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BRACHYTHERAPY
HANDBOOK 2025
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$P + \beta + \gamma$
$^{125}_{172}I \rightarrow 1^{15}Te + \beta +)$
$Ir \rightarrow 1^{3}Pt + \alpha$
$^{12}_{12}I = \gamma$
$^{19}_{12}\mathrm{Ir} \rightarrow {}^{19}_{24}\mathrm{P} + \alpha$
$^{1}_{1}\mathrm{H} = \mathrm{D}_{-\gamma}$

TABLE OF CONTENTS

Brachytherapy Handbook

Each chapter contains its own independent reference list, numbered in Vancouver style.

Preface & Chapter I – Foundations
This document is prepared as part of a structured handbook on brachytherapy. It is intended for residents and clinicians seeking a thorough understanding of brachytherapy history, physics, isotopes, applicators, imaging, and safety.

Preface

Brachytherapy is one of the oldest yet continually evolving modalities in radiation oncology. Despite the rapid expansion of external beam techniques such as IMRT, VMAT, and proton therapy, brachytherapy remains irreplaceable in the management of cervical cancer, prostate cancer, and several other malignancies. Its ability to deliver high doses directly to the tumor while sparing surrounding organs at risk (OARs) makes it unique and highly effective. This handbook aims to provide residents with the necessary foundations and practical knowledge to safely implement brachytherapy in modern clinical practice.

Brachytherapy remains one of the most technically demanding and intellectually rewarding areas of radiation oncology. It requires not only knowledge of radiation physics and radiobiology, but also surgical skill, imaging expertise, and multidisciplinary collaboration. This handbook was conceived as a **practical guide for trainees and early-career practitioners**, bridging the gap between comprehensive textbooks and everyday clinical decision-making.

The content is organized into four main chapters. The opening section reviews the **historical foundations** of brachytherapy and the evolution of isotopes, applicators, and planning systems. The subsequent chapters detail **clinical indications**, **practical aspects of applicator insertion, imaging, treatment planning, and delivery**, and conclude with a forward-looking exploration of **current research and emerging technologies**.

To complement the main text, an extensive set of **appendices (A–K)** is provided. These serve as **ready-to-use reference tools**, including key formulas, dosimetric parameters, QA checklists, clinical templates, toxicity grading systems, and resources for further learning. Together, the chapters and appendices aim to provide a **comprehensive yet concise reference** that supports safe and effective practice.

This handbook does not replace formal training, institutional protocols, or published guidelines. Rather, it should be seen as a **companion resource** to aid understanding, reinforce safe practice, and stimulate curiosity. The material has been aligned, wherever possible, with the recommendations of international societies such as ABS, ESTRO, AAPM, and ICRU.

It is our hope that this handbook will serve both as a **learning tool for residents** and as a **quick reference for practicing clinicians**, fostering confidence and competence in the art and science of brachytherapy.

Chapter I – Foundations

1. Brief History of Brachytherapy

The history of brachytherapy is inseparable from the discovery of radioactivity itself. In 1898, Marie and Pierre Curie isolated radium from pitchblende, an achievement that not only won them the Nobel Prize but opened the door to the controlled use of radioisotopes in medicine [1]. Within just a few years, radium was being applied to dermatologic diseases such as lupus vulgaris. The first report of brachytherapy in humans is credited to Danlos and Bloch in 1901, who placed radium directly onto skin lesions with promising results [2].

The interstitial approach — placing radioactive sources within tissue — followed quickly. In 1905, Robert Abbe, a New York surgeon, reported implanting radium needles into malignant tumors [16]. This established the two enduring approaches of brachytherapy: intracavitary (within a natural body cavity) and interstitial (implanted directly into tissues).

Early practitioners faced a problem: dose was not standardized. At first, treatments were empirical, guided by patient tolerance and tumor response. Over time, systems of dose specification emerged. The Paris system, developed in the 1960s by Pierquin and Dutreix, standardized implant geometry and linear source activity [17]. The Manchester system, formulated by Meredith and colleagues in the 1950s and 1960s, introduced the concept of “point A” for gynecologic treatments, which dominated cervical brachytherapy for decades [18].

A major limitation of early brachytherapy was radiation safety. Physicians and nurses often handled radium needles directly, resulting in a tragic legacy of radiation injuries among early pioneers. The invention of afterloading in the 1950s changed this. Applicators could first be placed into the patient, and only afterward were radioactive sources inserted — reducing staff exposure dramatically [19]. The arrival of remote afterloading in the 1970s, combined with new isotopes like Iridium-192, ushered in the modern HDR era [20].

The last two decades have seen the rise of image-guided adaptive brachytherapy. With MRI, clinicians can delineate high-risk and intermediate-risk target volumes, adjusting each fraction as tumors shrink. This approach, pioneered by the GEC-ESTRO group and validated by the EMBRACE trials, has transformed gynecologic brachytherapy outcomes [1,2].

From radium needles crudely applied over a century ago, brachytherapy has evolved into one of the most precise, image-guided, and biologically effective treatments in modern oncology: A woman with stage IIB cervical cancer treated in the 1920s might have undergone radium insertion using a tandem and ovoid system, with doses prescribed empirically. Today, the same patient would receive image-guided adaptive brachytherapy with MRI-defined HR-CTV and DVH-based planning.

2. Physics and Principles

The physical basis of brachytherapy lies in the inverse square law: radiation dose decreases with the square of the distance from the source [Fig. 1]. This property allows very high doses to be delivered to small volumes while rapidly sparing nearby tissues. Unlike external beam radiotherapy, brachytherapy dose distributions are inherently inhomogeneous, often with 'hot spots' inside the target volume [3] [Fig. 2].

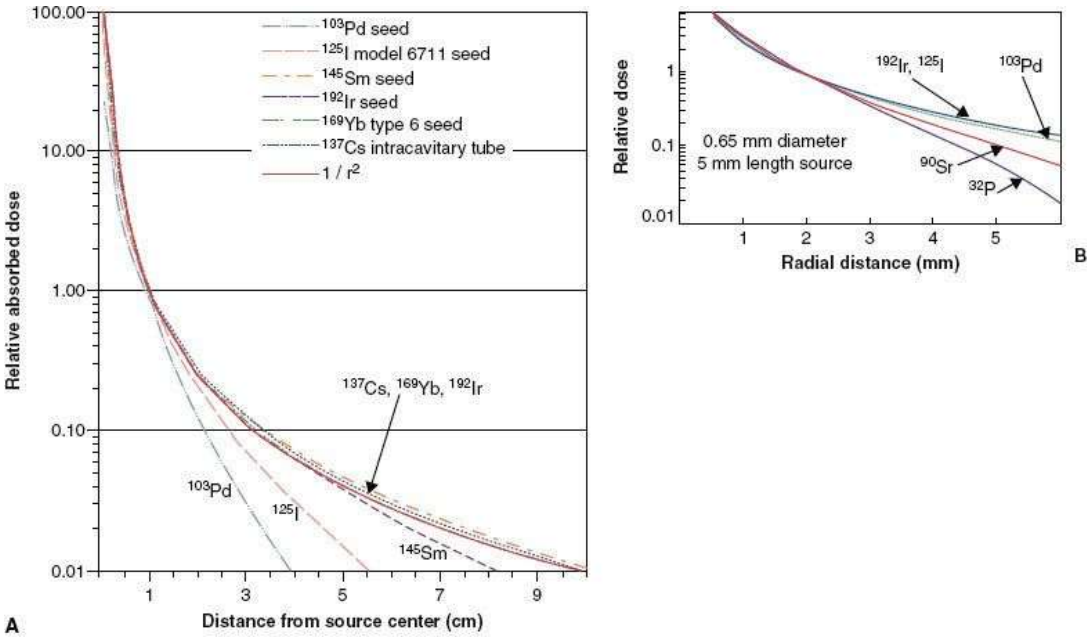

Figure 1. Dose distribution demonstrating inverse square law with a point source. This chart demonstrates that as you move away from the source, the dose drops rapidly, following an approximate inverse-square trend, reinforcing why placing sources close to tumors is so effective while sparing surrounding tissue. *Source: Physics and Biology of Brachytherapy, OncohemaKey (open-access educational resource).*

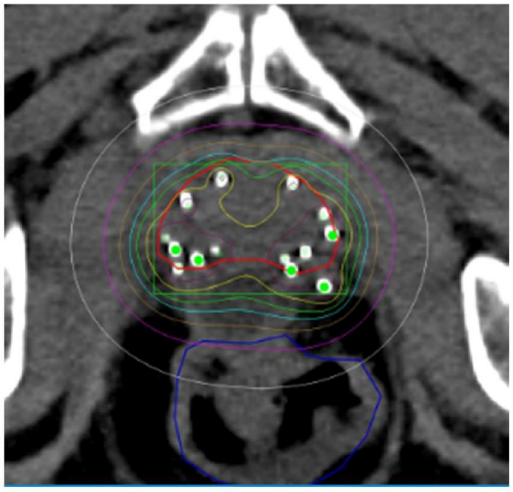

Figure 2. Axial CT slice from an ^{125}I prostate implant, with dose color overlays: most of the gland is covered by the prescription dose (red), but high-dose "hot spots" (>120%) are visible (yellow), and areas receiving less than 40% are shown in purple—demonstrating inhomogeneous dose distribution typical to brachytherapy. *Source: ResearchGate*

Treatment planning is guided by ICRU recommendations [4]. Key parameters include reference dose points (e.g., Point A for cervical cancer), dose-volume histograms (DVHs), and target definitions (GTV, CTV, HR-CTV) [3] [Figure 3]. Modern planning incorporates 3D CT and MRI imaging.

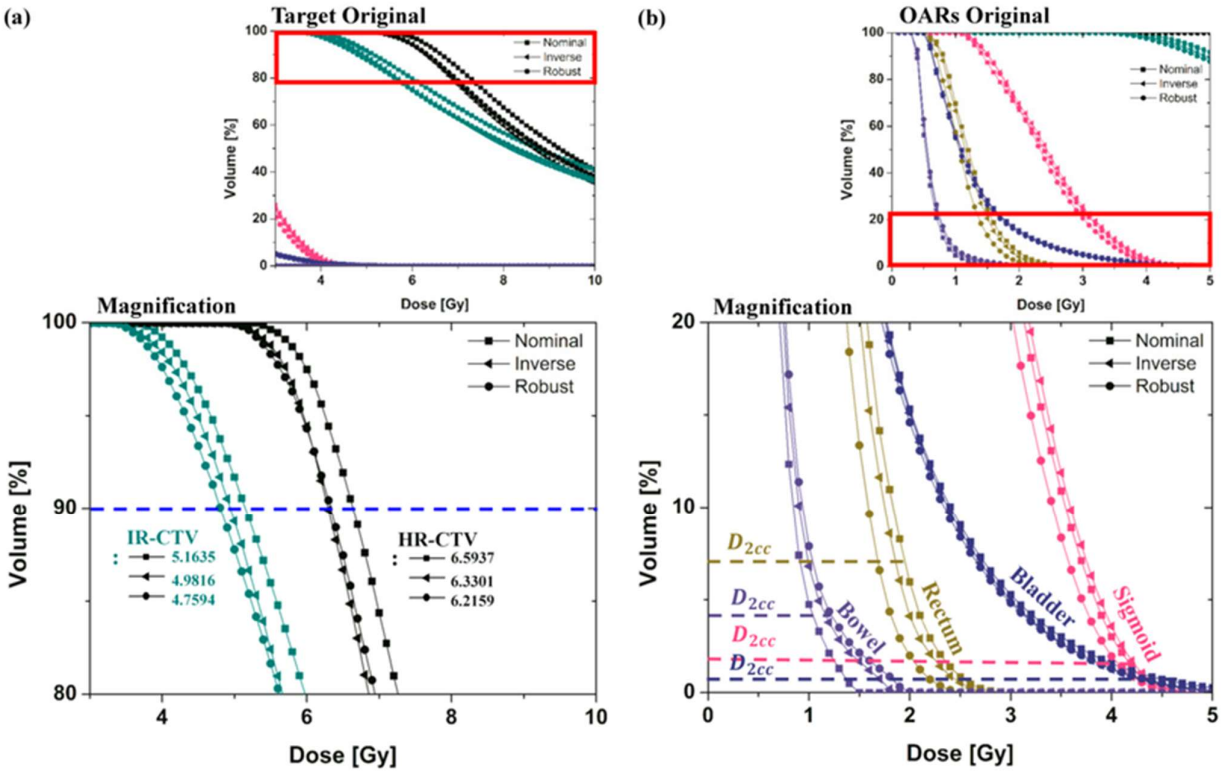

Figure 3. DVH comparison of HR-CTV and OARs in MRI-based planning.

It displays a dose-volume histogram from a brachytherapy treatment plan, showing coverage of the target [CTV] alongside doses to organs at risk—typically bladder, rectum, etc. *Source: Brachytherapy plan DVH sheet, published in open-access educational diagram (Scientific Diagram / ResearchGate).*

3.1. Radioactive Isotopes in Clinical Use

Common isotopes include [Table 1]:

- Cesium-137: historically used for LDR intracavitary treatments.
- Iridium-192: the most widely used isotope in HDR brachytherapy due to high specific activity.
- Cobalt-60: used in some HDR afterloaders, longer half-life than Ir-192.
- Iodine-125 and Palladium-103: commonly used for permanent interstitial implants, especially in prostate brachytherapy.
- Gold-198: occasionally used for permanent implants in head and neck tumors.

Table 1. Common isotopes used in brachytherapy and their half-lives [7, 8, 9]

Isotope	Half-life	Radiation type	Common applications
Radium-226	1600 years	α, β, γ	Historic use (obsolete today) [7]
Cesium-137	30.1 years	γ (0.662 MeV)	LDR intracavitary (gynecological, now mostly replaced) [7,8]
Iridium-192	73.8 days	γ (0.136–1.06 MeV)	HDR brachytherapy, interstitial & intracavitary [7–9]
Cobalt-60	5.27 years	γ (1.17, 1.33 MeV)	HDR brachytherapy (some afterloaders) [9]
Iodine-125	59.4 days	γ (0.028 MeV)	Permanent seed implants (prostate, eye plaques) [7,8]
Palladium-103	17 days	γ (0.021 MeV)	Permanent prostate seed implants [7]
Gold-198	2.7 days	β, γ	Rare, used in interstitial H&N implants [7]

3.2. Emerging Isotopes in Brachytherapy

While most clinical brachytherapy today relies on ^{192}Ir, ^{125}I, ^{137}Cs, and ^{103}Pd, there is increasing research into **alpha-emitting isotopes**, which offer very high linear energy transfer [LET] and short path lengths, potentially improving tumor control while sparing normal tissue [Table 2].

- **Radium-224**
    - *Half-life:* 3.66 days
    - *Radiation type:* α-particles (plus β, γ from daughter isotopes)
    - *Concept:* Delivers clustered, irreparable DNA double-strand breaks in tumor cells due to high LET.
    - *Applications:* Investigated in **targeted alpha therapy (TAT)** and **brachytherapy patches** (e.g., for non-melanoma skin cancers, mesothelioma, and bone metastases).
    - *Status:* Experimental, not part of routine clinical practice.

Other alpha emitters under exploration for radionuclide therapy (though not classic brachytherapy) include **Actinium-225** and **Bismuth-213**.

Table 2. Comparison of alpha vs. beta/gamma emitters in brachytherapy and radionuclide therapy [13, 14, 15]

Property	Alpha emitters (e.g., Ra-224, Ac-225, Bi-213)	Beta/Gamma emitters (e.g., Ir-192, Cs-137, I-125)
Type of radiation	Heavy α particles (helium nuclei)	Electrons (β) and photons (γ, X-ray)
Energy (typical)	4–8 MeV per particle	20 keV – 1.3 MeV depending on isotope
LET (Linear Energy Transfer)	Very high (~80–120 keV/µm)	Low–moderate (~0.2–2 keV/µm)
Range in tissue	50–100 µm (micrometers)	Millimeters to several centimeters
Biological effect	Dense, clustered DNA double-strand breaks; irreparable	Sparsely ionizing damage, often repairable
Cross-fire effect	Minimal (no coverage beyond a few cells)	Strong cross-fire; allows coverage of larger volumes
Main use	Experimental, targeted alpha therapy; surface/interstitial research [13–15]	Established clinical brachytherapy (cervix, prostate, breast, etc.) [7–9]
Toxicity profile	Highly potent locally, but risk if daughters redistribute [13,14]	Predictable OAR dose, well established in QA [7,9]

4. Applicators and Techniques

Intracavitary brachytherapy uses applicators placed in natural body cavities, such as tandem and ovoid/ring for cervix [1] [Figure 3], vaginal cylinders for endometrium, and esophageal or bronchial applicators. Interstitial brachytherapy uses needles or catheters inserted directly into tissues, either temporarily (HDR) or permanently (LDR seeds).

Modern applicators are CT/MRI compatible and often combine interstitial needles with intracavitary templates for hybrid approaches [2] [Table 3].

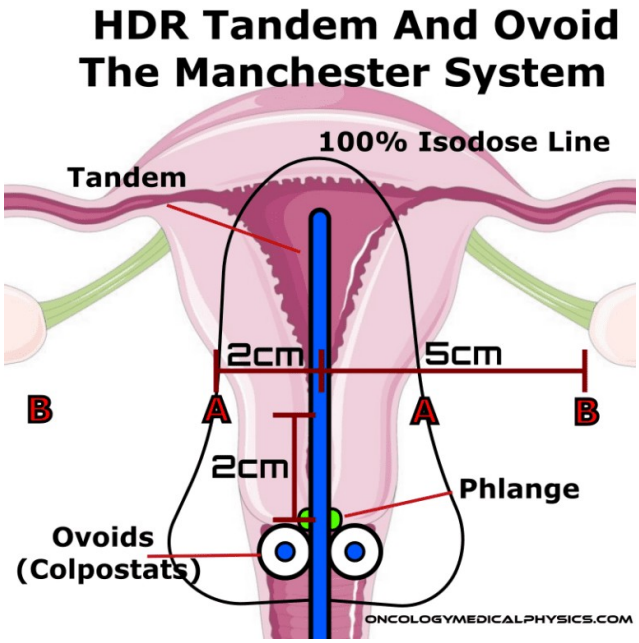

Figure 3. Tandem and ovoid applicator for cervical cancer brachytherapy.

This figure clearly labels the tandem and ovoids within the applicator. It depicts a 100% isodose line following the Manchester system layout. *Source: Gynecological brachytherapy schematic, Oncology Medical Physics [open-source educational image].*

Table 3. Applicator types and common indications [10, 11, 12]

Applicator type	Category	Typical indications
Tandem and ovoid / ring	Intracavitary	Cervical cancer [10,11]
Vaginal cylinder	Intracavitary	Endometrial cancer (vaginal cuff boost) [12]
Esophageal applicator	Intracavitary	Esophageal cancer [10]
Bronchial applicator	Intracavitary	Endobronchial tumors, palliative use [10]
Interstitial needles/catheters	Interstitial	Prostate, breast, soft tissue sarcoma, gynecological boost [11]
Prostate seed implants	Interstitial (LDR)	Localized prostate cancer [12]
Hybrid applicators (Vienna, Utrecht)	Intracavitary + Interstitial	Locally advanced cervical cancer requiring parametrial coverage [11]

5. Imaging and Treatment Planning

Traditional brachytherapy planning was based on 2D radiographs and reference points. Current practice emphasizes 3D image-guided brachytherapy using CT or MRI [2]. MRI is considered the gold standard for cervix brachytherapy, enabling precise delineation of the high-risk CTV and organs at risk [2,4,6]. Treatment planning software allows dose optimization and visualization of isodose distributions. Ultrasound plays an essential role in prostate brachytherapy, guiding the implantation of seeds or catheters [2].

6. Quality Assurance and Safety

QA in brachytherapy includes source calibration, verification of applicator reconstruction, and checks of treatment planning system outputs. Remote afterloaders require daily, monthly, and annual QA, including source positioning accuracy and timer tests [5]. Radiation protection measures are vital: shielding of treatment rooms, exposure monitoring of staff, and emergency procedures in case of source

misplacement [5].

The IAEA and ESTRO provide detailed QA protocols for brachytherapy practice [5].

Clinical Pearls - Foundations

• **Inverse square law is your friend and enemy.** A 1 mm shift in source position can mean a huge change in local dose. Always double-check applicator reconstruction.

• **Hot spots aren't always bad.** Unlike EBRT (external beam radiotherapy), brachytherapy thrives on inhomogeneity. Small "hot zones" inside the target often boost tumor control without causing excess toxicity.

• **MRI is the gold standard.** For cervix brachytherapy, MRI defines HR-CTV and OARs far better than CT. If MRI is unavailable, use CT with caution — overestimating rectum or bladder dose is common.

• **Needle geometry matters.** In interstitial implants (prostate, gynecologic, sarcoma), the quality of the geometry determines the plan quality. A bad implant can't be rescued by optimization.

• **Seed migration is real.** In permanent prostate implants (^{125}I, ^{103}Pd), seeds can embolize to the lung or shift positions. Post-implant imaging (CT or radiographs) isn't optional.

• **Shielding is critical.** Remote afterloaders make staff exposure low, but never forget source-misplacement scenarios. Every department should rehearse emergency retrieval protocols.

• **Point A vs. volumes.** Classic 2D planning revolved around Point A, but modern brachytherapy is 3D and volume-based. Some older exams (and senior colleagues!) still ask in terms of Point A.

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Chapter 2. Clinical Applications of Brachytherapy

Brachytherapy has evolved into a cornerstone of radiation oncology across a wide spectrum of malignancies. Its value stems from the ability to deliver a very high dose directly to the tumor while minimizing exposure to surrounding normal tissues. Clinical applications vary according to tumor site, applicator technology, and isotope availability. This chapter reviews the major disease sites where brachytherapy is currently established, highlighting indications, technical considerations, and expected outcomes.

2.1 Gynecological Malignancies

Cervical cancer

Cervical carcinoma remains the prototypical indication for brachytherapy. For locally advanced disease, brachytherapy is mandatory to achieve curative outcomes, in combination with external beam radiotherapy and concurrent chemotherapy [1]. Modern image-guided adaptive brachytherapy (IGABT) with MRI or CT has replaced traditional 2D planning, allowing individualized contouring of the high-risk clinical target volume (HR-CTV) and organs at risk (OARs) [2][Figures 2, 3].

Tandem and ovoid or tandem and ring applicators are the most frequently used intracavitary devices. In bulky or parametrial disease, hybrid intracavitary–interstitial techniques using Vienna or Utrecht applicators improve target coverage [3][Figure 1]. Dose is prescribed to HR-CTV, with constraints expressed as D90 for target and D2cc for OARs. Clinical trials and multicenter studies have demonstrated significant improvements in local control and reduction in severe toxicity with MRI-guided brachytherapy compared to historical 2D methods [4].

Key applicators and constraints are summarized in Table 2.1.

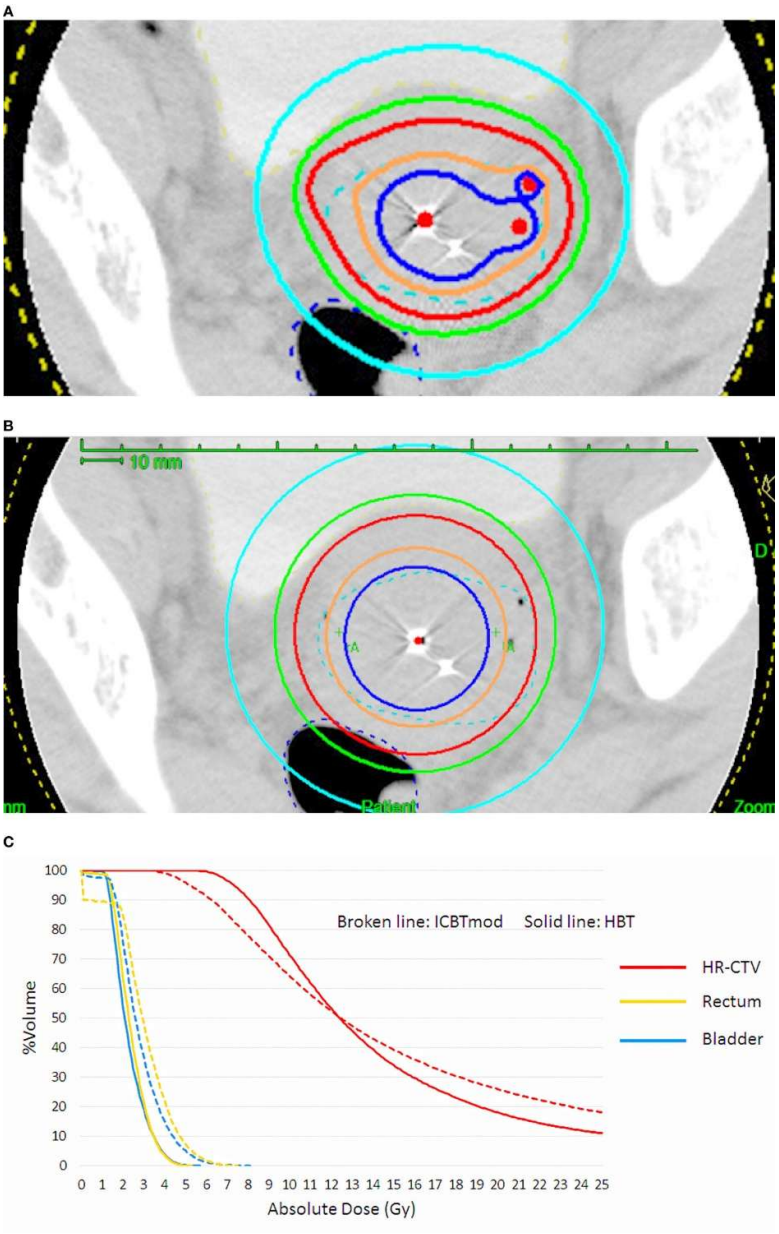

Figure 1. Isodose distribution of hybrid intracavitary–interstitial applicator, showing improved HR-CTV coverage compared to intracavitary alone.

This image from Frontiers in Oncology (Figure 1 of Hybrid Brachytherapy article) highlights how combining intracavitary and interstitial elements alters dose patterns — ideal for advanced cervix cases.

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Endometrial cancer

The most common indication is adjuvant vaginal cuff brachytherapy after hysterectomy for intermediate- and high-risk disease [5]. Vaginal cylinders of various diameters are used, typically treating the upper 3–5 cm of the vagina. Dose fractionation schemes vary, but common regimens include 7 Gy × 3 fractions or 5.5 Gy × 4 fractions prescribed at 5 mm depth [6]. Randomized trials (e.g., PORTEC-2) have shown that vaginal cuff brachytherapy provides excellent local control with fewer side effects compared to pelvic external beam radiotherapy in selected patients [7].

Key applicators, fractionation and constraints are summarized in Table 1.

Table 1. Gynecologic Brachytherapy Applications, Fractionation, and Constraints

Site	Applicator(s)	Typical Fractionation	Key Dose Constraints	Notes
Cervix (locally advanced)	Tandem + ovoid / ring, Vienna/Utrecht hybrid (intracavitary + interstitial) [Figure 2]	HDR: 7 Gy × 4–5 (to HR-CTV D90)	HR-CTV D90 ≥ 85 Gy EQD2; Bladder D2cc < 90 Gy; Rectum, sigmoid D2cc < 75 Gy [21–24]	MRI-guided adaptive planning standard of care [2,4,22,23,25][Figure 3]
Endometrium (post-op vaginal cuff)	Vaginal cylinder	7 Gy × 3 or 5.5 Gy × 4 (at 5 mm depth)	Vaginal mucosa ≤ 130% prescribed dose [6]	Adjuvant in intermediate/high-risk patients (PORTEC-2) [5,7]

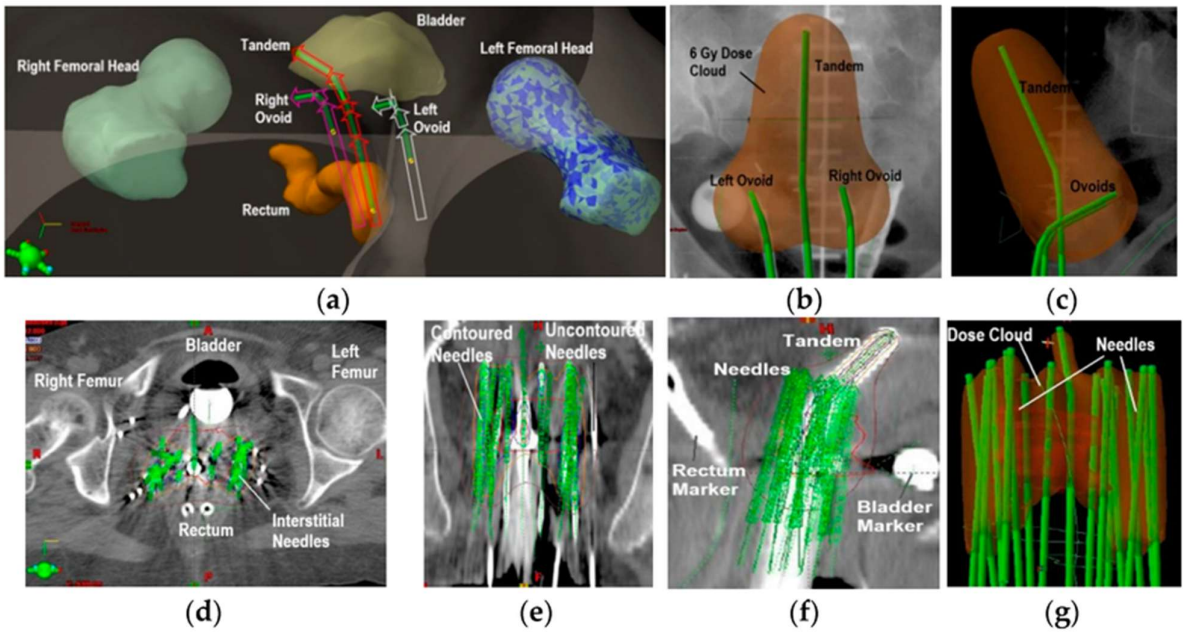


Figure 2. CT-based 3D rendering of tandem-and-ovoids brachytherapy showing applicators, OARs, and isodose coverage. A real-patient CT-based rendering with applicator geometry, dwell positions, and isodose contours. Fantastic for demonstrating how planning translates into real anatomy. Reproduced from Roa D E, Kuo J, Moyses H, et al. *Fiber-Optic Based Laser Wakefield Accelerated Electron Beams and Potential Applications in Radiotherapy Cancer Treatments* (2022). Image used courtesy of the authors / via ResearchGate.

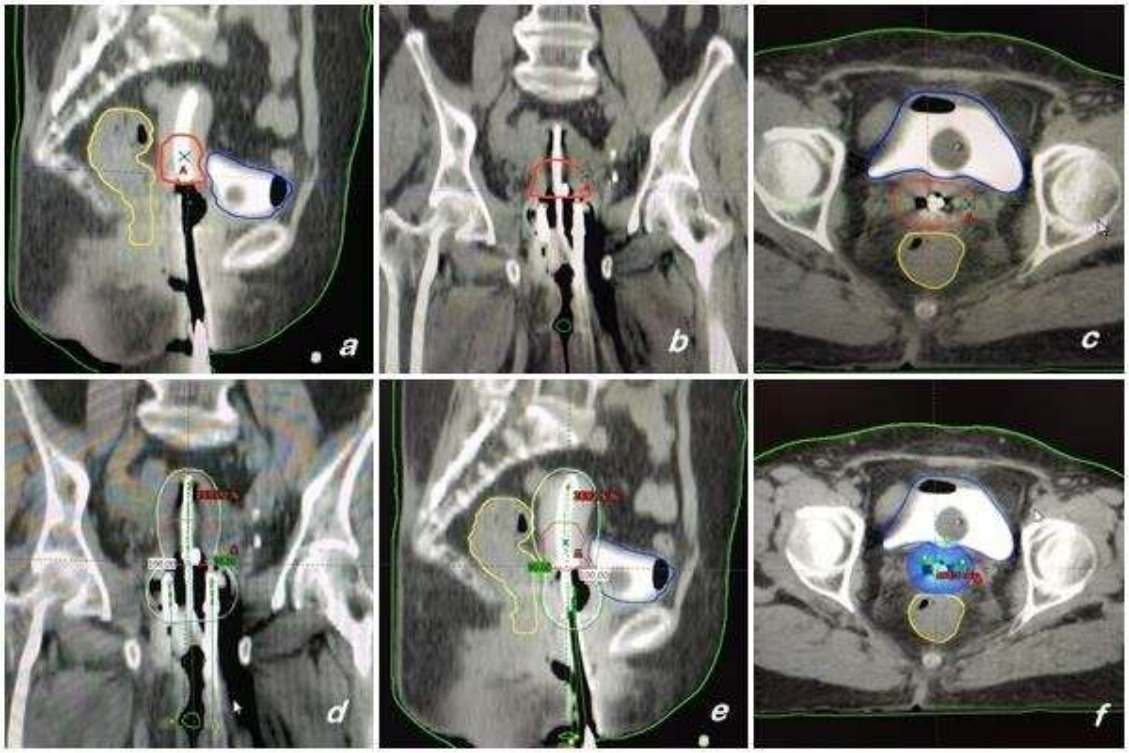


Figure 3. *Axial CT showing HR-CTV contour (red) and isodose distribution (green = 90%, white = 100%) in MRI-guided planning.* Reproduced from Bandyopadhyay A, Ghosh AK, Chhatui B, Das D, *Reports of Practical Oncology & Radiotherapy* 2021;26(2):170–178. Licensed under CC BY-NC-ND 4.0.

2.2 Prostate Cancer

Brachytherapy is a well-established modality for localized prostate carcinoma. Two main approaches exist: permanent low-dose-rate (LDR) seed implantation and temporary high-dose-rate (HDR) brachytherapy.

A comparison of permanent LDR and temporary HDR approaches is shown in Table 2.

Permanent LDR implants

Radioactive seeds (^{125}I or ^{103}Pd) are implanted transperineally under ultrasound guidance [8]. This technique provides durable biochemical control rates comparable to radical prostatectomy in low- and selected intermediate-risk patients [9]. Post-implant CT or MRI is performed to assess dosimetry, ensuring that V100 (percentage of prostate receiving 100% of prescription dose) exceeds 90% and that rectal and urethral constraints are respected [10].

HDR brachytherapy

HDR brachytherapy [Figure 4] is used either as monotherapy or as a boost to EBRT. It allows modulation of dwell times and source positions, providing highly conformal coverage [Figure 5]. Fractionation schemes include 9.5 Gy × 4 or 13.5 Gy × 2 for monotherapy, and 15 Gy × 1 or 19 Gy × 2 as boost regimens [11]. Randomized and prospective studies show favorable biochemical control, especially in intermediate- and high-risk disease, with acceptable toxicity [12].

Table 2. Prostate Brachytherapy Approaches

Technique	Isotopes	Typical Prescription	Ideal Candidates	Notes
LDR seeds (permanent)	I-125 (145 Gy), Pd-103 (125 Gy) [10]	V100 > 90% [10]	Low-risk, selected intermediate-risk [8,10]	Requires careful post-implant dosimetry [10]
HDR (temporary)	Ir-192 [11]	Monotherapy: 9.5 Gy × 4 [11], 13.5 Gy × 2 [12]; Boost: 15 Gy × 1 or 19 Gy × 2 [11,12]	Intermediate/high-risk [9,11,12]	Flexible dwell times, excellent conformity [11]

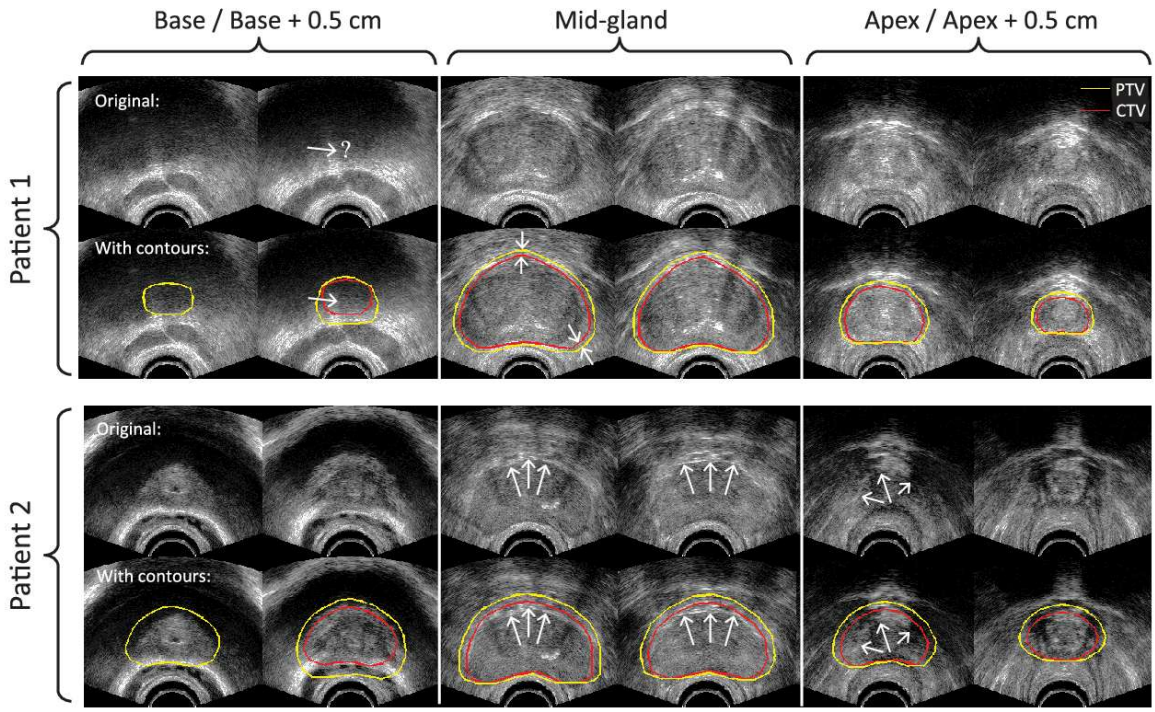
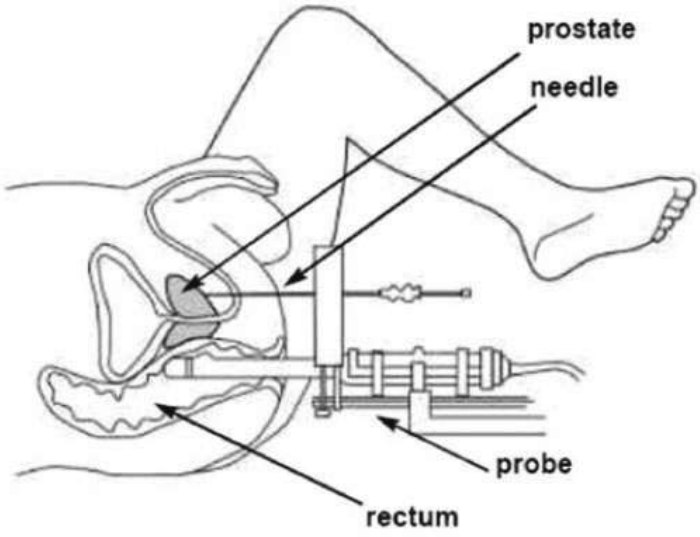


Figure 4. Transperineal needle insertion under real-time TRUS using a template grid, typical of HDR prostate brachytherapy. *Source unknown*, used for educational purposes.



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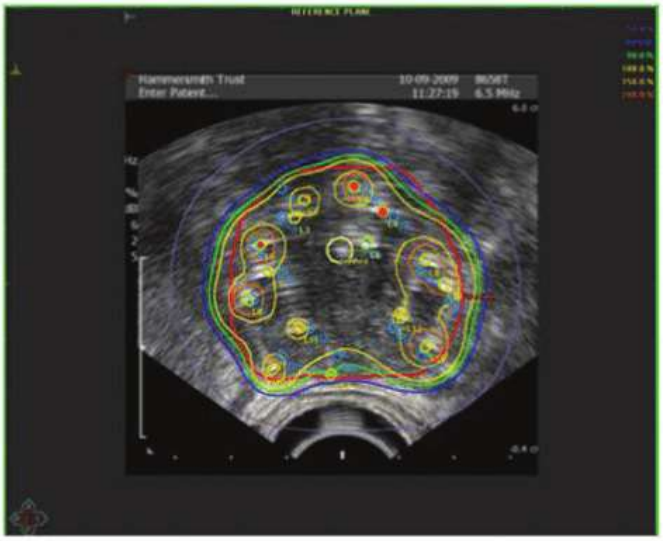


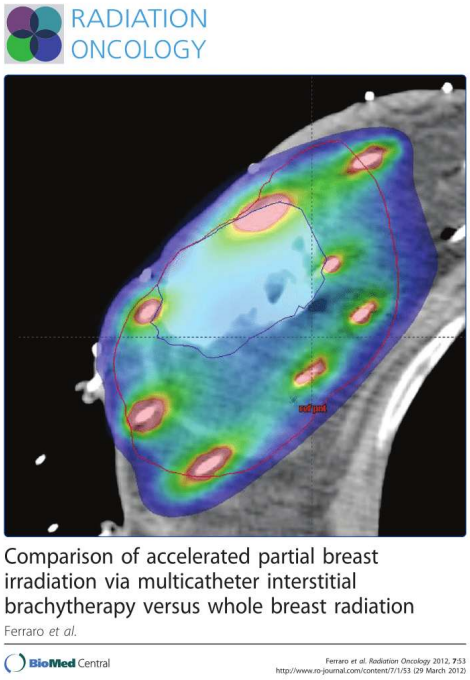
(b)

Figure 5. TRUS image with isodose overlay from HDR prostate brachytherapy, illustrating how dwell point mapping ensures target coverage. **Reproduced from** Challapalli A, Jones E-L, Harvey C, Mangar S, *High-dose-rate prostate brachytherapy: an overview of the rationale, experience and emerging applications in the treatment of prostate cancer*, **Clin Oncol (R Coll Radiol)** 2012;24(8):e193-e200. Reproduced for educational purposes.

2.3 Breast Cancer

Accelerated partial breast irradiation (APBI) is an increasingly adopted alternative to whole-breast irradiation in selected early-stage breast cancer patients. Interstitial multicatheter brachytherapy [Figures 5, 6] remains the most mature and evidence-based APBI technique [13]. Candidates include women ≥50 years with tumors ≤3 cm, negative margins, and node-negative disease.

Several randomized trials (e.g., GEC-ESTRO, Budapest trial) have confirmed equivalence in local control compared to whole-breast radiotherapy, with shorter treatment times [14]. The technique requires careful catheter placement around the lumpectomy cavity, often under ultrasound or CT guidance, followed by planning with dose constraints for skin, ribs, and heart.



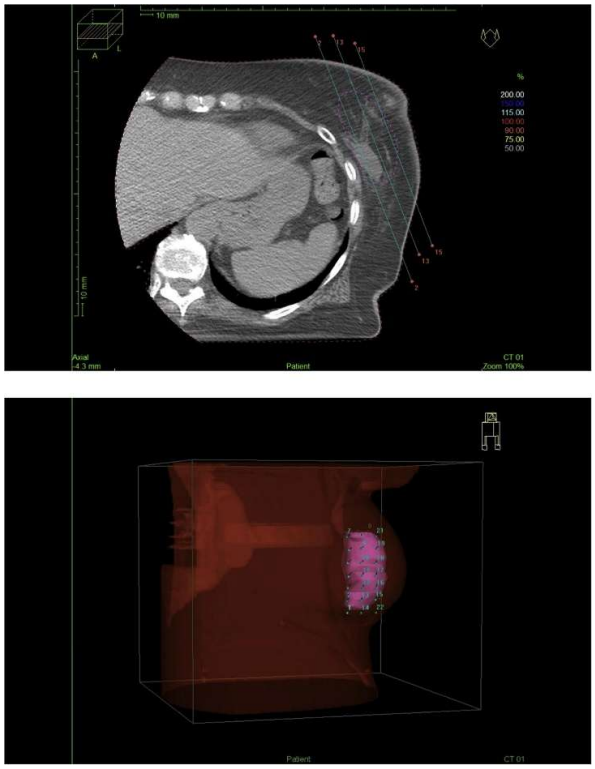


Figure 5. Dose distribution for multicatheter APBI showing high-dose regions around the lumpectomy cavity and steep gradients to surrounding tissue. *Reproduced from Ferraro et al.Radiation Oncology 2012, 7:53 http://www.ro-journal.com/content/7/1/53 (29 March 2012). Reproduced for educational purposes.*	**Figure 6**. 3D CT rendering of multicatheter interstitial brachytherapy for APBI, showing source paths and applicator layout.**Source:** Strnad V, Hannoun-Levi JM, Guinot JL, Lössl K, Kauer-Dorner D, Resch A, et al. *ESTRO-ACROP guideline: Interstitial multi-catheter breast brachytherapy as accelerated partial breast irradiation alone or as boost.* ***Radiother Oncol.*** *2018;128(3):411-420. © 2018 Elsevier B.V. All rights reserved. Educational purposes.*

2.4 Head and Neck Cancers

Interstitial brachytherapy can be applied as definitive or boost therapy for oral cavity, oropharynx, and lip cancers [15]. The main advantage is the ability to deliver a high localized dose while sparing salivary glands and mandible. Techniques involve placement of afterloading catheters using templates or freehand approaches.

In early-stage mobile tongue and lip cancers, local control rates above 85% have been reported, with good functional preservation [16]. In the oropharynx, brachytherapy is mostly reserved for selected boost indications due to the widespread adoption of IMRT.

2.5 Esophageal and Bronchial Cancers

Endoluminal brachytherapy provides palliation of dysphagia in advanced esophageal carcinoma. HDR brachytherapy using specialized applicators can relieve obstruction quickly, often in combination with stenting or EBRT [17]. For bronchial cancers, intraluminal brachytherapy is mainly used for symptom palliation of hemoptysis or obstruction, with immediate relief in most patients [18].

2.6 Soft Tissue Sarcomas

After conservative surgery, interstitial brachytherapy can be used as adjuvant therapy for selected extremity sarcomas. Catheters are placed intraoperatively in the tumor bed, allowing early postoperative irradiation [19]. While external beam radiotherapy remains standard, brachytherapy may be advantageous in specific anatomic locations or when postoperative wound healing is a concern.

2.7 Other Indications

- **Anal canal cancer:** Brachytherapy boost after chemoradiation in selected T1–T2 cases.
- **Skin cancers:** Surface applicators or Leipzig-style applicators provide a non-invasive alternative to surgery in selected basal cell or squamous cell carcinomas.
- **Ocular tumors:** Episcleral plaque brachytherapy with ^{125}I or ^{106}Ru remains standard for choroidal melanoma [20].

Additional selected indications are outlined in Table 3.

Table 3. Selected Other Indications

Site	Technique	Outcomes / Role
Breast (APBI)	Interstitial multicatheter	Equivalent LC to whole-breast RT in randomized trials (Budapest, GEC-ESTRO) [13,14] ; reduced treatment time
Head & Neck	Interstitial catheters (lip, tongue)	Local control >85% in early lesions; good function preservation [15,16]
Esophagus	Endoluminal HDR	Palliation of dysphagia; often combined with stent or EBRT [17]
Lung (bronchus)	Intraluminal HDR	Effective relief of obstruction and hemoptysis [18]
Sarcoma	Intraoperative interstitial	Adjuvant boost, especially in extremity tumors [19]
Ocular (uveal melanoma)	Episcleral plaque (I-125, Ru-106)	Eye-preserving standard therapy [20]

2.8 Organ-At-Risk Dose Constraints

An essential principle of brachytherapy is achieving adequate tumor coverage while respecting the tolerance of surrounding normal tissues. Because brachytherapy delivers highly localized but inhomogeneous dose distributions, organs at risk (OARs) are particularly sensitive to excess dose. Unlike external beam radiotherapy, where dose is expressed in uniform fields, brachytherapy relies on small-

volume metrics such as **D2cc** (dose to the most exposed 2 cm^3 of an organ) or **D0.1cc** for certain critical structures [21].

International consensus statements, particularly those of **GEC-ESTRO** and the **American Brachytherapy Society (ABS)**, recommend expressing cumulative doses from both EBRT and brachytherapy in **EQD2 (equivalent dose in 2 Gy fractions)**, using an α/β of 10 Gy for tumor and 3 Gy for late-responding tissues [22,23]. This harmonization allows comparison across different fractionation schedules.

Adherence to published constraints has been shown to significantly reduce the risk of severe late toxicity, including rectal bleeding, bladder fistulae, urethral strictures, and skin necrosis [24,25]. These thresholds should therefore be considered non-negotiable during planning, and treatment plans should be iteratively optimized to keep all OARs below accepted limits whenever possible.

Key dose constraints across the most common brachytherapy indications are summarized in **Table 4**.

Table 4. Organ-at-risk (OAR) dose constraints in brachytherapy (EQD2, α/β = 3 for OARs, 10 for tumor)

Site / Organ	Typical Constraint	Notes
Cervix (GEC-ESTRO, ABS guidelines)		
Bladder	D2cc ≤ 90 Gy EQD2 [21–23]	Higher doses increase late cystitis, fistula risk
Rectum	D2cc ≤ 75 Gy EQD2 [21–24]	Above threshold, risk of rectal bleeding/ulceration
Sigmoid	D2cc ≤ 75 Gy EQD2 [21–24]	Cumulative from EBRT + BT
Small bowel	D2cc ≤ 70 Gy EQD2 [23,24]	Usually less relevant unless high pelvic coverage
Prostate		
Urethra	D10 < 118% (LDR seeds) [10]; Dmax ≤ 110% of prescription (HDR) [11]	Stricture risk rises above
Rectum	V100 ≤ 1 cc (LDR) [10]; D2cc < 75 Gy EQD2 (HDR) [11]	Minimizes proctitis, bleeding
Breast (APBI interstitial)		
Skin	Dmax < 100% prescription [13,14]	Avoid telangiectasia, necrosis
Rib	Dmax < 100% prescription [13,14]	Pain, fracture risk if higher
Heart (left-sided)	Dmax < 40% prescription [13,14]	Applies for medial tumors

Clinical Pearls – OAR Dose Constraints

- **Always check cumulative EQD2**: Add EBRT + BT doses before judging constraints.

- **D2cc matters, not rectal point alone**: The old ICRU rectal point underestimates dose to rectum and sigmoid.
- **Bladder dose is tricky**: Bladder filling changes D2cc significantly — aim for consistency across fractions.
- **Urethra = critical in prostate HDR**: Review sagittal slices; hotspots >110% increase risk of stricture.
- **Skin dose in breast APBI**: Keep catheters ≥5 mm from skin to prevent necrosis/telangiectasia.
- **Sigmoid and small bowel**: Their mobility can make DVH less reliable — always review CT/MRI anatomy alongside numbers.
- **"Constraint exceeded" ≠ automatic failure**: If tumor control is compromised, a carefully discussed deviation may be justified, but document and justify in the chart.

Clinical Pearls – Clinical Applications of Brachytherapy

- **Cervix cancer**: MRI-based image-guided adaptive brachytherapy (IGABT) is the gold standard; Point A is history, but still tested on exams. Aim HR-CTV D90 ≥85 Gy EQD2 [21,22].
- **Endometrium**: Vaginal cuff brachytherapy is simple, effective, and non-invasive. Always treat to **5 mm depth** or surface depending on risk; avoid mucosal overdosing (PORTEC-2 showed equivalent LC to EBRT with less toxicity).
- **Prostate**:
    - **LDR**: Permanent seeds (I-125 or Pd-103) are ideal for low-risk disease; V100 >90% is critical for control.
    - **HDR**: More flexible dwell optimization, excellent for high-risk or boost strategies; always check urethra and rectum constraints.
    - ***Pearl*:** Geometry of the implant dictates the plan — a poor implant cannot be rescued by physics wizardry.
- **Breast**: APBI with interstitial catheters achieves equivalent local control in selected patients. Respect skin and rib doses — cosmetic outcomes matter as much as control.
- **Head & Neck**: Interstitial BT preserves function in lip and tongue cancers with >85% LC in early lesions. Don't forget catheter geometry — parallelism matters.
- **Esophagus & bronchus**: HDR brachy provides fast palliation of obstruction or bleeding. Combine with EBRT for durable relief. Always beware of **fistula risk** in previously irradiated patients.
- **Sarcoma**: Intraoperative/interstitial BT gives conformal boost in extremity sarcomas, improving limb preservation. Close collaboration with surgeons is essential.
- **Ocular melanoma**: Episcleral plaque (I-125, Ru-106) is standard eye-preserving therapy; plaque positioning and dosimetry precision are critical.

- **General principle**: Hot spots are a feature, not a bug — brachytherapy thrives on dose inhomogeneity inside the target, but toxicity comes from exceeding OAR thresholds.

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Chapter 3. Practical Aspects of Brachytherapy

3.1 Patient Selection and Work-Up

Proper patient selection is critical for brachytherapy. The decision to offer brachytherapy depends on tumor type, stage, patient anatomy, performance status, and institutional expertise [1][Table 1]. For instance, in prostate cancer, patients with localized disease and life expectancy >10 years are candidates for LDR permanent seed implants or HDR boost combined with EBRT [2]. In cervical cancer, brachytherapy remains an essential component of curative treatment for locally advanced disease, with strong evidence that omission of brachytherapy worsens outcomes [3].

Table 1. Patient Selection Criteria for Brachytherapy (Examples by Disease Site)

Disease Site	Indications (typical candidates)	Contraindications / Limitations
Cervix	Locally advanced disease (FIGO IB2–IVA), residual tumor after EBRT, intact uterus [2,3,4,7]	Medical inoperability for anesthesia, severe uterine/cervical stenosis, inability to tolerate applicator [3,6]
Prostate	Localized low/intermediate risk (LDR seeds), intermediate/high-risk with EBRT boost (HDR) [1,5,8,16]	Large prostate volume (>60 cc for LDR), prior TURP, severe obstructive urinary symptoms [1,5,16]
Breast	Early-stage breast cancer, boost after breast-conserving surgery, accelerated partial breast irradiation (APBI) [17]	Multifocal disease, diffuse microcalcifications, prior breast irradiation [17]
Sarcoma	Soft-tissue sarcoma with close/positive margins after surgery [12]	Extensive disease, inability to implant due to anatomical constraints [12]

Work-up includes a detailed clinical examination, imaging (MRI or ultrasound for gynecologic tumors; multiparametric MRI and TRUS for prostate), and staging according to TNM or FIGO classification. Baseline organ function (renal, hepatic, hematologic) and patient comorbidities must be evaluated, as anesthesia or sedation is often required [4].

3.2 Applicator Insertion and Immobilization

3.2.1. Principles of Applicator Insertion

Applicator insertion is the cornerstone of brachytherapy.

- **Intracavitary procedures** (e.g., tandem and ovoids, tandem and ring for cervical cancer) require correct positioning under anesthesia, often with transabdominal or transrectal ultrasound guidance [5].
- **Interstitial procedures** (e.g., prostate, breast, sarcoma) rely on template-based needle placement. For prostate, a transperineal approach under TRUS guidance [Figure 1] allows precise needle insertion through a stepper unit with perineal template [6].

Immobilization techniques vary. Vaginal packing is used in cervical applications to stabilize applicators and displace bladder/rectum. For cervix [Figure 2] and prostate, a combination of perineal template fixation and urinary catheterization ensures reproducibility [7].

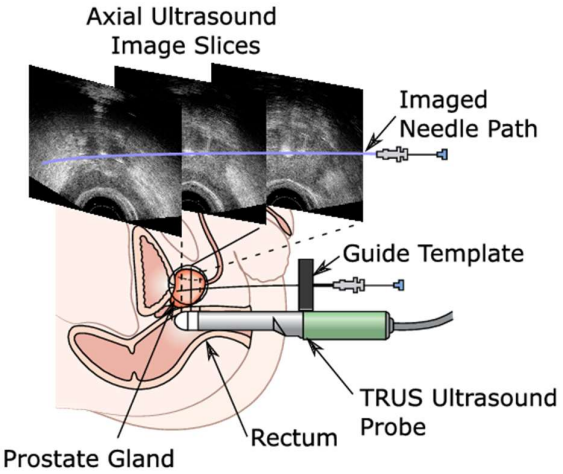

Figure 1. Standard TRUS-guided prostate brachytherapy setup: ultrasound probe, template grid, and needle insertion paths. *Reproduced from Carriere J, Rossa C, Sloboda R, et al. "Standard brachytherapy setup with TRUS probe and template." In Carriere J, Rossa C, Sloboda R, Tavakoli M. Real-time Needle Shape Prediction in Soft-Tissue… (conference paper). Figure courtesy of Cancer Research UK / Wikimedia Commons.*

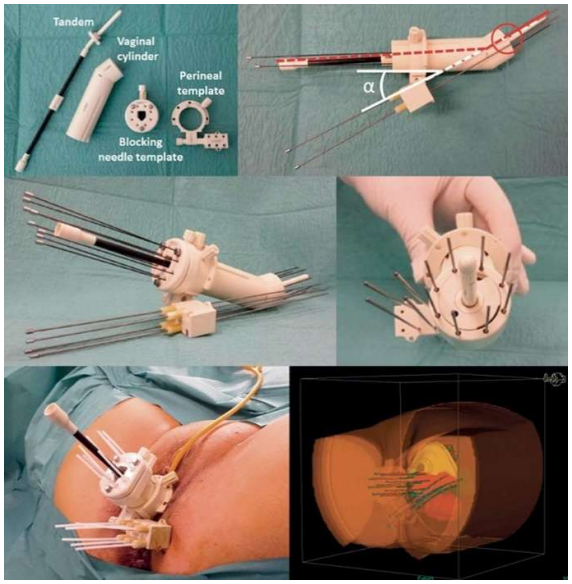

Figure 2. Overview of a combined intracavitary/interstitial applicator for cervical cancer brachytherapy: (A) components before assembly; (B) assembled applicator showing oblique perineal template orientation; (C) assembled unit; (D) frontal view; (E) postoperative 3D reconstruction with applicator and needles. *Reproduced from Bailleux C, Falk AT, Chand-Fouche ME, et al. "Concomitant cervical and transperineal parametrial high-dose-rate brachytherapy boost for locally advanced cervical cancer." Brachytherapy. 2016 Feb;15(1):41-49. Licensed under Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0).*

3.2.2 Anatomy and Hands-On Skills in Applicator Insertion

The safe and effective placement of applicators requires familiarity with regional anatomy and the ability to translate imaging findings into real-world procedures.

Gynecologic brachytherapy demands knowledge of uterine orientation, cervical dilation, vaginal fornices, and proximity of bladder and rectum. Examination under anesthesia allows assessment of cavity depth and axis, guiding safe tandem placement [2–4]. Packing displaces organs at risk while securing the applicators [6].

Prostate brachytherapy hinges on mastery of TRUS interpretation, accurate needle placement via the perineal template, and recognition of anatomical barriers such as the pubic arch [1,5,8,9]. Urethral and rectal landmarks must be respected to balance target coverage and toxicity constraints [13].

Breast and head & neck applications require geometric catheter placement: parallelism, equal spacing, and symmetry according to Paris system rules [17,26]. Precision ensures homogeneous dose distribution and preserves cosmetic and functional outcomes.

Practical pearls for residents:

- Always correlate tactile examination with imaging; this develops three-dimensional anatomical intuition [3].
- Ultrasound guidance significantly reduces uterine perforations and should be routine where available [20].
- The quality of packing directly affects OAR doses — treat it as a key procedural step, not a minor detail [6].
- For prostate, learn to interpret both sagittal and axial TRUS planes simultaneously; this prevents base/apex under-dosage [1].

3.2.3 Complication Management in Brachytherapy

Even with careful technique, complications can occur. Prompt recognition and appropriate management are crucial.

- **Uterine perforation:** most frequent in tandem placement; suspected with loss of resistance or excessive depth. Confirm with ultrasound or fluoroscopy. Never use a perforated tandem for treatment [4,20].
- **Bleeding:** minor bleeding is common; major bleeding requires packing, hemostasis, and possible surgical input [3].
- **Applicator displacement:** can occur post-imaging; repeat imaging if in doubt, as millimeter shifts compromise coverage [6].
- **Seed migration (LDR prostate):** typically asymptomatic but reduces target coverage; detect with Day 0/30 CT and chest X-ray [13,24].
- **Catheter misidentification (HDR):** catastrophic if unrecognized; independent double-checks against insertion diagrams and afterloader plan are mandatory [14].
- **Infection:** especially in prostate or breast implants; prevented by sterile technique and peri-procedural antibiotics [25].
- **Long-term sequelae from misplacement:** include fistulae, rectal ulceration, urethral strictures; adherence to OAR constraints is preventive [7,16].

A tabular summary of complications in brachytherapy is presented in Table 2 below.

Table 2. Common Complications in Brachytherapy: Causes, Impact, and Management

Complication	Typical Cause	Clinical Impact	Management / Prevention
Uterine perforation	Forceful tandem insertion; extreme uterine flexion; cervical stenosis	Risk of incorrect dose delivery, bleeding, infection	Use ultrasound guidance; confirm with imaging; abort or reposition; never treat through perforated tandem [4,20]
Bleeding	Trauma to cervix, vagina, or perineum during insertion	Minor bleeding common; major bleeding may compromise stability	Apply packing, hemostasis; surgical consult if uncontrolled [3]
Applicator displacement	Inadequate packing, patient movement, removal of tamponade	Undercoverage of target, OAR overdose	Secure applicators; verify stability; repeat imaging if displacement suspected [6]
Seed migration (LDR prostate)	Seed embolization via venous plexus	Reduced prostate coverage; rare pulmonary migration	Detect with CT Day 0/30 and chest X-ray; use stranded seeds [13,24]
Catheter misidentification (HDR)	Incorrect numbering or swapping of channels	Dose delivered to wrong location	Cross-check with insertion diagram and afterloader plan; independent verification mandatory [14]
Infection	Breach of sterile field; prolonged catheter dwell	Pain, fever, abscess, wound complications	Aseptic technique; peri-procedural antibiotics; early recognition and treatment [25]
Long-term sequelae from misplacement	Inadequate insertion, dose inhomogeneity	Rectal ulceration, fistula, urethral stricture, fibrosis	Respect OAR constraints; repeat imaging for verification; meticulous insertion technique [7,16]

3.3 Imaging for Treatment Planning

Modern brachytherapy requires 3D image-based planning. CT imaging has been widely adopted; however, MRI is considered the gold standard for cervical cancer due to superior soft-tissue resolution [8]. MRI allows accurate delineation of the high-risk clinical target volume (HR-CTV) and organs-at-risk (OARs). A visual comparison of applicator appearance in phantom MRI vs patient MRI, highlighting reconstruction accuracy and challenges is shown in Figure 3.

Ultrasound remains essential in prostate brachytherapy. TRUS provides real-time guidance during seed placement or HDR catheter implantation. Intraoperative planning systems integrate TRUS images with seed dosimetry to achieve conformal dose distribution [9].

Hybrid imaging approaches (CT/MRI fusion, PET-MRI) are under investigation and may enhance biological target definition [10]. Table 3 presents the applications, the advantages and the limitations of the currently available imaging devices for brachytherapy planning.

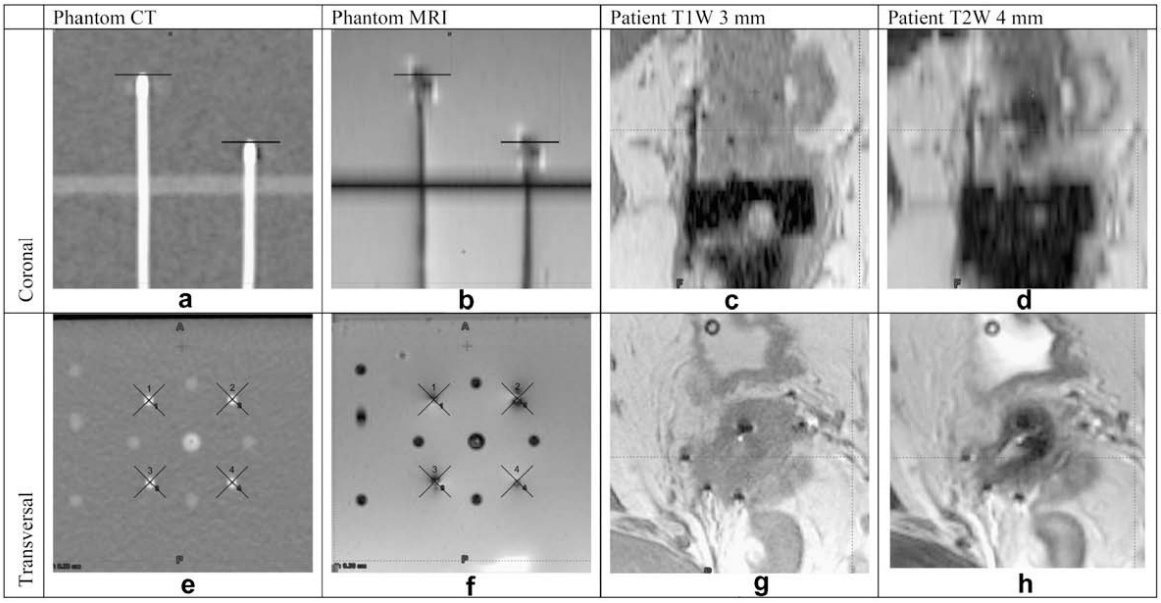

***Figure 3**. MRI-based applicator reconstruction using phantom and patient imaging (comparison panels).* Reproduced from Hellebust TP, Kirisits C, Berger D, et al. *Considerations and pitfalls in commissioning and applicator reconstruction in 3D image-based treatment planning of cervix cancer brachytherapy.* Radiother Oncol. 2010;96(2):153–160. © 2010 Elsevier Ireland Ltd. All rights reserved.

Table 3. Imaging Modalities in Brachytherapy Planning

Imaging Modality	Applications	Advantages	Limitations
Ultrasound (TRUS, intraoperative)	Prostate (LDR/HDR), gynecologic applicator placement [1,5,8]	Real-time, inexpensive, non-ionizing	Limited soft-tissue contrast, operator dependent [8]
CT	Prostate, cervix, breast, sarcoma [10,12]	Wide availability, reproducible, easy applicator reconstruction	Poor soft tissue definition for tumor boundaries [10]
MRI	Cervix (gold standard), prostate, rectum [2,4,7,10]	Best soft tissue delineation, excellent for HR-CTV definition [7]	Cost, access, applicator artifacts [10]
PET/CT, PET/MRI (research)	Biological target volume definition [9]	Functional/biological information	Limited evidence, not standard [9]

3.4 Treatment Planning Systems and Dose Calculation

Treatment planning has shifted from 2D point-based systems (Manchester system, Paris system) to 3D conformal planning with advanced software. Modern treatment planning systems (TPS) allow reconstruction of applicator geometry, dose optimization algorithms, and dose-volume histogram (DVH) analysis [11][Figure 4].

Dose calculation algorithms assume a line or point source model, with dose fall-off following the inverse-square law. Source anisotropy and tissue heterogeneities are accounted for through

updated algorithms, though brachytherapy dose distributions remain inherently inhomogeneous, often with hot spots inside the target [12].

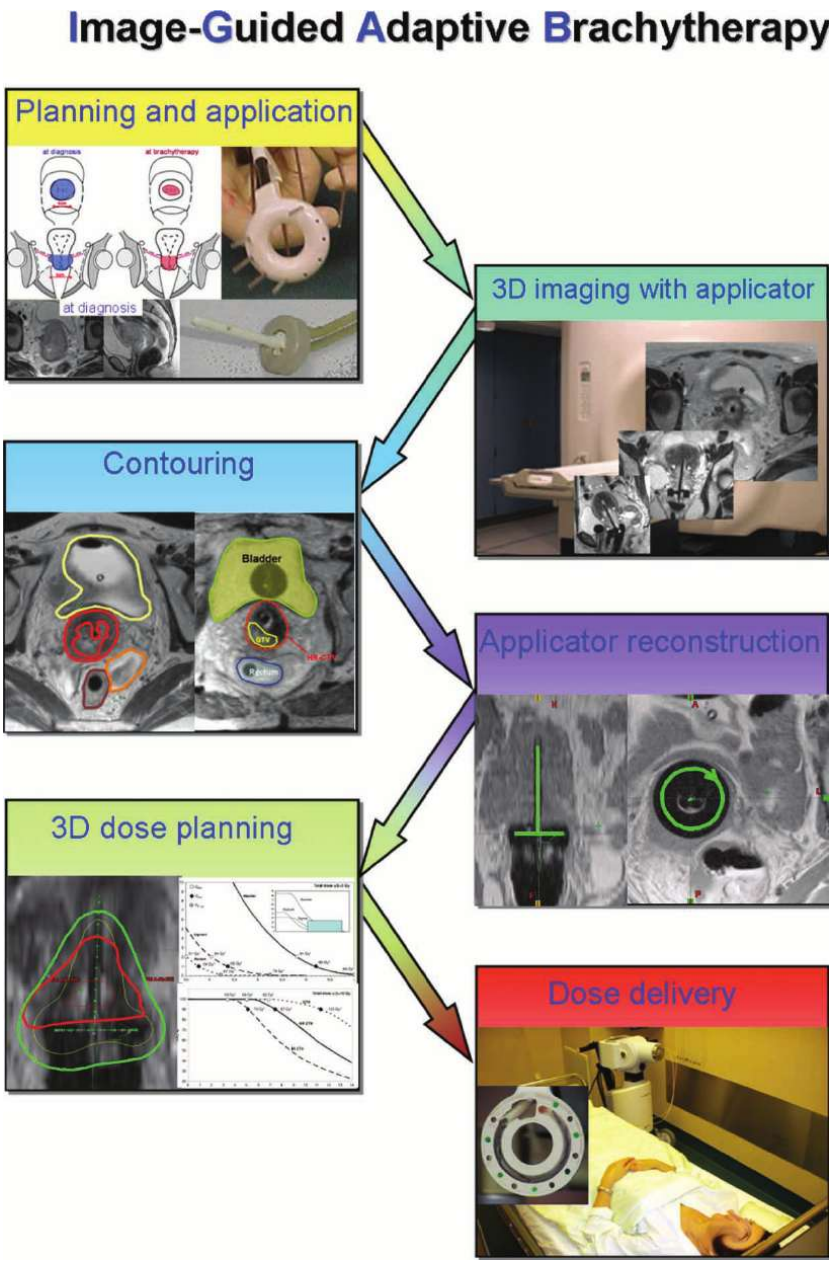

***Figure 4**. Treatment chain for 3D image-guided adaptive cervix cancer brachytherapy using MRI.* Reproduced from Pötter R, Kirisits C, Fidarova E, Lindegaard JC. *Image-guided adaptive brachytherapy for cervix cancer: present status and future.* Radiother Oncol. 2009 [Figure 2]. Available under fair-use for educational purposes.

3.5 Treatment Delivery and Radiation Protection

After applicator insertion and imaging, the patient is transferred to a shielded brachytherapy suite.

- **HDR brachytherapy** uses a remote afterloader with a single ^{192}Ir source stepping through catheters according to dwell times. This reduces radiation exposure to staff [13]. The workflow of an HDR Brachytherapy Procedure is presented in Table 4.
- **LDR brachytherapy** involves permanent implantation of seeds (^{125}I, ^{103}Pd, ^{131}Cs). Radiation protection includes patient education, activity restrictions, and exposure monitoring for close contacts [14].

Table 4. The workflow of an HDR Brachytherapy Procedure

Step	Key actions (with references)	Professionals involved
1. Patient preparation & consent	Confirm indication, review imaging/staging, discuss risks/benefits, obtain consent; bladder/rectal prep protocols; peri-procedural meds (analgesia/α-blocker when appropriate) [3,23].	RO, Anesthesia, Nurse
2. Applicator/catheter insertion	**Intracavitary (cervix):** correct tandem–ovoid/ring positioning under anesthesia and US guidance when helpful [4]. **Interstitial (prostate):** transperineal, template-guided insertion under TRUS with stepper [1,5,8].	RO, RTT, Anesthesia
3. Imaging acquisition (with applicators in situ)	CT for reconstruction and planning [10,12]; MRI preferred in cervix for HR-CTV/OAR definition [2,7]; TRUS intra-op for prostate HDR geometry verification [1].	RO, MP, Radiology/RTT
4. Applicator reconstruction	Reconstruct source path(s) using applicator libraries/direct visualization; verify tips and channel IDs; be alert to MRI/CT artifacts and geometric pitfalls [10].	MP, RO
5. Contouring	Delineate HR-CTV/IR-CTV and OARs per GEC-ESTRO concepts; leverage MRI when available; set EQD2 objectives/constraints consistent with IGABT practice [4,7,9].	RO
6. Plan optimization	Inverse planning (e.g., IPSA/HIPO) and dwell-time modulation to meet target coverage while sparing OARs [11,12].	MP, RO
7. Plan evaluation	DVH review: HR-CTV D90 goal, OAR limits (e.g., bladder/rectum/sigmoid D2cc) per protocol/EMBRACE-style constraints [7,9].	RO, MP
8. Independent QA & readiness checks	Second check of catheter numbering, dwell positions/times; daily/periodic afterloader QA; dummy-source test and emergency retrieval readiness [14,1].	MP, RO, RTT
9. Treatment delivery	Remote afterloader HDR (Ir-192) delivery with continuous monitoring; verify patient/applicator stability immediately prior to start [14].	RTT, MP, RO (on call)
10. Inter-fraction adaptation (if multi-fraction)	Re-image and re-plan based on tumor regression/anatomical change; accumulate EQD2 across EBRT+BT fractions as needed [20,21,2].	RO, MP
11. Post-treatment care & documentation	Applicator removal, immediate post-procedure assessment, discharge instructions, symptom/toxicity counseling; complete plan/dose documentation [23].	RO, Nurse

Abbreviations: RO = Radiation Oncologist; MP = Medical Physicist; RTT = Radiation Therapist/Technologist; HR-CTV/IR-CTV = high-/intermediate-risk clinical target volume; OAR = organ at risk; DVH = dose–volume histogram; IGABT = image-guided adaptive brachytherapy.

Stringent quality assurance (QA) is mandatory. Daily QA checks for source strength, afterloader functionality, and emergency procedures are part of practice. Radiation oncologists, medical physicists, and specialized radiation therapy technologists collaborate in all steps [15]. A list of common errors and their mitigation strategies is presented in Table 5.

Table 5. Common Applicator Reconstruction Errors and Mitigation Strategies

Error Type	Example	Impact on Dosimetry	Mitigation (with references)
Incorrect source path reconstruction	Misidentified catheter tip	Under/over-dosage to CTV	Use dummy sources, perform orthogonal or 3D verification [10,14].
Applicator displacement post-imaging	Tandem shift after packing removal	Target undercoverage, OAR overdose	Secure applicators with packing/sutures, repeat imaging if instability suspected [6,20].
MRI-related artifact	Applicator obscured in T2 MRI	Contouring uncertainty	Use MRI-compatible applicators, fuse MRI with CT for reconstruction accuracy [7,10].
Mislabeling catheters	HDR channels swapped	Dose delivered to wrong location	Cross-check catheter numbering against insertion diagram; independent verification before treatment [1,14].

A schematic workflow from treatment prescription to auto-generated plan and DICOM RT output is presented in Figure 5.

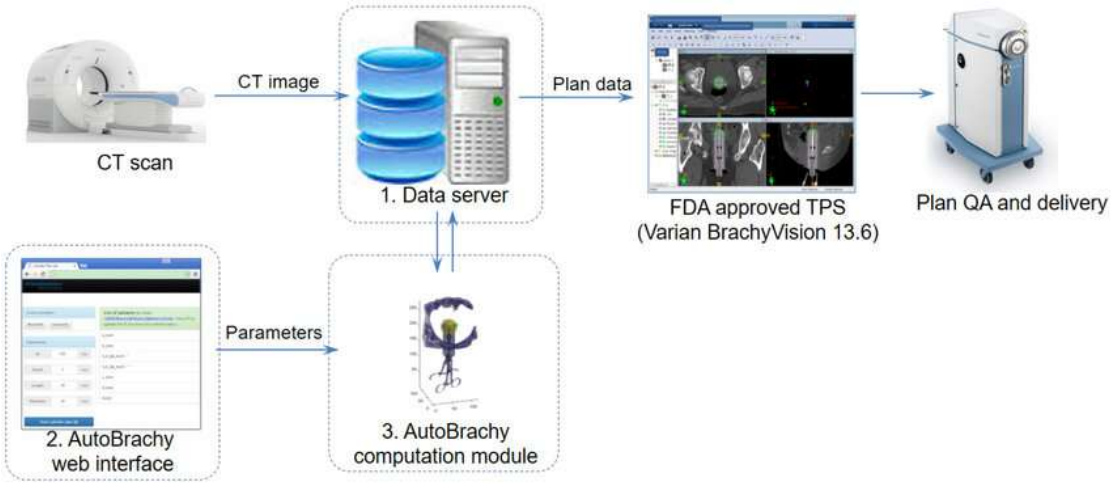

Figure 5. HDR brachytherapy automated planning workflow: from prescription through plan generation to DICOM-RT output. Reproduced from Zhou Y, et al. "Workflow of the HDR brachytherapy auto-planning module" in **Physica Medica** (part of Phys Med Biol). Used under educational fair-use guidelines.

3.6 Acute and Late Toxicities

Side effects vary by disease site:

- **Gynecologic brachytherapy**: vaginal mucositis, cystitis, proctitis acutely; vaginal stenosis, rectal bleeding, or fistulae as late effects [16].
- **Prostate brachytherapy:** urinary retention, frequency, dysuria, and rectal irritation are common acutely; long-term toxicities include erectile dysfunction and persistent lower urinary tract symptoms [17].
- **Breast brachytherapy:** localized skin erythema, induration, fat necrosis, and cosmetic changes may occur [18].
- See Table 6 for more detailed acute/late effects by disease site.

Dose-volume correlations are crucial. For cervical cancer, bladder D2cc <90 Gy EQD2 and rectum/sigmoid D2cc <75 Gy EQD2 are recommended [19].

Table 6. Acute and Late Toxicities by Treatment Site

Site	Acute Effects	Late Effects	References
Cervix	Vaginal mucositis, cystitis, proctitis	Vaginal stenosis, rectal bleeding, fistulae	[15,18,20,21]
Prostate	Urinary retention, dysuria, rectal irritation	Erectile dysfunction, chronic LUTS, rectal bleeding	[5,16,19]
Breast	Erythema, edema, pain	Fat necrosis, fibrosis, cosmetic deformity	[17]
Sarcoma	Local pain, wound healing delay	Fibrosis, limb dysfunction, secondary malignancies (rare)	[12]

3.7 Special Considerations

- **Anesthesia**: Spinal or general anesthesia is often needed for gynecologic applications; local anesthesia with sedation is typical in prostate implants [20].
- **Applicator reconstruction errors** can compromise target coverage. Verification imaging after insertion is strongly recommended [21].
- **Adaptive brachytherapy**: repeated imaging and replanning across multiple fractions allow dose escalation to residual tumor while sparing OARs [22].
- **Patient communication**: discussing the invasiveness, expected toxicities, and procedural steps improves compliance and reduces anxiety [23].

Clinical Pearls in Brachytherapy Practice

Patient Preparation

- A well-prepared bladder and empty rectum make planning and OAR (organs at risk) sparing much easier. Always check compliance before applicator insertion.
- Pain and anxiety control are not luxuries—they directly affect applicator stability and patient tolerance.

Applicator Insertion

- In cervical cancer, always verify tandem placement relative to the uterine axis with imaging. A malpositioned tandem is the single most common reason for inadequate coverage.
- In prostate HDR, pubic arch interference can limit needle placement—always check with pre-planning imaging or TRUS sweep.
- Securing applicators with vaginal packing or sutures reduces both intra-fraction and inter-fraction motion.

Imaging and Contouring

- MRI is the gold standard for cervix contouring: never trust CT alone if MRI is available.
- When MRI is not accessible, use CT but err on the side of over-contouring the HR-CTV to compensate for poor tumor–normal tissue contrast.
- TRUS images in prostate implants should be acquired both in sagittal and axial views—this helps avoid "geographic miss" at the base and apex.

Treatment Planning

- Always optimize to **DVH parameters**, not just point doses:
    - HR-CTV D90 ≥ prescribed dose
    - Rectum and sigmoid D2cc ≤ 75 Gy EQD2
    - Bladder D2cc ≤ 90 Gy EQD2
- Pay special attention to hotspots in OARs—dosimetry looks beautiful until you realize 2–3 dwell positions are delivering 140% to the rectum.

Quality Assurance

- Dummy source checks *must* be performed for every new applicator insertion before delivery—no exceptions.
- Independent second checks of dwell times and catheter numbers prevent catastrophic misadministration.
- Always re-image after patient transport—catheters shift more than you think.

Treatment Delivery

- Confirm applicator stability before pressing "Start." A few millimeters of tandem displacement can translate into several Gy under- or overdose.
- Radiation therapists should be trained to recognize alarms and emergency protocols (afterloader stuck, source retrieval failure).

Toxicity Mitigation

- Vaginal dilator programs reduce the risk of post-treatment stenosis after cervical brachytherapy—patient education is key.
- Alpha-blockers and anti-inflammatories can substantially improve LUTS (lower urinary tract symptoms) after prostate HDR.
- Fibrosis and poor cosmesis in breast APBI are minimized by strict adherence to dose constraints and careful catheter placement geometry.

Workflow Efficiency

- In high-volume centers, parallel processing (contouring while physics reconstructs catheters) can cut down procedure time and reduce anesthesia duration.
- A consistent, stepwise checklist culture reduces both dosimetric variability and medico-legal risks.

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Chapter 4. Future Directions and Research Trends in Brachytherapy

4.1 Introduction

Brachytherapy, one of the oldest modalities in radiation oncology, is simultaneously a field rooted in tradition and one of rapid innovation. While its clinical role remains established in cervical, prostate, breast, and skin cancers, ongoing research is reshaping its scope. Technological advances, novel isotopes, and integration with systemic and molecular therapies promise to keep brachytherapy central in cancer treatment for decades to come [1].

4.2 Novel Radioisotopes and Targeted Delivery

Traditional isotopes such as ^{192}Ir, ^{125}I, and ^{103}Pd continue to dominate clinical practice. However, recent efforts focus on alpha-emitting radionuclides [Figure 1] due to their high linear energy transfer (LET) and short path length, which make them well-suited for highly localized tumor control with potentially reduced toxicity [2][Table 1].

- **Radium-224 (^{224}Ir):** Demonstrates promise in intracavitary applications for ovarian and peritoneal malignancies due to its short-range alpha emissions and manageable half-life (~3.6 days). Clinical trials are underway investigating safety and efficacy [3].
- **Bismuth-213 (^{213}Bi) and Actinium-225 (^{225}Ac):** Alpha emitters explored in experimental targeted brachytherapy and radioimmunoconjugates [4].
- **Holmium-166 (^{166}Ho):** Being tested in intra-tumoral brachytherapy and liver-directed therapies, with the added benefit of paramagnetic properties enabling MRI-based dosimetry [5].

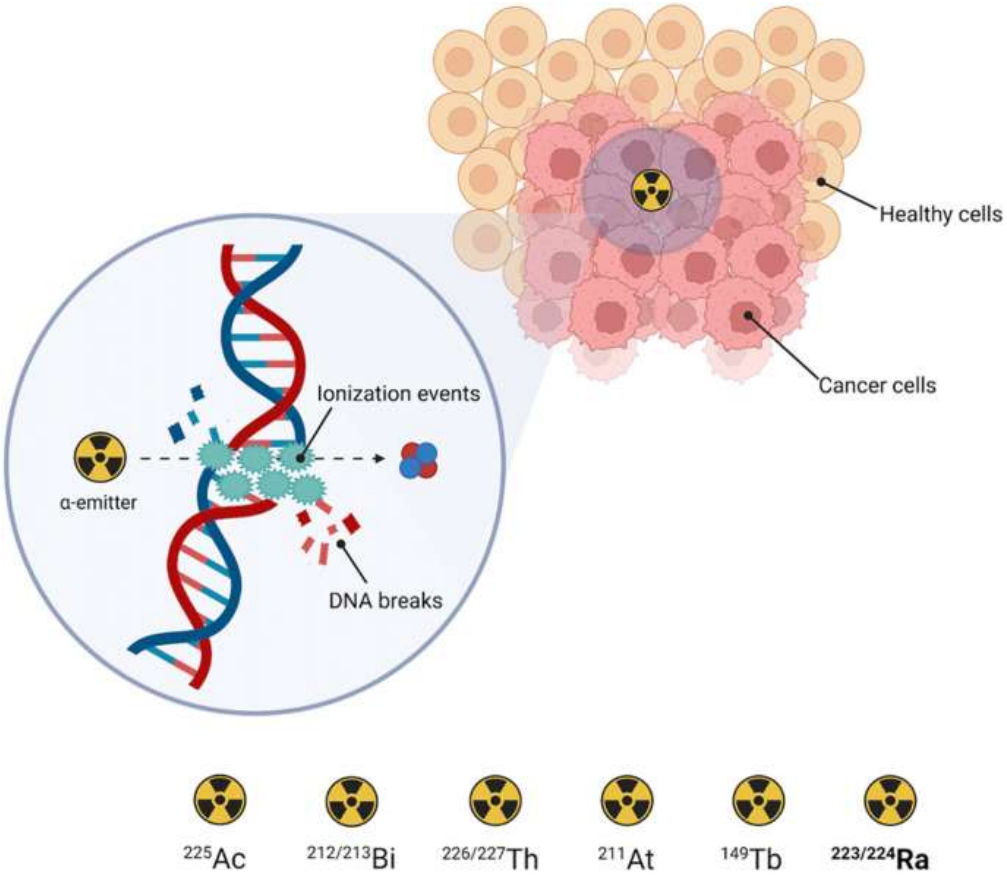

Figure 1 – Alpha Radiation Effects at Cellular Level

Schematic representation of α-particle emitter radiopharmaceutical effects at the cellular and subcellular level.
Reproduced from Eychenne et al., *"Schematic representation of the effect of α-radiation at cellular and sub-cellular level and list of medically relevant α-emitters,"* in *EJNMMI Radiopharm Chem* 2021;6:–. Figure used under educational fair-use guidelines.

These isotopes reflect a shift toward *theranostic* brachytherapy, where the same radionuclide can provide both imaging and therapy [Figure 2].

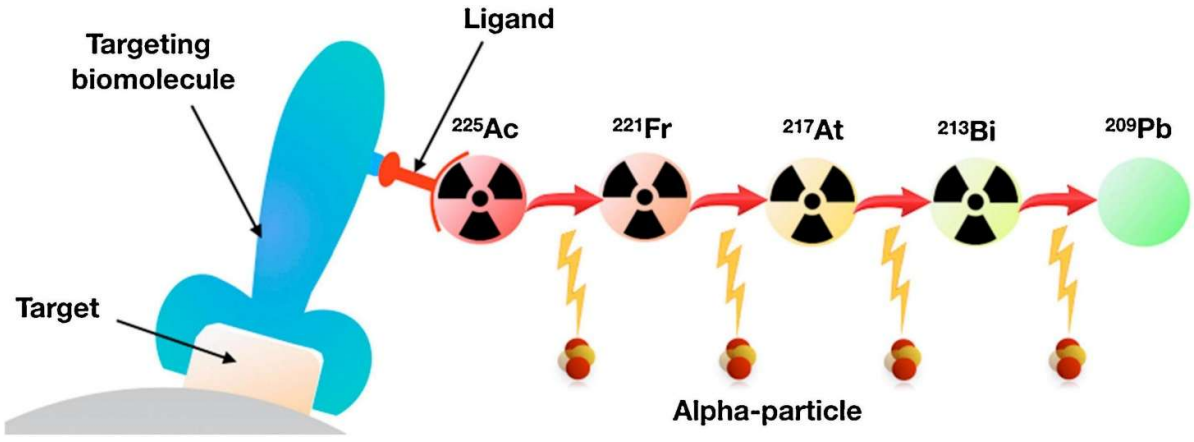

Figure 2 – Nanoparticle-based Theranostic Platform

Graphic illustrating theranostic nanoparticle design for targeted radionuclide delivery and simultaneous imaging and therapy.

Reproduced from Chen et al., *"Organic and inorganic nanoplatforms for theranostic nanoparticle synthesis," J Nucl Med* 2014;55:1919. Used with permission.

Table 1. Novel Isotopes in Experimental and Clinical Brachytherapy

Isotope	Type of Emission	Half-life	Current/Proposed Applications	Key Advantages	References
Ra-224	α	3.6 days	Intracavitary/peritoneal therapy (ovarian, GI malignancies)	High LET, short path length; promising in peritoneal carcinomatosis	[3]
Bi-213	α	46 min	Radioimmunotherapy, targeted brachytherapy	Ultra-short range; effective against micrometastases	[4]
Ac-225	α	10 days	Prostate, hematologic, targeted vectors	Multiple α emissions per decay; strong theranostic potential	[4]
Ho-166	β + γ	26.8 h	Intratumoral injections, liver-directed therapy	MRI visibility; direct dosimetry possible	[5]

4.3 Advances in Imaging and Treatment Planning

Three major research directions are shaping imaging in brachytherapy [Table 2]:

1. **PET-MRI fusion:** Integrates biological information from PET (e.g., hypoxia, proliferation markers) with the superior anatomical detail of MRI, improving target definition [6].
2. **Functional imaging biomarkers:** Diffusion-weighted MRI, dynamic contrast-enhanced MRI, and PET tracers (FMISO, FET, PSMA) are being studied to adapt dose painting to subvolumes with biological aggressiveness [7].
3. **Artificial intelligence (AI):** Deep learning algorithms show great promise in automating contouring and applicator reconstruction, reducing inter-observer variability and saving time in busy clinics [8].

Table 2. Advances in Imaging for Brachytherapy Planning

Modality	Application	Advantages	Limitations	References
MRI	Cervical, prostate	Gold-standard for HR-CTV delineation; superior soft-tissue contrast	Limited availability; costly	[6,7]
PET-MRI fusion	Research use in cervix, prostate	Integrates anatomy + biology (hypoxia, PSMA, FDG)	Limited tracers; experimental	[6]
TRUS	Prostate HDR/LDR	Real-time intraoperative guidance; cost-effective	Limited field of view; steep learning curve	[8]
CT	Most tumor sites	Readily available; robust applicator reconstruction	Poor soft tissue contrast; requires MRI fusion for cervix	

4.4 Biological Dose Painting and Personalization

Current brachytherapy practice prescribes uniform dose distributions to the entire HR-CTV. However, molecular imaging and genomic profiling are paving the way for **biological dose painting**—escalating dose to resistant tumor subregions while sparing surrounding tissue [9].

Furthermore, patient-specific radiogenomic signatures may one day allow personalized prescriptions based on predicted toxicity or tumor radiosensitivity [10].

4.5 Automation, Robotics, and Adaptive Brachytherapy

Automation is emerging as a solution to variability in applicator placement and plan optimization [Table 3], [Figure 3].

- **Robotic-assisted brachytherapy:** Being tested in prostate implants to increase accuracy of needle placement, particularly in patients with difficult anatomy [11].
- **Auto-planning modules:** Already implemented in HDR systems, providing dwell-time optimization within minutes (see Figure 5 in Chapter 3). Early data show reduced planning time without compromising dosimetry [12].
- **Adaptive brachytherapy:** Integration of repeated MRI during treatment allows tailoring each fraction according to tumor regression and organ motion [13].

Table 3. Emerging Technologies in Brachytherapy

Technology	Clinical Use	Potential Benefits	Development Stage
Robotic needle placement	Prostate HDR/LDR	Higher placement accuracy; reproducibility	Preclinical & early clinical [11]
Auto-planning algorithms	Cervical & prostate HDR	Fast, reproducible dwell-time optimization	Clinical adoption in progress [12]
Adaptive brachytherapy	Cervix, head & neck	Tailored dose per fraction; spares OARs	Ongoing EMBRACE-II trial [13]
Electronic brachytherapy (eBx)	Skin, breast	No radionuclides; outpatient-friendly	Approved in select centers [15]

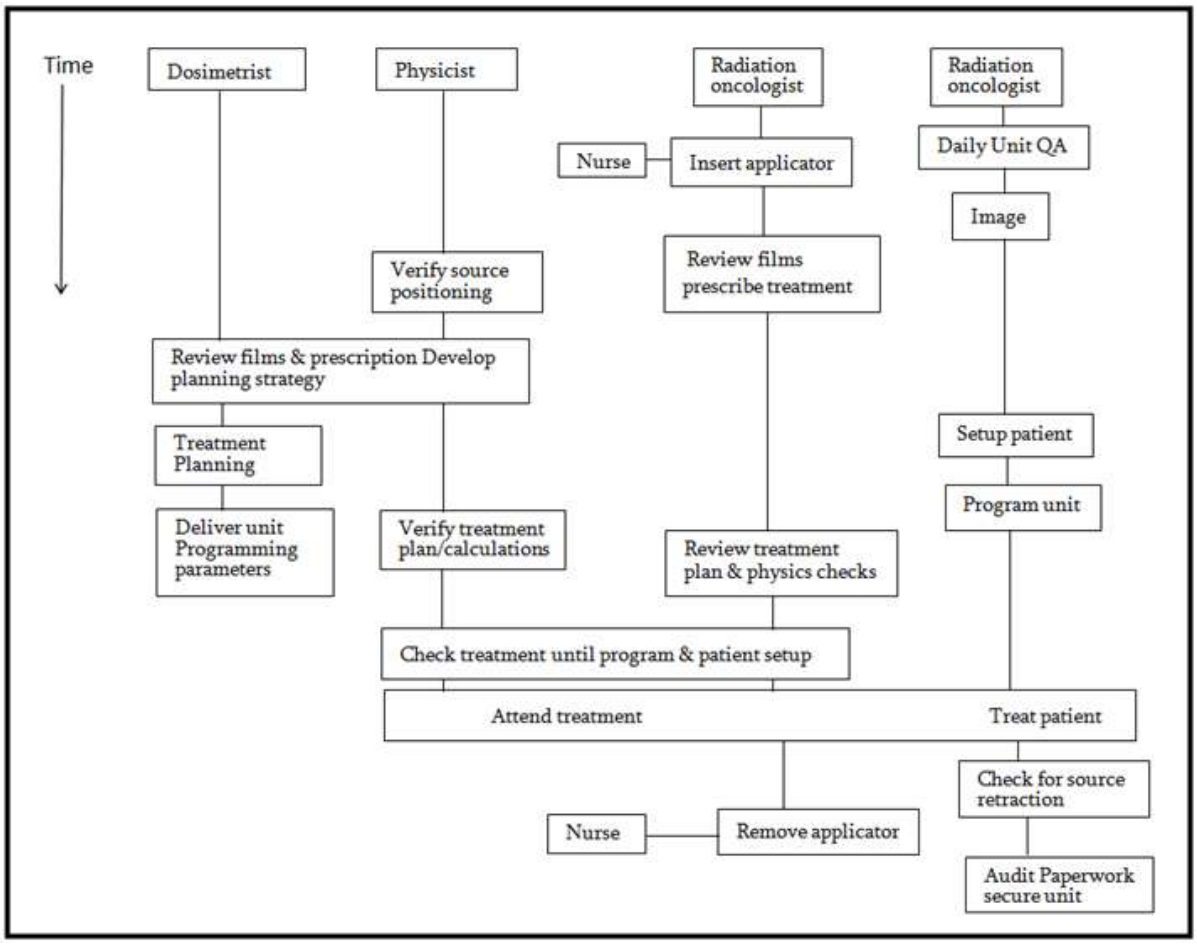

Figure 3. HDR Brachytherapy Automated Planning Workflow
Workflow of the HDR brachytherapy auto-planning module—from prescription through automatic plan generation to DICOM-RT export for clinical use.
Reproduced from Zhou Y, Klages P, Tan J, et al. *Automated high-dose-rate brachytherapy treatment planning for a single-channel vaginal cylinder applicator*. Phys Med Biol. 2017;62(11):4361-4374. Used under educational fair-use guidelines.

4.6 Expanding Indications

Research is broadening the indications of brachytherapy [Table 4]:

- **Breast cancer:** APBI with multicatheter HDR and balloon-based systems continues to be refined, with new trials showing long-term efficacy in selected low-risk patients [14].
- **Skin cancers:** Surface applicators and electronic brachytherapy (eBx) units enable outpatient treatments without radioactive source handling [15].
- **Oligometastatic disease:** Early-phase studies are testing brachytherapy as a local ablation technique in lung, liver, and lymph node metastases [16].

Table 4. Potential Future Indications of Brachytherapy

Tumor Site	Technique	Rationale	Current Status
Oligometastatic lung/liver	HDR interstitial	Ablative dose with precision; alternative to SBRT	Early clinical trials [16]

Tumor Site	Technique	Rationale	Current Status
Immuno-brachytherapy	Cervix, prostate	Synergy with checkpoint inhibitors; immune modulation	Phase I/II trials [18]
Nanoparticle-assisted therapy	Intratumoral	Targeted radionuclide release; theranostics	Preclinical [19]
Next-gen breast APBI	Multicatheter HDR, balloon	Long-term efficacy in low-risk; improved cosmesis	Mature Phase III trials [14]

4.7 Integration with Systemic and Immunotherapies

The immune-modulatory effects of radiation are of rising interest. Brachytherapy's ability to deliver ablative doses in confined volumes makes it an ideal partner for immunotherapy combinations [17][Figure 4].

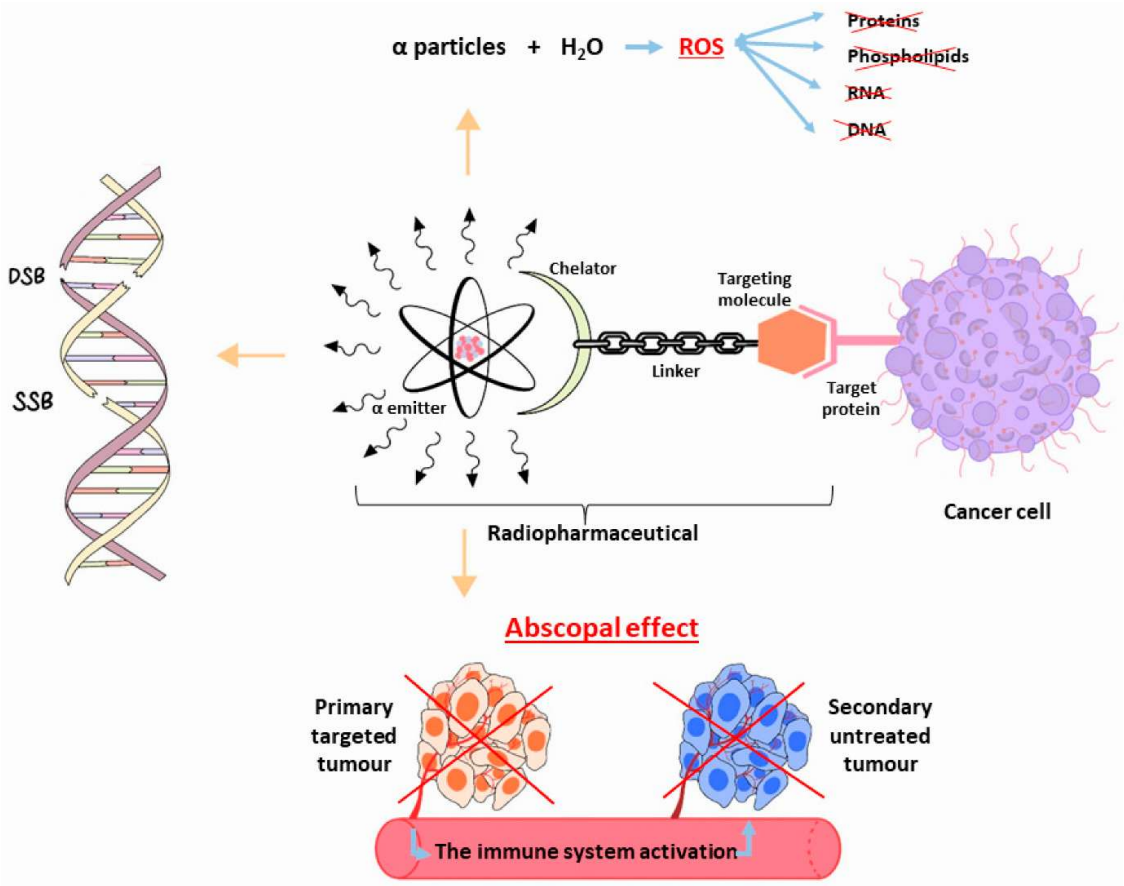

Figure 4 – Targeted Alpha Therapy (TAT) Schematic

Diagram of targeted alpha therapy showing a ligand–α-emitter conjugate binding to tumor, with localized α-particle emission.

Reproduced from Birnbaum et al. (Tanderup K paper), *"Schematic representation of targeted radiotherapy," Radiother Oncol* 2016;120:388–396. Used under educational fair-use.

Ongoing trials are investigating combinations of cervical brachytherapy with checkpoint inhibitors, aiming to enhance systemic anti-tumor responses while preserving local control [18]. Radiogenomic signatures may eventually guide such combined-modality therapy [19].

4.8 Outlook

The future of brachytherapy will likely be characterized by greater personalization, supported by AI-driven planning, functional imaging, and novel isotopes. Its role will continue to expand beyond "classical" indications, while adaptive and robotic technologies will strengthen its precision. Despite challenges in training, logistics, and reimbursement, brachytherapy remains uniquely positioned as a modality where physics, imaging, and biology converge [20].

Clinical Pearls

- **Stay Ahead with Imaging Skills:** Novel PET tracers and advanced MRI sequences will likely enter routine brachytherapy planning. Begin cultivating expertise in multimodal imaging interpretation to stay future-ready.
- **Embrace Adaptive Thinking:** Adaptive brachytherapy, already standard in cervical cancer, is expected to expand. Develop comfort with fraction-to-fraction replanning and cumulative dose tracking — these will be crucial skills.
- **Learn Automation, Not Just Physics:** Artificial intelligence and auto-planning are not meant to replace clinical judgment but to accelerate workflows. Understanding how algorithms optimize dwell positions will help residents critically review AI-generated plans.
- **Prepare for Isotope Innovation:** Isotopes such as **Ra-224** and targeted alpha therapies are under clinical investigation. Awareness of their radiobiology and logistical implications will be essential for early adopters.
- **Think Multimodality:** Future oncologic care is not radiation-alone. Brachytherapy will increasingly be tested in synergy with immunotherapy and radiosensitizers. Residents should be proactive in learning trial designs and systemic–local interactions.
- **Global Disparities Remain:** While high-tech developments attract attention, many centers worldwide still lack MRI or HDR capabilities. Pearls for the future also include advocacy: ensuring equitable dissemination of new techniques.

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Preface to the Appendices

The appendices of this handbook have been designed as **practical companions** to the main chapters.
While the body of the text provides theoretical foundations and clinical guidance, the appendices are intended to serve as **ready-to-use resources at the point of care** and **structured learning tools for trainees**.

Each appendix covers a specific domain:

- **Appendix A** introduces the radiobiological principles essential for dose prescription and interpretation.
- **Appendices B–E** provide technical references: dose–volume histograms, key formulas, clinical protocols, and dosimetric exercises.
- **Appendices F–H** focus on safe practice, patient communication, toxicity grading, and aftercare.
- **Appendices I–J** guide further learning, with curated resources and a glossary of essential terms.
- **Appendix K** offers a case log template to support training documentation.

Together, these appendices form a **comprehensive toolkit** that complements the clinical content of the handbook. They are designed to be updated and expanded as the field evolves, ensuring that the handbook remains a **living resource** for current and future practitioners of brachytherapy.

Appendix A – Radiobiology Quick Reference

1. Basic Formulas

Biologically Effective Dose (BED):

$$BED = nd \times (1 + d / (\alpha/\beta))$$

Where:

- n = number of fractions

- d = dose per fraction (Gy)

- α/β = tissue-specific ratio (Gy)
  - Tumor: typically 10 Gy
  - Late-responding tissues (OARs): typically 3 Gy

Equivalent Dose in 2 Gy Fractions (EQD2):

$$EQD2 = BED / (1 + 2 / (\alpha/\beta))$$

2. Worked Examples

Cervical cancer HDR fractionation

Prescription: 7 Gy × 4 = 28 Gy total (HDR, HR-CTV).
For tumor (α/β = 10):
BED = 4 × 7 × (1 + 7/10) = 74.8 Gy
EQD2 = 74.8 / (1 + 2/10) = 62.3 Gy
(Combined with EBRT 45 Gy → Total EQD2 ≈ 107 Gy to HR-CTV).

Prostate HDR monotherapy

Prescription: 9.5 Gy × 4 = 38 Gy total.
For tumor (α/β = 1.5):
BED = 4 × 9.5 × (1 + 9.5/1.5) = 361 Gy
EQD2 = 361 / (1 + 2/1.5) = 144 Gy

Bladder constraint in cervix HDR

Dose: 6 Gy × 4 = 24 Gy (to 2cc).
For OAR (α/β = 3):
BED = 4 × 6 × (1 + 6/3) = 96 Gy
EQD2 = 96 / (1 + 2/3) = 57.6 Gy
(Added to EBRT 45 Gy → Total EQD2 ≈ 102.6 Gy).

3. Quick Conversion Table (Approximate EQD2)

(for α/β = 10, tumors)

Fraction size (Gy)	**BED per fraction (Gy)**	**EQD2 per fraction (Gy)**
5	7.5	4.2
6	9.6	5.3
7	11.9	6.2
8	14.4	7.2
9	17.1	8.1
10	20.0	9.1

Appendix B: Dosimetric Parameters and DVH Reference

This appendix summarizes key dosimetric parameters commonly reported in brachytherapy, along with reference dose-volume histogram (DVH) constraints used in clinical practice. Values are based on GEC-ESTRO, ABS, and AAPM guidelines, as well as major clinical trials.

Table B.1. Common Dosimetric Parameters in Brachytherapy

Parameter	Definition
D90	Dose received by 90% of the target volume (CTV/HR-CTV).
V100	Percentage of target volume receiving 100% of the prescribed dose.
V150	Percentage of target volume receiving 150% of the prescribed dose (hotspot indicator).
D2cc	Minimum dose to the most irradiated 2 cm^3 of an organ at risk (OAR).
EQD2	Equivalent dose in 2 Gy fractions, based on the linear-quadratic model (α/β = 10 for tumor, 3 for OARs).

Table B.2. Reference DVH Constraints (EQD2)

Organ / Site	Constraint (EQD2)	Notes
Cervix – HR-CTV	D90 ≥ 85 Gy	Improved local control [Pötter et al., 2007; Sturdza et al., 2016].
Bladder	D2cc ≤ 90 Gy	Risk of cystitis, fistula [Georg et al., 2011].
Rectum	D2cc ≤ 75 Gy	Risk of bleeding, ulceration [Tanderup et al., 2016].
Sigmoid	D2cc ≤ 75 Gy	Cumulative with EBRT [Viswanathan et al., 2012].
Prostate – CTV	D90 ≥ 100% prescription	Associated with biochemical control [Stock et al., 2006].
Urethra	D10 < 118% (LDR), Dmax ≤ 110% (HDR)	Avoids stricture [Hoskin et al., 2014].
Breast – PTV	V100 ≥ 90%	APBI studies, good cosmesis [Polgár et al., 2013].
Breast – Skin	Dmax < 100%	Prevents necrosis, telangiectasia [Strnad et al., 2016].

References

1. Pötter R, et al. Radiother Oncol. 2007;83(2):148–155.
2. Sturdza A, et al. Radiother Oncol. 2016;120(3):428–433.
3. Georg P, et al. Int J Radiat Oncol Biol Phys. 2011;79(2):356–362.
4. Tanderup K, et al. Int J Radiat Oncol Biol Phys. 2016;95(2):588–597.
5. Viswanathan AN, et al. Brachytherapy. 2012;11(1):33–46.
6. Stock RG, et al. Int J Radiat Oncol Biol Phys. 2006;64(2):527–533.
7. Hoskin PJ, et al. Radiother Oncol. 2014;113(3):307–312.
8. Polgár C, et al. Radiother Oncol. 2013;108(2):197–202.
9. Strnad V, et al. Lancet. 2016;387(10015):229–238.

Appendix C. Commonly Used Formulas and Calculations in Brachytherapy

This appendix summarizes the most relevant formulas and calculation principles commonly used in brachytherapy physics and treatment planning. These are essential for accurate dose prescription, optimization, and reporting.

1. Source Strength Specification

- Air-Kerma Strength (Sk):
  $Sk = K_{air}(d) \times d^2$
  where $K_{air}(d)$ is the air-kerma rate at distance d in free space.
- Reference Air-Kerma Rate (RAKR):
  $RAKR = K_{air}(d) \times d^2$ (measured at d = 1 m)

These quantities are standardized in ICRU Report 89 and AAPM TG-43 formalism [1,2].

2. TG-43 Dose Calculation Formalism

The dose rate at a point (r, θ) around a source is given by:

$$D(r, \theta) = Sk \times \Lambda \times [G(r, \theta) / G(r0, \theta0)] \times gL(r) \times F(r, \theta)$$

where:
- Sk = air-kerma strength (U)
- Λ = dose-rate constant (cGy h^{-1} U^{-1})
- G(r, θ) = geometry function
- gL(r) = radial dose function
- F(r, θ) = anisotropy function

This formalism forms the basis of all clinical brachytherapy TPS dose calculation [2,3].

3. Biologically Effective Dose (BED) and EQD2

- BED:
  $BED = nd \times [1 + (d / (\alpha/\beta))]$
- EQD2:
  $EQD2 = BED / [1 + (2 / (\alpha/\beta))]$

where n = number of fractions, d = dose per fraction, and α/β is the tissue-specific ratio.
This conversion enables comparison of fractionation schemes and cumulative EBRT + BT doses [4].

4. Dose-Volume Histogram Parameters

- D90: minimum dose received by 90% of the target volume (CTV/HR-CTV).
- V100: percentage of volume receiving 100% of the prescribed dose.
- D2cc: minimum dose to the most exposed 2 cc of an organ at risk (OAR).

These parameters are central to treatment evaluation and protocol compliance [5].

References

1. ICRU Report 89. Prescribing, Recording, and Reporting Brachytherapy for Cancer of the Cervix. J ICRU. 2013;13(1–2).

2. Rivard MJ, Coursey BM, DeWerd LA, et al. Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations. Med Phys. 2004;31(3):633–674.
3. Williamson JF. Brachytherapy technology and physics practice since 1950: a half-century of progress. Phys Med Biol. 2006;51(13):R303–R325.
4. Fowler JF. The linear-quadratic formula and progress in fractionated radiotherapy. Br J Radiol. 1989;62(740):679–694.
5. Pötter R, Haie-Meder C, Van Limbergen E, et al. Recommendations from Gynaecological (GYN) GEC-ESTRO Working Group: concepts and terms in 3D image-based treatment planning. Radiother Oncol. 2005;74(3):235–245.

Appendix D: Sample Clinical Protocol Templates in Brachytherapy

1. Cervical Cancer HDR Brachytherapy (Image-Guided, Adaptive)

Patient Selection:
- Locally advanced cervical cancer (FIGO IB2–IVA)
- Medically fit for anesthesia
- No contraindications to applicator insertion

Work-up:
- MRI pelvis for baseline evaluation
- EUA (examination under anesthesia)
- Cystoscopy/proctoscopy as indicated

Treatment Protocol:
- EBRT 45–50.4 Gy ± concurrent chemotherapy
- HDR brachytherapy: 7 Gy × 4 fractions to HR-CTV D90
- Image-guided with MRI preferred; CT acceptable if MRI not available

Dose Constraints (EQD2, $\alpha/\beta=3$):
- Bladder D2cc ≤ 90 Gy
- Rectum/sigmoid D2cc ≤ 75 Gy
- Small bowel D2cc ≤ 70 Gy

2. Prostate Brachytherapy

LDR (Permanent Seed Implant):
- Isotopes: I-125 (145 Gy), Pd-103 (125 Gy)
- Candidates: low-risk or favorable intermediate-risk prostate cancer
- Post-implant dosimetry within 30 days

HDR (Temporary, Ir-192):
- Monotherapy: 13.5 Gy × 2 fractions or 9.5 Gy × 4 fractions
- Boost: 15 Gy × 1 fraction after EBRT 45 Gy
- Constraints: Urethra D10 < 118%, Rectum V100 < 1 cc

3. Breast Brachytherapy (Accelerated Partial Breast Irradiation, APBI)

Eligibility:
- Early-stage invasive breast cancer (≤3 cm, node-negative)
- Age > 50 years, negative margins

Protocol:
- Interstitial multicatheter HDR
- Dose: 34 Gy in 10 fractions BID (3.4 Gy per fraction)
- Skin Dmax < 100% prescribed dose

- Rib Dmax < 100% prescribed dose

4. Head and Neck Brachytherapy

Sites: Lip, oral tongue, floor of mouth

Technique:
- Interstitial catheters with Paris system geometry
- HDR or LDR depending on center expertise

Dose:
- HDR: 3–4 Gy × 10–12 fractions
- LDR: 60–70 Gy over 6–7 days

Notes:
- Good local control in early lesions (>85%)
- Organ preservation benefit

5. Palliative Indications

Esophagus:
- HDR intraluminal brachytherapy 8–10 Gy × 1–2 fractions for dysphagia relief

Lung (endobronchial):
- HDR 10 Gy × 1 fraction, repeat as needed
- Often combined with EBRT or stenting

References

1. Pötter R, et al. Recommendations from Gynaecological (GYN) GEC-ESTRO Working Group: concepts and terms in 3D image-based treatment planning in cervix cancer brachytherapy. Radiother Oncol. 2005;74(3):235-45.
2. Viswanathan AN, Thomadsen B. American Brachytherapy Society consensus guidelines for locally advanced carcinoma of the cervix. Brachytherapy. 2012;11(1):33-46.
3. Hoskin PJ, et al. High dose rate brachytherapy alone for localized prostate cancer. Radiother Oncol. 2014;113(3):307-12.
4. Polgár C, et al. Clinical results of accelerated partial breast irradiation using interstitial brachytherapy. Radiother Oncol. 2013;108(2):197-202.
5. Guinot JL, et al. Exclusive interstitial brachytherapy in the treatment of base of tongue carcinoma. Radiother Oncol. 2011;98(1):66-70.
6. Gaspar LE, et al. Brachytherapy in esophageal cancer: a review. Int J Radiat Oncol Biol Phys. 1997;38(6):1271-6.

Appendix E. Dosimetric Exercises and Case Studies

This appendix provides practical dosimetric exercises and illustrative case studies to support training in brachytherapy treatment planning. Each case highlights key planning principles, contouring challenges, and dose-volume evaluation, with references to current guidelines.

Exercise 1. Cervical Cancer HDR Brachytherapy

A 52-year-old woman with FIGO stage IIB cervical carcinoma is planned for HDR brachytherapy using a tandem and ovoid applicator after external beam radiotherapy (EBRT). MRI imaging is available.

Tasks:

- Contour HR-CTV and OARs (bladder, rectum, sigmoid).
- Prescribe: HR-CTV D90 ≥ 85 Gy EQD2 (including EBRT contribution).
- Verify: Bladder D2cc < 90 Gy EQD2; Rectum/Sigmoid D2cc < 75 Gy EQD2.
- Optimize dwell positions and times to achieve dose constraints.

Exercise 2. Prostate LDR Brachytherapy

A 65-year-old man with low-risk prostate cancer is planned for permanent I-125 seed implantation.

Tasks:

- Perform pre-plan with TRUS images (prostate volume 35 cc).
- Prescribe 145 Gy to prostate, V100 > 95%.
- Ensure urethra D10 < 118% and rectum V100 ≤ 1 cc.
- Verify post-implant dosimetry on Day 30 CT.

Exercise 3. Breast APBI (Interstitial Multicatheter)

A 58-year-old woman with a 1.5 cm invasive ductal carcinoma treated by breast-conserving surgery is considered for accelerated partial breast irradiation (APBI) using interstitial HDR brachytherapy.

Tasks:

- Prescribe 34 Gy in 10 fractions (3.4 Gy BID).
- CTV: surgical cavity + 2 cm margin, limited to breast tissue.
- Verify: Skin Dmax < 100% prescription; Rib Dmax < 100%.
- Generate DVH and evaluate conformity index (CI).

Exercise 4. Head & Neck Interstitial Brachytherapy

A 70-year-old male with a T2 base of tongue carcinoma is treated with interstitial HDR brachytherapy boost.

Tasks:

- Prescribe 3.5 Gy × 10 fractions to GTV + margin.
- Verify mucosal sparing and symmetry of dose distribution.
- Discuss functional outcome considerations (speech, swallowing).

References

1. Pötter R, Tanderup K, Kirisits C, et al. The EMBRACE II study: The outcome and prospect of two decades of evolution within the GEC-ESTRO GYN working group and the EMBRACE studies. Clin Transl Radiat Oncol. 2018;9:48-60.
2. Nag S, Ciezki J, Cormack R, et al. In-room implant dosimetry in prostate brachytherapy: Report of the American Brachytherapy Society. Brachytherapy. 2012;11(1):6-19.
3. Polgár C, Major T, Fodor J, et al. Accelerated partial-breast irradiation using high-dose-rate brachytherapy: 12-year results of a prospective clinical study. Radiother Oncol. 2010;94(3):274-279.

4. Guinot JL, Rembielak A, Lipiński J, et al. Interstitial brachytherapy for head and neck tumors: guidelines of the GEC-ESTRO Head & Neck Working Group. Radiother Oncol. 2018;128(3):463-471.

Appendix F. Checklists for Safe Practice in Brachytherapy

These structured checklists support safe brachytherapy practice across HDR, LDR, and associated procedures. They can be adapted to local institutional requirements.

1. HDR Brachytherapy Procedure Checklist

Pre-procedure

□ Indication confirmed; consent obtained; time-out performed

□ Imaging and labs reviewed; anesthesia clearance obtained

□ Applicators and afterloader prepared; QA performed

□ Radiation safety arrangements in place

Applicator Insertion

□ Applicator insertion under anesthesia; US guidance used if indicated

□ Geometry confirmed; packing used where applicable

□ Channel labeling verified

2. LDR Prostate Seed Implant Checklist

Pre-implant

□ Eligibility confirmed (low/favorable intermediate risk prostate cancer)

□ Seed type and activity verified; pre-plan dosimetry completed

□ Radiation safety counseling performed

Intra-operative

□ TRUS guidance registered; template secured

□ Needle placement confirmed; seeds deployed as planned

□ Seed count reconciliation ongoing

3. Afterloader & Physics QA

Daily

□ Afterloader self-check passed; door interlock confirmed

□ Source strength constancy check performed

□ Emergency equipment available and tested

4. Emergency – Stuck Source Protocol

□ Press emergency stop; secure the room

□ Do not pull applicator; attempt automatic source retraction

□ Follow institutional manual retrieval protocol

□ Notify physics and radiation safety officer

References

1. AAPM TG-59. High dose-rate brachytherapy treatment delivery. Med Phys. 1998;25(4):375–403.

2. Thomadsen BR, et al. Quality assurance in brachytherapy. Med Phys. 1998;25(10):2203–2222.

3. ICRU Report 89. Prescribing, Recording, and Reporting Brachytherapy for Cancer of the Cervix. J ICRU. 2013;13(1–2).

4. Viswanathan AN, Thomadsen B. ABS consensus guidelines for locally advanced cervix cancer. Brachytherapy. 2012;11(1):33–46.

5. BGCS/RCR Guidelines for cervical and endometrial brachytherapy. Clin Oncol. 2021;33(6):e197–e208.

Appendix G. Sample Patient Consent Forms for Brachytherapy

This appendix provides model patient consent forms for common brachytherapy procedures. They are intended as educational examples and must be adapted to local legal, ethical, and institutional requirements.

1. HDR Brachytherapy for Cervical Cancer

I, _____, consent to undergo high-dose-rate (HDR) brachytherapy for treatment of cervical cancer.

The procedure involves:

• Placement of an applicator (tandem and ovoid or ring) into the uterus and vagina under anesthesia.

• Delivery of radiation using a temporary radioactive source (Iridium-192).

• Multiple treatment sessions, each lasting approximately 10–20 minutes.

Risks discussed include vaginal bleeding, pain, bladder/rectal irritation, fistula formation, and long-term narrowing of the vagina.

Alternative treatments and the right to refuse have been explained.

Signature of Patient: _____ Date: _____

Signature of Physician: _____ Date: _____

2. Permanent Seed Implant (Prostate LDR Brachytherapy)

I, _____, consent to undergo permanent seed brachytherapy for prostate cancer.

The procedure involves:

• Placement of radioactive seeds (I-125, Pd-103, or Cs-131) into the prostate gland under anesthesia.

• Seeds remain permanently but lose radioactivity after several months.

• Radiation is localized to the prostate with minimal exposure to others.

Risks discussed include urinary frequency, urgency, difficulty urinating, rectal irritation, erectile dysfunction, and very small risks to family contacts.

Alternative treatments such as surgery or external beam radiation were discussed.

Signature of Patient: _____ Date: _____

Signature of Physician: _____ Date: _____

3. Accelerated Partial Breast Irradiation (APBI)

I, _____, consent to undergo accelerated partial breast irradiation (APBI) using brachytherapy.

The procedure involves:

• Insertion of a balloon catheter or interstitial catheters into the breast lumpectomy cavity.

• Radiation delivery over 5–10 treatment sessions using Iridium-192.

• Removal of applicator after completion of treatment.

Risks include breast pain, swelling, infection, poor cosmetic outcome, fibrosis, and rarely rib fracture or lung exposure.

Alternative treatments such as whole breast irradiation were explained.

Signature of Patient: _____ Date: _____

Signature of Physician: _____ Date: _____

4. General Consent Clause

I confirm that I have received information in language I understand, had the opportunity to ask questions, and that all my questions have been answered.

References

1. Viswanathan AN, Thomadsen B, American Brachytherapy Society. Brachytherapy practice guidelines for locally advanced cervical cancer. Brachytherapy. 2012;11(1):33–46.
2. Hoskin PJ, Colombo A, Henry A, et al. GEC-ESTRO recommendations on high dose rate afterloading brachytherapy for localized prostate cancer. Radiother Oncol. 2013;107(3):325–332.
3. Polgár C, Strnad V, Major T. Brachytherapy for partial breast irradiation: the European experience. Semin Radiat Oncol. 2010;20(2):91–97.

Appendix H. Toxicity Grading and Patient Aftercare in Brachytherapy

This appendix summarizes standard toxicity grading systems relevant to brachytherapy and provides guidance on structured patient aftercare. Consistent documentation and proactive management improve outcomes and quality of life.

1. Toxicity Grading Systems

Two commonly used systems are CTCAE (Common Terminology Criteria for Adverse Events, v5.0) and RTOG/EORTC Late Radiation Morbidity Scoring. Both are widely referenced in brachytherapy literature.

Toxicity	Grade 1	Grade 2	Grade 3+
Genitourinary (CTCAE)	Mild frequency, urgency	Moderate; medication indicated	Severe; catheterization, surgery
Gastrointestinal (CTCAE)	Mild diarrhea, rectal discomfort	Moderate diarrhea, rectal bleeding	Obstruction, fistula, perforation
Gynecologic (RTOG/EORTC)	Mild vaginal dryness, telangiectasia	Stenosis requiring dilator	Obliteration, severe necrosis

2. Acute vs Late Toxicities

Acute effects occur within 90 days of treatment (mucositis, urinary frequency, dysuria, diarrhea), while late effects manifest months to years later (stricture, fistula, necrosis, fibrosis). Late toxicity grading is crucial for clinical trial reporting and long-term patient management.

3. Patient Aftercare

Follow-up visits should be structured and multidisciplinary. Key domains include:

• Gynecologic: Vaginal dilator use post-cervical brachytherapy to reduce stenosis.

• Urology: Post-prostate implant urinary flow monitoring; alpha-blockers if needed.

• Gastrointestinal: Stool softeners, dietary advice, and early colonoscopy if bleeding persists.

• Breast: Monitor for fat necrosis, fibrosis, cosmesis; counsel on self-examination.

• General: Psychosocial support, sexual health counseling, fertility considerations.

4. Recommended Follow-Up Schedule

• First visit: 4–6 weeks post-treatment
• Every 3–4 months during first 2 years
• Every 6 months until year 5
• Annually thereafter
Clinical exam at each visit; imaging and labs as indicated.

References

1. National Cancer Institute. Common Terminology Criteria for Adverse Events (CTCAE) v5.0. 2017.
2. Cox JD, Stetz J, Pajak TF. Toxicity criteria of the RTOG and the EORTC. Int J Radiat Oncol Biol Phys. 1995;31(5):1341–1346.
3. Kirchheiner K, Nout RA, Tanderup K, et al. Health-related quality of life and patient-reported symptoms after MRI-guided adaptive brachytherapy for cervical cancer. Radiother Oncol. 2015;117(2):198–204.
4. Yoshioka Y, Suzuki O, Otani Y, et al. High-dose-rate brachytherapy for prostate cancer: an analysis of long-term results. Int J Radiat Oncol Biol Phys. 2015;91(3):687–694.

Appendix I. Resources for Training and Further Reading in Brachytherapy

This appendix compiles key resources, guidelines, and educational materials useful for trainees and practitioners in brachytherapy. It includes international society guidelines, online modules, and reference textbooks.

1. Key Guidelines and Consensus Statements

• ICRU Report 89: Prescribing, Recording, and Reporting Brachytherapy for Cancer of the Cervix (2013).

• AAPM TG-43 and TG-186 reports: Dose calculation protocols in brachytherapy physics.

• ABS (American Brachytherapy Society) consensus guidelines: prostate, cervix, endometrium, breast.

• ESTRO (European Society for Radiotherapy and Oncology) GEC-ESTRO recommendations on image-guided adaptive brachytherapy (IGABT).

• BGCS/RCR guidelines for cervical and endometrial brachytherapy (UK, 2021).

2. Recommended Textbooks

• Perez & Brady's Principles and Practice of Radiation Oncology (chapters on brachytherapy).

• Levitt, Purdy, Perez, Poortmans: Technical Basis of Radiation Therapy.

• Hoskin P, Coyle C. Radiotherapy in Practice: Brachytherapy (Oxford University Press).

• Baltas D, Sakelliou L, Zamboglou N. The Physics of Modern Brachytherapy for Oncology.

• Nag S (ed). Principles and Practice of Brachytherapy.

3. Online Learning Resources

• IAEA Human Health Campus: free e-learning modules on brachytherapy.

• ESTRO School teaching courses: regular hands-on workshops and online classes.

• ASTRO/ABS webinars and contouring workshops.

• Radiopaedia.org: case-based radiology and radiation oncology resources.

4. Key Journals for Ongoing Research

• Brachytherapy (official journal of the American Brachytherapy Society).

• Radiotherapy and Oncology (The Green Journal).

• International Journal of Radiation Oncology Biology Physics (Red Journal).

• Journal of Contemporary Brachytherapy.

• Medical Physics / Physica Medica (brachytherapy physics content).

5. Professional Societies and Networks

• American Brachytherapy Society (ABS) – https://www.americanbrachytherapy.org

• European Society for Radiotherapy and Oncology (ESTRO) – https://www.estro.org

• International Atomic Energy Agency (IAEA) – https://www.iaea.org

• Association of Residents in Radiation Oncology (ARRO) – https://www.arro.org

• Global RT community and Contouring Collaborative for Consensus in Radiation Oncology (C3RO).

References

1. ICRU Report 89. Prescribing, Recording, and Reporting Brachytherapy for Cancer of the Cervix. J ICRU. 2013;13(1–2).
2. Rivard MJ, Coursey BM, DeWerd LA, et al. Update of AAPM TG-43 Report: A revised AAPM protocol for brachytherapy dose calculations. Med Phys. 2004;31(3):633–674.
3. Viswanathan AN, Thomadsen B, et al. American Brachytherapy Society consensus guidelines. Brachytherapy. Various sites (2005–2020).
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Appendix J. Glossary of Terms and Acronyms in Brachytherapy

This appendix provides a concise glossary of commonly used terms, acronyms, and abbreviations in brachytherapy. It is intended as a quick reference for trainees and practitioners.

Term/Acronym	Definition
ABS	American Brachytherapy Society – international professional society for brachytherapy practitioners.
Afterloader	A device that remotely drives the radioactive source into catheters/applicators during HDR or PDR brachytherapy.
APBI	Accelerated Partial Breast Irradiation – breast brachytherapy technique targeting the lumpectomy cavity.
BGCS	British Gynaecological Cancer Society – UK body that publishes brachytherapy guidelines.
BT	Brachytherapy – internal radiotherapy using sealed radioactive sources placed close to or inside the tumor.
CTV	Clinical Target Volume – tissue volume that contains gross tumor (GTV) and/or subclinical malignant disease.
D90	The minimum dose received by 90% of the target volume, widely used in prostate and cervical brachytherapy.
D2cc	Minimum dose received by the most exposed 2 cubic centimeters of an organ at risk (OAR).
DVH	Dose–Volume Histogram – graphical representation of dose distribution in targets and OARs.
EBRT	External Beam Radiation Therapy – treatment with external megavoltage X-rays or particles.
EQD2	Equivalent Dose in 2 Gy fractions – radiobiological dose standardization method using linear–quadratic model.
ESTRO	European Society for Radiotherapy and Oncology – professional society supporting brachytherapy (GEC-ESTRO group).
FIGO	International Federation of Gynecology and Obstetrics – staging system used in cervical cancer.
GEC-ESTRO	Groupe Européen de Curiethérapie – ESTRO subgroup developing brachytherapy guidelines.
HDR	High Dose Rate brachytherapy – dose rate >12 Gy per hour, delivered with remote afterloader.

HR-CTV	High-Risk Clinical Target Volume – defined in MRI-based cervix brachytherapy for residual tumor.
ICRU	International Commission on Radiation Units and Measurements – publishes brachytherapy dosimetry standards.
Ir-192	Iridium-192 – most common isotope used in HDR brachytherapy afterloaders.
LDR	Low Dose Rate brachytherapy – dose rate of 0.4–2 Gy per hour; includes permanent seed implants.
OAR	Organ at Risk – normal tissue structures sensitive to radiation damage.
PDR	Pulsed Dose Rate – brachytherapy delivery using pulses of HDR (often hourly) to mimic LDR.
PSA	Prostate-Specific Antigen – biomarker used in prostate cancer management and post-brachytherapy follow-up.
QA	Quality Assurance – systematic checks to ensure accuracy, safety, and reliability of brachytherapy delivery.
RTOG	Radiation Therapy Oncology Group – cooperative group providing clinical trial protocols and toxicity grading.
TG-43	AAPM Task Group 43 protocol for brachytherapy dose calculations.
TRUS	Transrectal Ultrasound – imaging modality used for prostate seed/HDR catheter placement.

References

1. ICRU Report 89. Prescribing, Recording, and Reporting Brachytherapy for Cancer of the Cervix. J ICRU. 2013;13(1–2).
2. Rivard MJ, Coursey BM, DeWerd LA, et al. Update of AAPM TG-43 Report. Med Phys. 2004;31(3):633–674.
3. Viswanathan AN, Thomadsen B, American Brachytherapy Society. ABS consensus guidelines. Brachytherapy. 2012;11(1):33–46.
4. ESTRO School resources on image-guided brachytherapy. https://www.estro.org

Appendix K. Sample Case Log Template for Brachytherapy Trainees

This appendix provides a structured case log template for residents and fellows performing or assisting in brachytherapy procedures. It facilitates documentation of clinical experience and can be adapted to institutional requirements.

Date	Patient ID (anonymized)	Site/Disease	Procedure Type (HDR/LDR)	Applicator / Technique	Role (Observer/ Assistant/ Primary)	Supervising Physician	Notes / Complications
2025-01-12	C001	Cervix (Stage IIB)	HDR	Tandem + Ring	Assistant	Dr. A. Smith	Successful insertion, MRI-guided plan
2025-02-03	P015	Prostate (Low risk)	LDR	I-125 seed implant	Primary	Dr. B. Jones	Post-implant CT completed
2025-03-10	B008	Breast (APBI)	HDR	Interstitial multicatheter	Observer	Dr. C. Lee	No complications, good cosmetic outcome

Trainees are encouraged to record at least 10–20 supervised cases per disease site (cervix, prostate, breast, head & neck) to ensure exposure to diverse brachytherapy techniques.

References

1. European Society for Radiotherapy and Oncology (ESTRO). Recommendations for brachytherapy training. Radiother Oncol. 2014;111(3):337–339.
2. American Brachytherapy Society. Brachytherapy curriculum for residents. Brachytherapy. 2015;14(5):587–592.
3. Royal College of Radiologists. Specialty training curriculum for clinical oncology. 2021.

Appendix L. Hands-On Training and Competency Milestones in Brachytherapy

Introduction

Brachytherapy is as much an interventional procedure as it is a radiotherapeutic one. Competence requires repeated exposure to patient anatomy, applicator placement, and treatment planning workflows. Unlike external beam radiotherapy, where planning is largely computer-based, brachytherapy demands **manual dexterity, spatial awareness, and an understanding of anatomy under anesthesia**. Structured training ensures safety, consistency, and confidence in independent practice [1,2].

1. Core Anatomical Knowledge

Female Pelvis (Gynecologic Brachytherapy)

- **Cervix and uterus**: variations in anteversion, retroversion, and cavity length dictate tandem angle and length.
- **Vaginal fornices**: determine placement of ovoids or ring; asymmetry reduces coverage.
- **Bladder and rectum**: displacement is critical; gauze packing or balloons help minimize dose [3].
- **Parametrium**: understanding its boundaries supports correct needle placement in hybrid or interstitial approaches.

Male Pelvis (Prostate Brachytherapy)

- **Prostate gland**: apex identification on TRUS is challenging but essential.
- **Urethra**: catheter delineation for protection during dwell optimization.
- **Rectum**: posterior boundary; proximity requires strict dosimetric constraints.
- **Pubic arch**: may obstruct anterior needle insertion; evaluation pre-procedure avoids complications [4].

Breast and Head & Neck Sites

- **Breast cavity**: requires geometric catheter placement; cosmetic outcome depends on symmetry.
- **Oral cavity/tongue**: catheter spacing (typically 1 cm) must follow Paris system principles.

2. Practical Skills to be Mastered

Gynecologic HDR

- Sounding the uterus with a uterine sound; recognizing when dilatation is required.
- Gentle tandem insertion, preferably under ultrasound guidance to avoid perforation.
- Correct positioning of ovoids/ring in fornices.
- Use of packing or balloons to stabilize applicators and spare organs.

Prostate HDR/LDR

- Lithotomy positioning and perineal preparation.
- TRUS-guided needle insertion with stepper and template.
- Maintaining consistent geometry between imaging and planning.
- Post-implant dosimetry (Day 0 and Day 30 for LDR).

Breast and Head & Neck

- Template-guided breast catheter insertion around the lumpectomy cavity.
- Interstitial catheter placement for tongue/lip lesions: symmetry and parallelism essential.

3. Progressive Training Milestones

Stage	Resident Role	Minimum Exposure	Competencies Acquired
Observation	Observe procedures (cervix, prostate, breast, H&N)	≥10 per site	Understand anatomy, applicators, workflow
Assisted Practice	Assist supervisor in applicator insertion	≥10 per site	Hands-on familiarity with instruments, packing, imaging
Supervised Practice	Perform insertions under direct supervision	≥10 cases (mixed sites)	Safe insertion, recognition of complications
Independent Planning	Contour applicators, HR-CTV, OARs, perform dosimetry	≥20 cases	Planning independence, dosimetric analysis
Final Competency	Independently perform supervised full procedure	≥10 cases	Full workflow competence, eligible for sign-off

4. Managing Complications

- **Uterine perforation**: recognize immediately, confirm with ultrasound, abort insertion if unsafe [5].
- **Bleeding**: apply pressure, cautery, or packing; escalate to gynecologic surgeon if needed.
- **Seed misplacement (LDR)**: post-implant imaging critical; identify and report migration.
- **Catheter dislodgement (HDR)**: re-image before treatment; never deliver without verification.

5. Competency Sign-Off Framework

A training log should document:

- Number of cases observed, assisted, and performed.
- Independent treatment plans created and approved.
- Supervisor's sign-off for readiness.
  This aligns with ESTRO and ABS recommendations for resident education [6,7].

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4. Nag S, Ciezki J, Cormack R, et al. In-room implant dosimetry in prostate brachytherapy. *Brachytherapy*. 2012;11(1):6–19.
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