialized modality of brachytherapy utilized within interventional radiology, endoscopy, and open surgery. It is categorized as an extremely low-dose-rate (LDR) radiation therapy, distinguishing it from standard LDR and High-Dose-Rate (HDR) treatments.
Physical and Radiobiological Characteristics

- Decay Process: The I-125 isotope has a half-life (T_{1/2}) of 59.4 days. It is produced via beta emission from Xenon-125, ultimately decaying into Tellurium-125.
- Radiation Emission: The isotope emits X-rays and gamma rays. These emissions exert biological control through targeted DNA damage, the inhibition of the Warburg effect (aerobic glycolysis), and a significant reduction in tumor-related angiogenesis.
- Dose Rate Comparison: I-125 delivers an extremely low dose rate of approximately 0.7 \, \text{cGy/h}. This provides a prolonged therapeutic window compared to HDR sources like Iridium-192, which can deliver up to 100 \, \text{Gy/h}.
- Seed Construction: Each seed typically measures 4.5 \, \text{mm} \times 0.8 \, \text{mm}. The I-125 is plated onto a silver wire and encapsulated within a titanium shell. This shell is critical not merely for structural protection, but for the secure encapsulation of the isotope to prevent leakage into the systemic circulation while remaining transparent to therapeutic photon emission.

II. CLINICAL INDICATIONS AND PATIENT SELECTION

Patient selection for I-125 therapy involves a rigorous assessment of tumor volume, accessibility, and the patient's prior oncological history. Notably, certain malignancies—such as pancreatic cancer—demonstrate low-dose radiation hypersensitivity, making them ideal candidates for this LDR approach.

Primary Indications

- Residual or recurrent malignancy following surgery or External Beam Radiation Therapy (EBRT).
- Localized solid tumors with a diameter <7 \, \text{cm}.
- Histology-proven malignancy with favorable percutaneous or endoscopic access.
- Expected patient survival exceeding 3 months.
- Patient refusal or clinical contraindication to conventional surgery or EBRT.

Contraindications for Therapy

Absolute Contraindications	Relative Contraindications
Low performance status (ECOG/Karnofsky)	Extensive or diffuse metastases
Uncorrectable coagulopathy	Severe comorbidities (e.g., uncontrolled Diabetes)
Active tumor rupture	Active systemic infection or immunocompromised state
Absence of a safe percutaneous access track	Renal insufficiency
Documented intolerance to I-125 seeds	Allergy to Iodinated Contrast Media (IOCM)
Intended dose delivery lower than prescribed dose	

III. DOSIMETRIC GOALS AND TREATMENT PLANNING

Precision in medical physics is paramount to ensure tumoricidal efficacy while sparing adjacent critical structures. The total radiation dose utilized in a typical procedure is generally up to 1 \, \text{mCi}.

Target Volume Definitions

- Gross Tumor Volume (GTV): The primary visible extent of the malignant lesion as identified on cross-sectional imaging.
- Clinical Target Volume (CTV): The total treated volume, encompassing the GTV plus a circumferential margin to account for sub-clinical microscopic disease.

Ideal Dosimetric Profile To optimize the therapeutic index, the following quantitative targets must be met:

- D90 (Minimum dose received by 90% of the tumor volume): >100\% of the prescribed dose.
- V100 (Percentage of the organ volume receiving the prescribed radiation): >90\%.
- V150 (Percentage of the volume receiving 150% of the prescribed dose): <60\%.

Clinical Quality Indices Plan quality is further assessed via the Conformational Index (COIN), which evaluates dose-to-target fit; the Coverage Index (CI), measuring the extent of target encapsulation; and the Homogeneity Index (HI), ensuring uniform dose distribution within the target.

IV. CLINICAL USE CASES AND IMPLEMENTATION STRATEGIES

I-125 is deployed as a versatile tool, functioning as a primary treatment or a synergistic adjuvant. Standalone Therapy Commonly used for low-to-intermediate risk early prostate cancer (Standard LDR). It is also effective for other solid tumors, including head and neck, lung, liver, kidney, and bone cancers. In pancreatic cancer, I-125 leverages the specific low-dose hypersensitivity of the tissue for improved local control.

Combination Therapies Synergy is achieved by pairing I-125 with other modalities to address tumor heterogeneity:

- Microwave Ablation (MWA): Used for retroperitoneal (RP) liposarcomas. The thermal energy of MWA kills the tumor core, while the I-125 seeds address the peripheral margins where thermal margins might be limited by adjacent structures.
- TACE: Combined with transarterial chemoembolization for hepatic lesions to provide continuous radiation alongside ischemia.
- Surgery & Chemotherapy: Adjuvant seeds are often placed during pancreatic resections or combined with systemic protocols in lung cancer.

Novel Delivery Platforms

- Seed-Integrated Stents: Radioactive seeds can be integrated into stents (magnesium alloys or polymers) for hollow organs (esophagus, biliary tree). This prevents tumor recurrence and controls granulation tissue proliferation. In these applications, utilizing two strands of seeds is significantly more effective than one for maintaining luminal patency.
- Sensitization: Experimental use of ultrasound-activated, oxygen-carrying microbubbles is employed to reverse tumor hypoxia and enhance radiosensitivity.

V. COMPLICATION MANAGEMENT AND TECHNICAL SAFETY

The primary specific risks of I-125 therapy are mechanical rather than radiological.
Primary Complications

- Seed Migration and Pulmonary Embolism (PE): Loose seeds may enter the venous circulation, potentially leading to embolization in the pulmonary vasculature.
- Imaging Artifacts: The metallic construction of the seeds generates significant beam-hardening artifacts on CT and susceptibility artifacts on MRI.

Technical Mitigation Strategies

- Daisy-Chaining: This involves placing seeds in strands or catheters at fixed intervals. Beyond ensuring proper spacing, this provides mechanical stability within the tissue track, significantly reducing the risk of seed migration into vessels.
- Imaging Guidance: Ultrasound (US) is the preferred modality for intra-operative placement due to the absence of metallic artifacts and real-time visualization. Conversely, CT or MRI are utilized for post-plan dosimetry to confirm the D90 and V100 goals have been achieved.

VI. SUMMARY OF CLINICAL ADVANTAGES

The integration of I-125 seeds into the interventional oncology toolkit provides several core strengths:

1. Extreme Precision: Adherence to D90 and V100 goals ensures lethal dosing to the tumor with a rapid dose fall-off, sparing adjacent healthy tissue.
2. Biological Efficacy: The extremely LDR profile is particularly effective against hypersensitive tumors like pancreatic cancer and inhibits the Warburg effect.
3. Mechanical Stability: The use of "daisy-chained" strands and double-strand configurations in stents provides superior stability and effectiveness over loose seeds.
4. Adjuvant Synergy: Seeds complement thermal ablation and chemoembolization by treating the microscopic margins and providing continuous therapy post-procedure.
5. Technical Safety: Encapsulation in titanium shells and the use of US-guided placement ensure a controlled and reproducible delivery of radiation.

VII. USE CASE SCENARIOS

Scenario 1: Standalone Therapy for Early-Stage Malignancy

In early prostate cancer, I-125 LDR brachytherapy is a standard-of-care for low-to-intermediate risk patients with good urinary function. The seeds are permanently implanted in situ to provide continuous, localized radiation. This application is also extended to other solid tumors, including breast, renal, and abdominal wall cancers.

Scenario 2: Recurrent or Residual Disease

I-125 implantation is indicated for tumors <7 cm in diameter that are residual or have recurred following surgery or external beam radiation therapy (EBRT). It serves as a vital salvage therapy when a patient refuses further surgery or is ineligible for traditional EBRT.

Scenario 3: Combination Strategies

- Pancreatic Cancer: Favorable outcomes when combined with surgery to address the high radiation sensitivity of these cells.
- Lung Cancer: Often combined with chemotherapy to enhance tumor response.

- Hepatocellular Carcinoma (HCC): Can be combined with TACE (Transarterial Chemoembolization) to improve overall survival through additive immune-mediated mechanisms.
- Sarcomas: Combined with Microwave Ablation (MWA) for retroperitoneal liposarcomas to ensure complete marginal control.

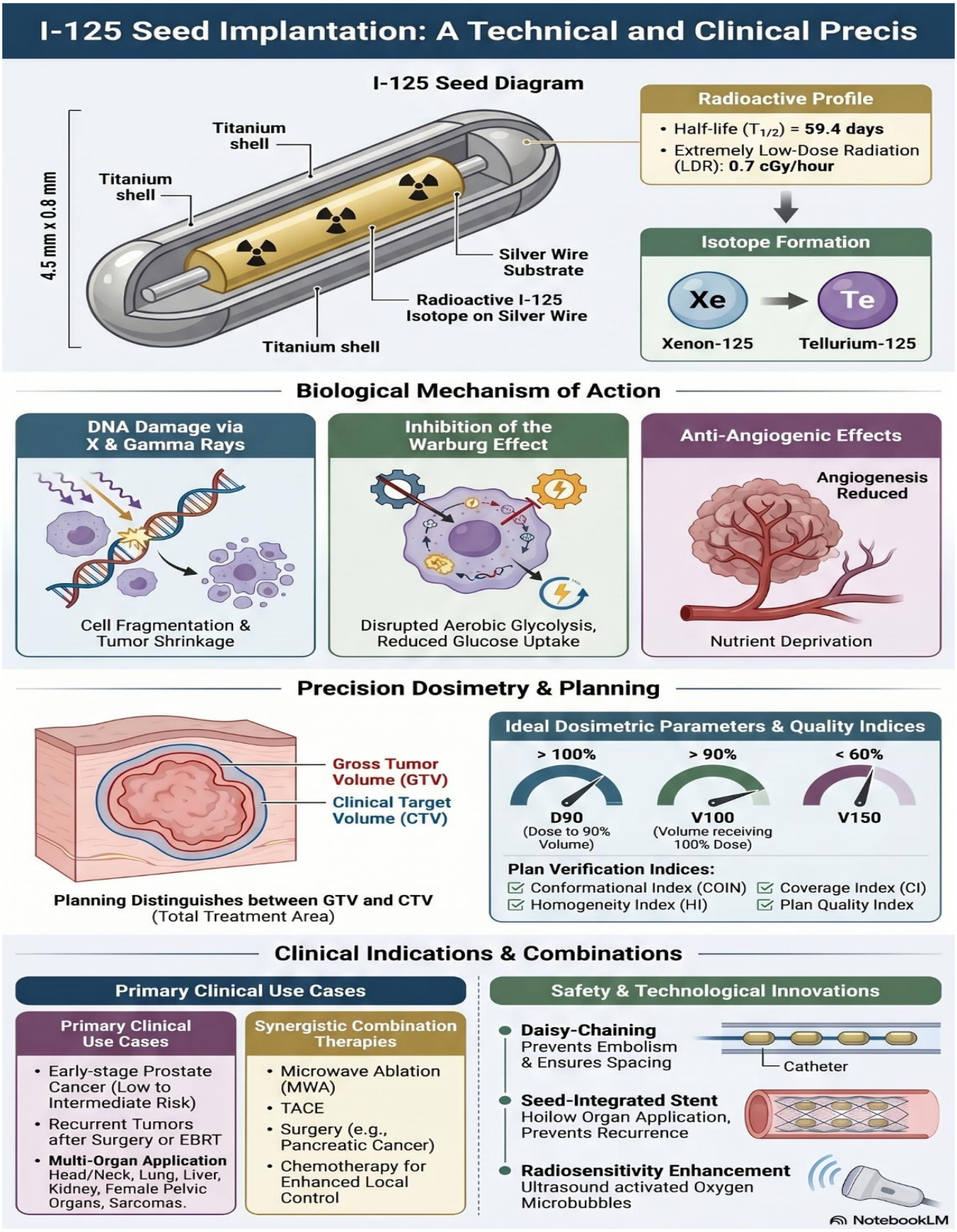
Scenario 4: Novel Delivery Platforms (Stents and Microbubbles)
To prevent tumor recurrence and granulation tissue proliferation in hollow organs, I-125 seeds are being integrated into biodegradable scaffolds or magnesium alloy stents. Additionally, experimental use of oxygen-carrying microbubbles—activated by ultrasound—is being explored to increase the radiosensitivity of solid tumors during I-125 therapy.

VIII. CONCLUSION

I-125 seed implantation has established itself as a versatile and highly precise tool within the arsenal of interventional oncology. Its primary strength lies in the ability to deliver low-dose-rate (LDR) radiation (0.7 cGy/hour) continuously and locally, which maximizes DNA damage and inhibits angiogenesis within the clinical target volume while preserving surrounding healthy tissues.

Unlike other modalities, its compatibility with ultrasound (US) guidance allows for real-time planning and execution, avoiding the metallic artifacts that often complicate CT or MR-guided procedures. Its application is not limited to early-stage prostate cancer; it has proven to be a vital salvage alternative for recurrent or residual tumors less than 7 cm in diameter, particularly in patients who are not candidates for surgery or conventional external beam radiation therapy.
The future of this technology is promising, driven by innovations in delivery systems. The use of seed strands (daisy-chaining) to prevent migration, integration into biodegradable or magnesium alloy stents for hollow organs, and the experimental use of oxygen-carrying microbubbles to increase radiosensitivity suggest a move toward even more personalized and effective treatment. Ultimately, the synergy of I-125 brachytherapy with techniques such as microwave ablation (MWA) or transarterial chemoembolization (TACE) opens new frontiers for the control of complex malignancies, significantly improving patient outcomes and quality of life.

IX. FIGURE


I-125 Seed Implantation: A Technical and Clinical Precis
I-125 Seed Diagram
Titanium shell
Titanium shell
4.5 mm x 0.8 mm
Silver Wire Substrate
Radioactive I-125 Isotope on Silver Wire
Titanium shell
Radioactive Profile
• Half-life ($T_{1/2}$) = 59.4 days
• Extremely Low-Dose Radiation (LDR): 0.7 cGy/hour
Isotope Formation
Xe
Te
Xenon-125
Tellurium-125
Biological Mechanism of Action
DNA Damage via X & Gamma Rays
Cell Fragmentation & Tumor Shrinkage
Inhibition of the Warburg Effect
Disrupted Aerobic Glycolysis, Reduced Glucose Uptake
Anti-Angiogenic Effects
Angiogenesis Reduced
Nutrient Deprivation
Precision Dosimetry & Planning
Gross Tumor Volume (GTV)
Clinical Target Volume (CTV)
Planning Distinguishes between GTV and CTV
(Total Treatment Area)
Ideal Dosimetric Parameters & Quality Indices
> 100%
D90
(Dose to 90% Volume)
> 90%
V100
(Volume receiving 100% Dose)
< 60%
V150
Plan Verification Indices:
Conformational Index (COIN)
Coverage Index (CI)
Homogeneity Index (HI)
Plan Quality Index
Clinical Indications & Combinations
Primary Clinical Use Cases
Primary Clinical Use Cases
• Early-stage Prostate Cancer (Low to Intermediate Risk)
• Recurrent Tumors after Surgery or EBRT
• Multi-Organ Application Head/Neck, Lung, Liver, Kidney, Female Pelvic Organs, Sarcomas.
Synergistic Combination Therapies
• Microwave Ablation (MWA)
• TACE
• Surgery (e.g., Pancreatic Cancer)
• Chemotherapy for Enhanced Local Control
Safety & Technological Innovations
Daisy-Chaining
Prevents Embolism & Ensures Spacing
Catheter
Seed-Integrated Stent
Hoilow Organ Application, Prevents Recurrence
Radiosensitivity Enhancement
Ultrasound activated Oxygen Microbubbles
NotebookLM

ACKNOWLEDGEMENTS

Logistics: Sri Siba Prasad Patra and Smt. Ruma Das.
AI help: Google NoteBook LLM, Gemini 3.1 Flash, Meta AI, ChatGPT
Author contributions:
SP - Primary author,
RD, SSP - Editing and fine tuning,
SP - Overview

REFERENCES

[1] Hu et al. I125 seed implantation and dosimetry in brachytherapy. 2023.
[2] European Society for Medical Oncology (ESMO). Applications of stand-alone brachytherapy in solid tumors. 2024.
[3] Novel applications and combinations of I125 brachytherapy. 2024.
[4] Combination of RFA and TACE with I125 in HCC. 2024.
[5] Hu et al. Dosimetry and Quality Indices in Brachytherapy. 2023.