JOINT ICTP-IAEA WORKSHOP ON RADIATION PROTECTION IN IMAGE-GUIDED RADIOTHERAPY (IGRT)

IGRT in Brachytherapy

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Outline

Introduction to IGRT in Brachytherapy

Imaging Modalities: Ionizing vs. Non-Ionizing

Brachytherapy Workflow: Role of Imaging

Clinical Applications of IGRT in Brachytherapy

Radiation Protection and Dose Reduction

Future Directions in IGRT for Brachytherapy

1. INTRODUCTION TO IGRT IN BRACHYTHERAPY

LO

What is Brachytherapy?

:Internal radiotherapy using radioactive sources placed inside or near the tumor.

- **History**:
  - Early 1900s: Use of radium implants for treating tumors.
  - Modern developments: HDR (high-dose-rate) and LDR (low-dose-rate) techniques.
  - Integration of advanced imaging for better precision and outcomes.

- **Types of Sources Used**:
  - **LDR**: Permanent radioactive seeds, commonly using isotopes like Iodine-125 or Palladium-103.
  - **HDR**: Temporary sources using isotopes like Iridium-192, often removed after treatment sessions.
  - **Other Sources**: Cobalt-60 or Cesium-137 used in specific types of treatments.

Advantages:

- Delivers high dose locally with minimal exposure to healthy tissue.
- Effective for treating cancers like cervical, prostate, breast, and head/neck.

Key Feature: High precision and control compared to external beam radiotherapy.

Image Guidance in Brachytherapy

Relevance:

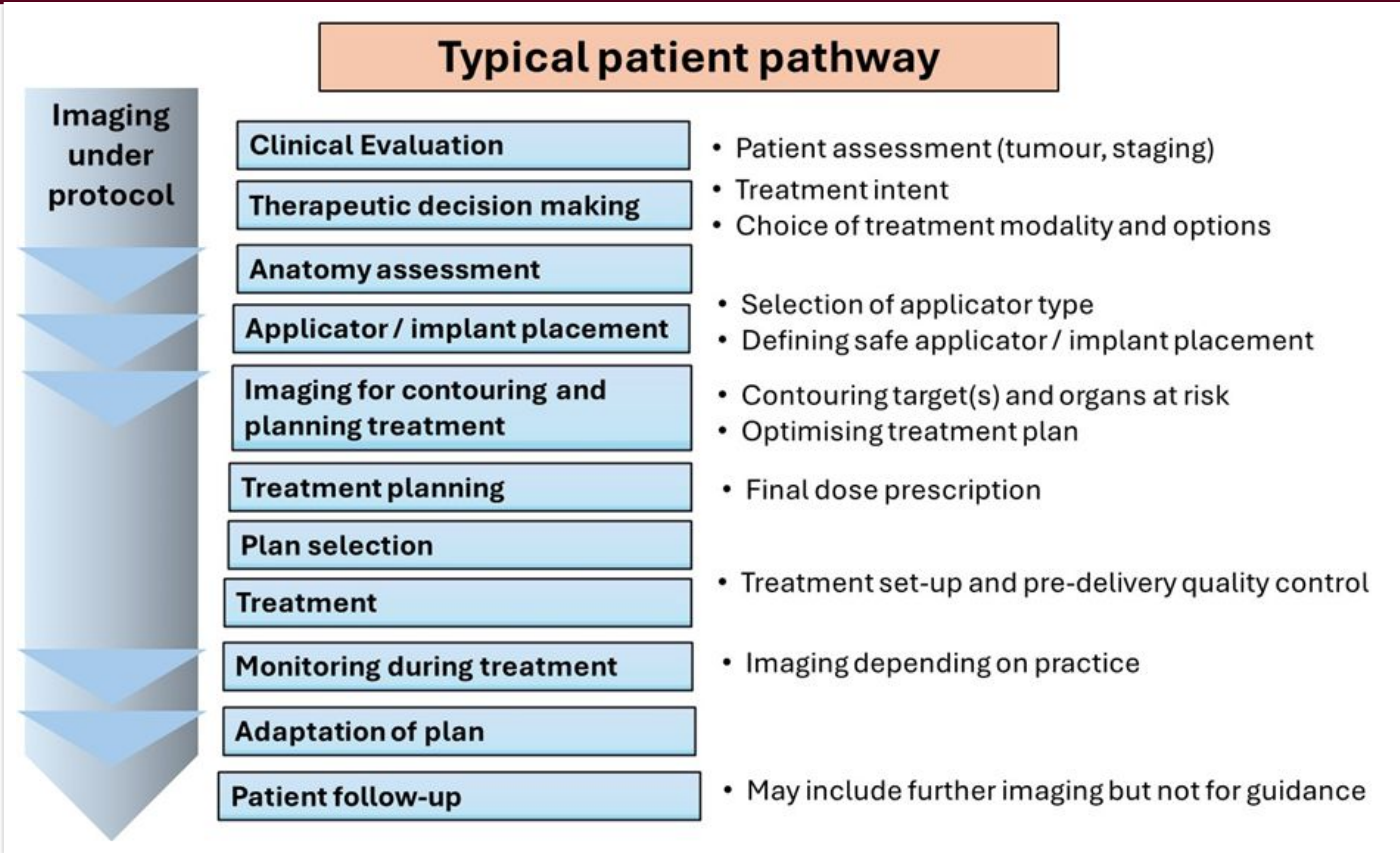
- Essential for accurate applicator placement and verification.
- Improves tumor targeting while sparing nearby organs at risk (OARs).

Integration:

- Imaging is used at key stages: during applicator insertion, treatment planning, and dose verification.

Precision and Adaptation:

- Imaging allows for treatment adaptation, ensuring high-dose radiation is delivered to the tumor with minimal exposure to healthy tissues.



Modified from Figure 1, IAEA, The Transition from 2-D Brachytherapy to 3-D High Dose Rate Brachytherapy, Human Health Reports No. 12, IAEA, Vienna (2015) (IAEA, 2015b

2. IMAGING MODALITIES IN BRACHYTHERAPY

Imaging Modalities in Brachytherapy

1- Ionizing Imaging: CT, radiographs, fluoroscopy.

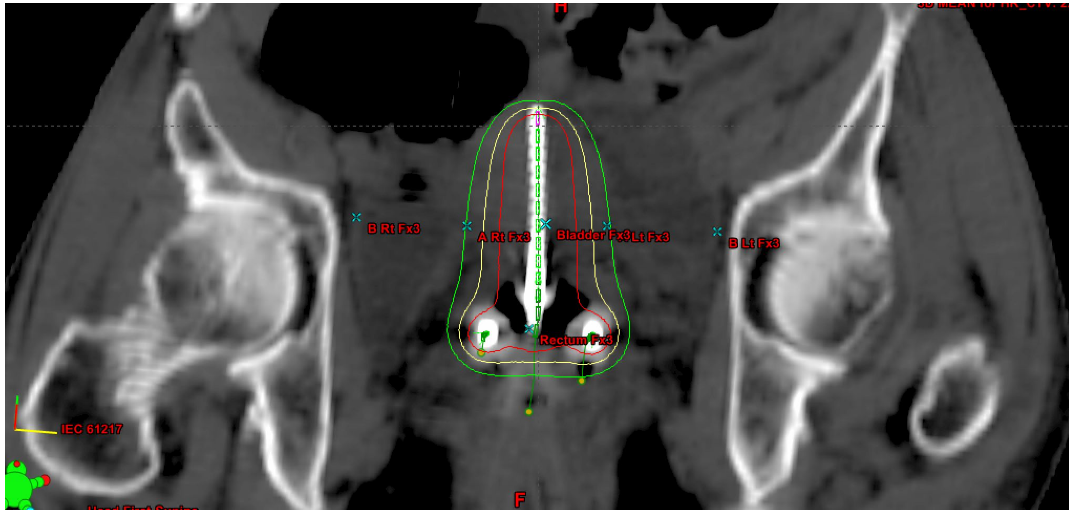
- **Benefits:** Accurate visualization of applicators and treatment area
- **Drawbacks:** Radiation exposure to the patient.

2- Non-Ionizing Imaging: MRI and ultrasound.

- **Benefits:** No radiation, better soft tissue contrast (MRI especially).
- **Drawbacks:** Resource limitations, MRI compatibility, and operator dependency (ultrasound).

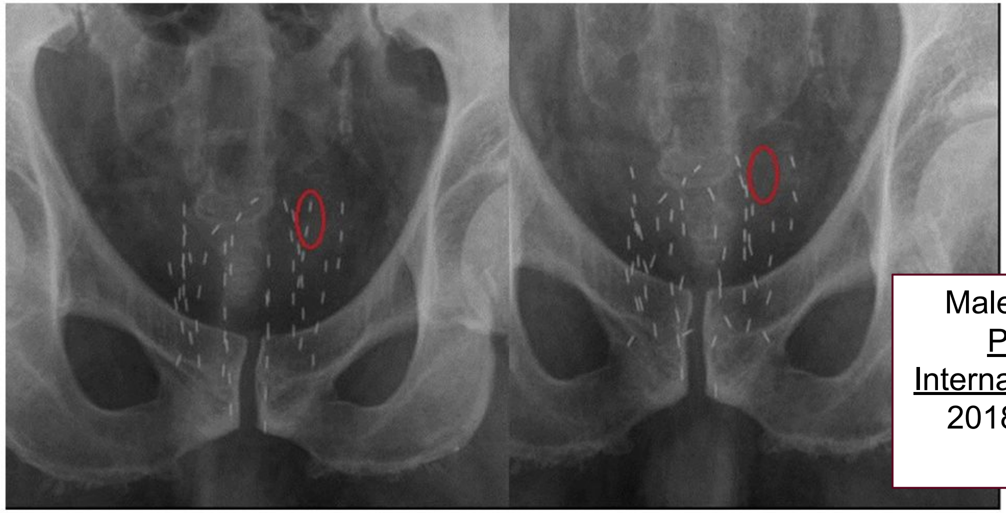
Key Considerations: Tumor site, technique complexity, and ***availability of imaging resources.***

Imaging Modalities in Brachytherapy: CT, Radiographs, Fluoro



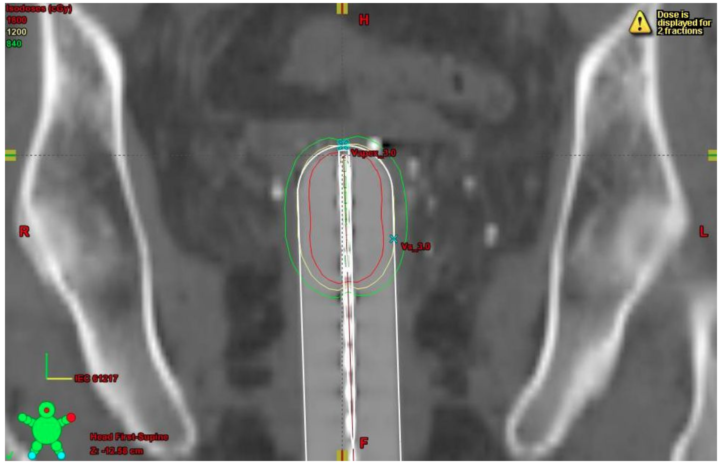
Tandem and Ovoids

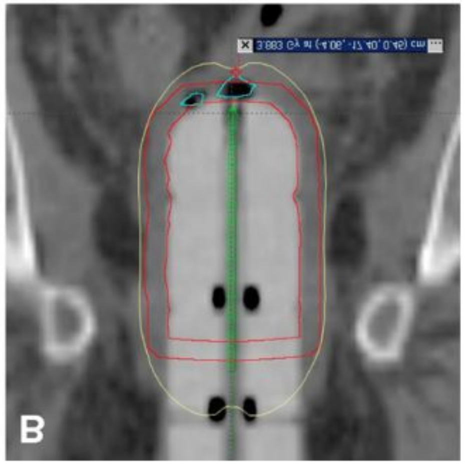
Courtesy Matt Harkenrider, MD



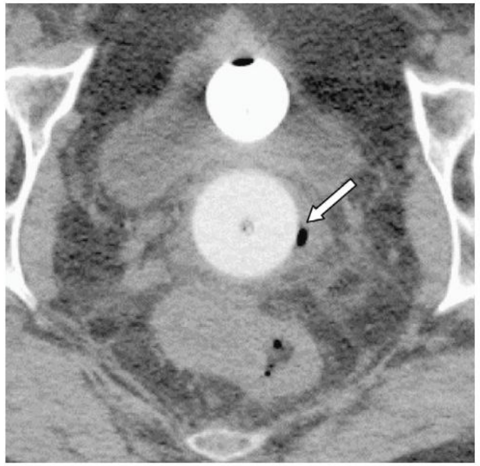
Maletzki et al., Prostate International v6 (2) 2018, P 66-70

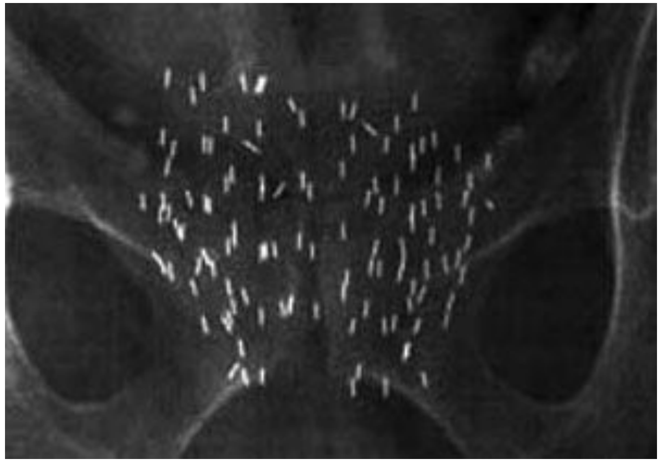
Fig 1. Seed loss. Pelvic X-ray shows loss of two seeds (red circle) in follow-up on 1st day after seed implantation.





Vaginal Cylinder

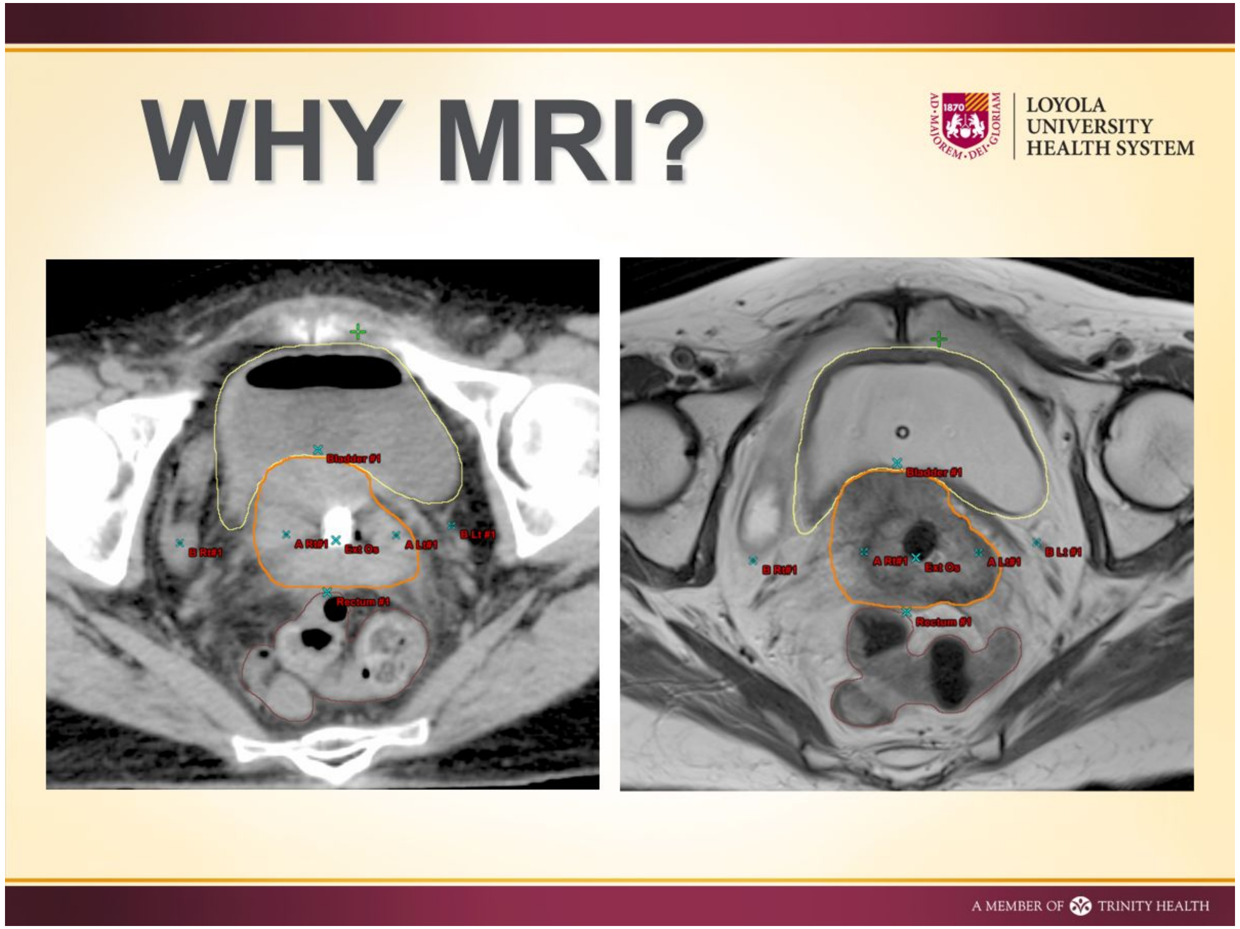


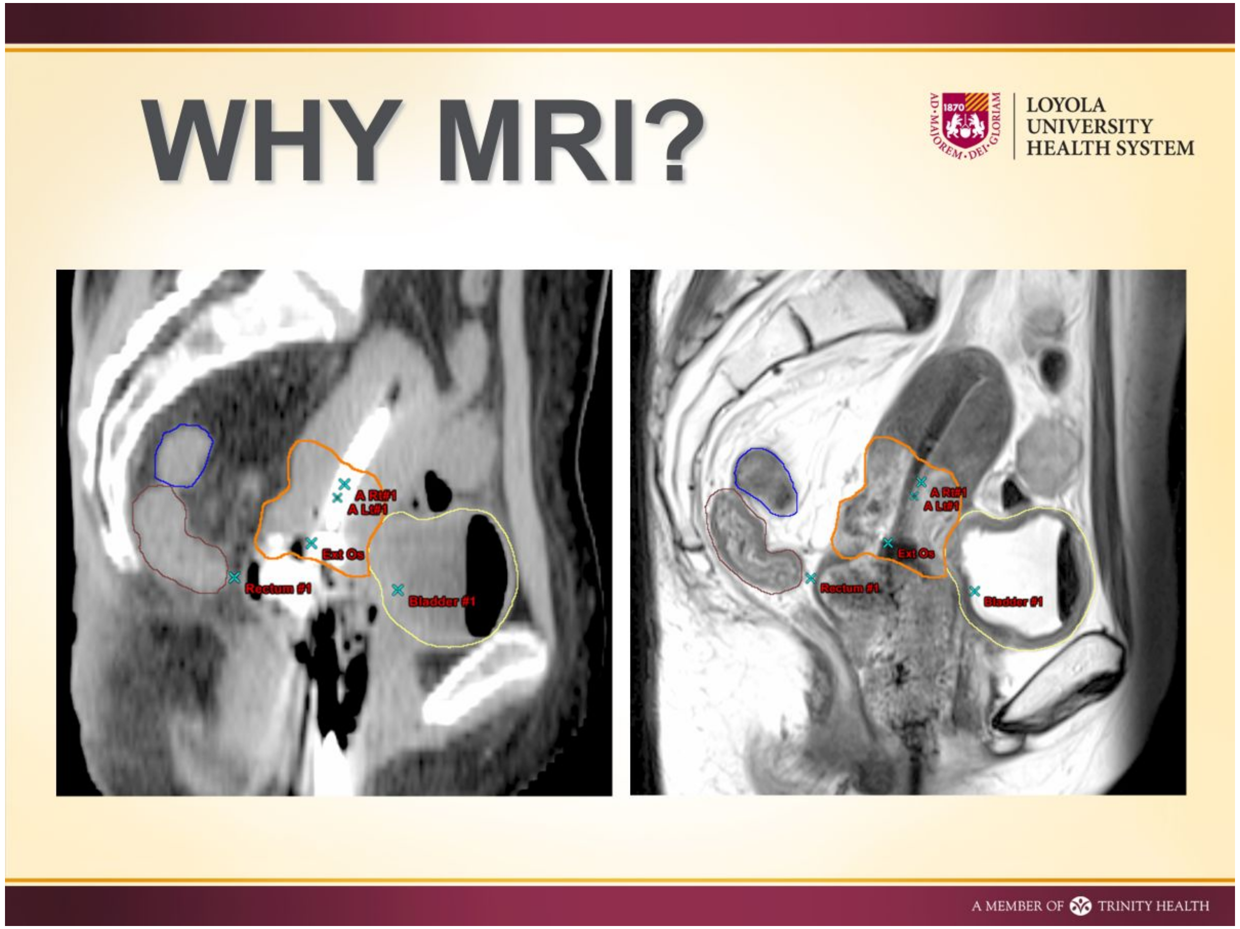


Prostate Post implant radiograph

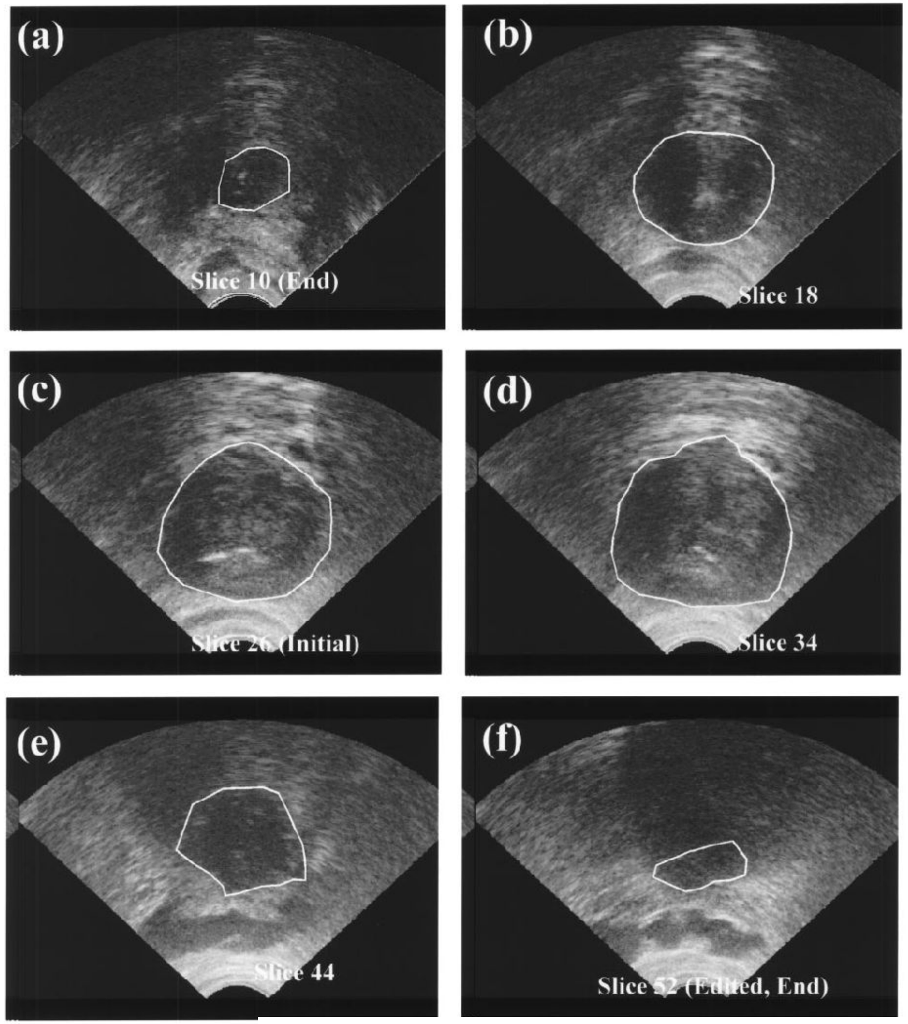
Imaging Modalities in Brachytherapy: MRI

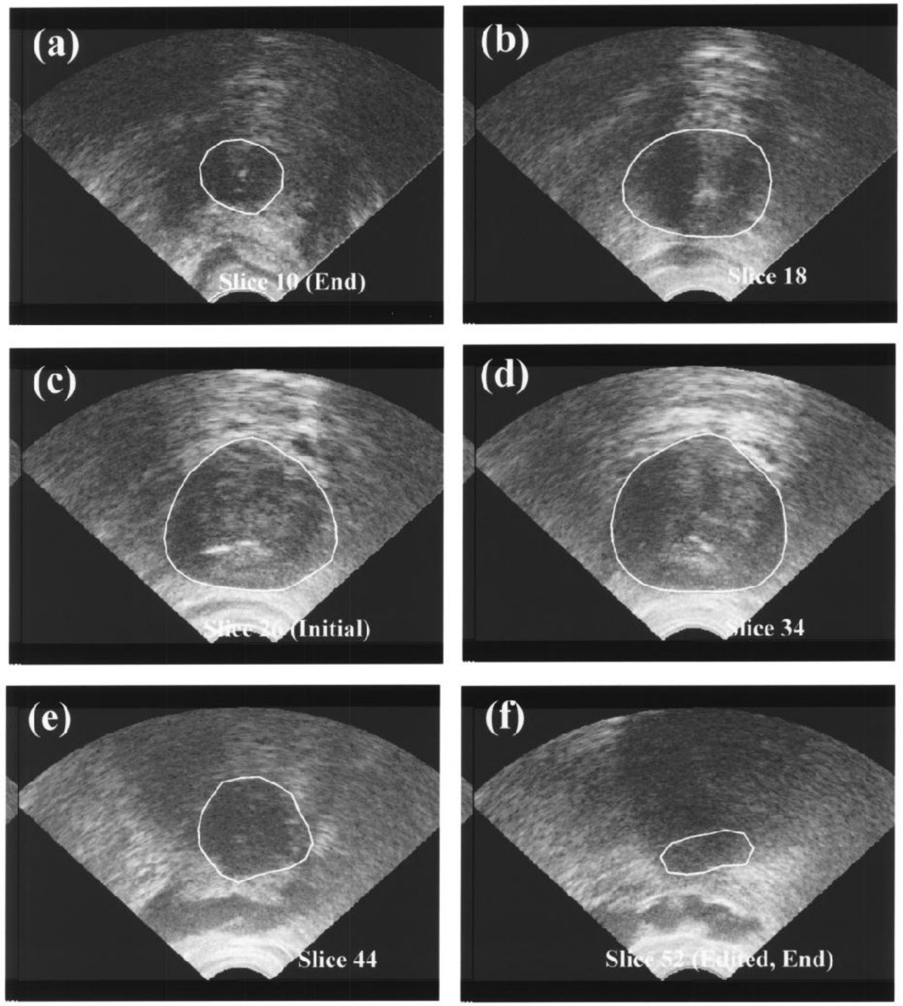
Courtesy
Matt Harkenrider, MD





Imaging Modalities in Brachytherapy: US

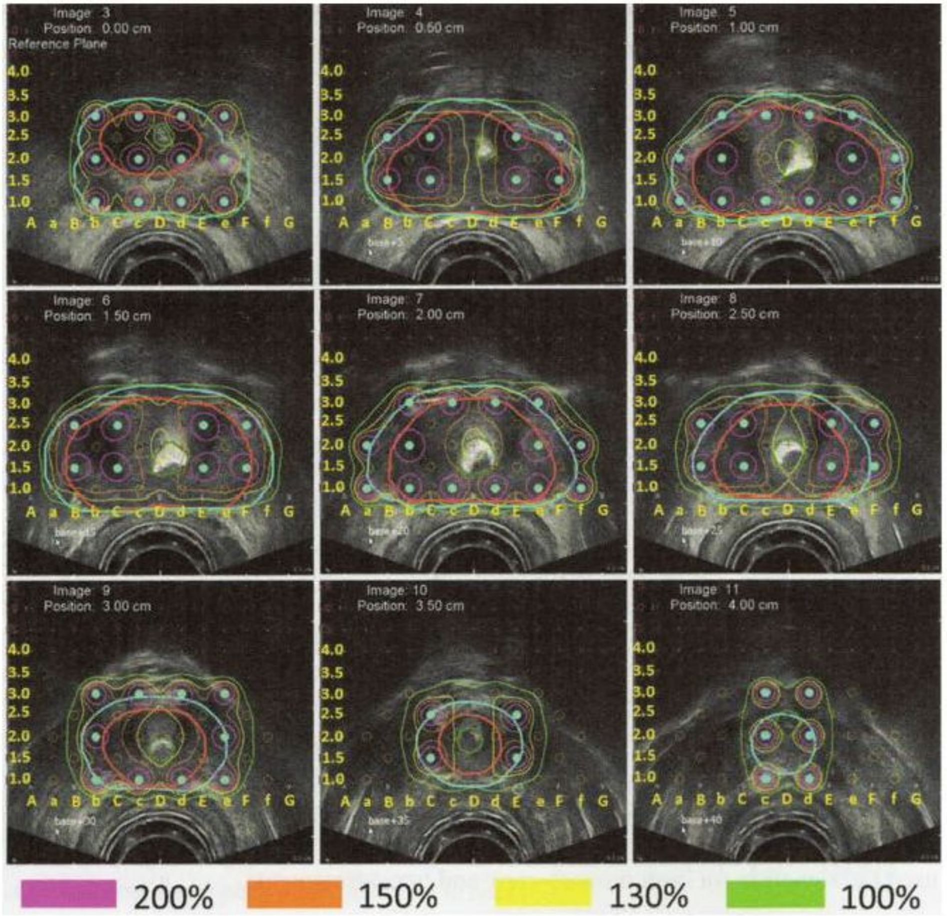




Wang, Y., et al., (2003), Semiautomatic three-dimensional segmentation of the prostate using two-dimensional ultrasound images. Med. Phys., 30: 887-897. https://doi.org/10.1118/1.1568975

Imaging Modalities in Brachytherapy: US

URETHRA: Identified with aerated gel during volume study



- Plan here is to purposely divert needle E1.5 to reduce urethra dose.

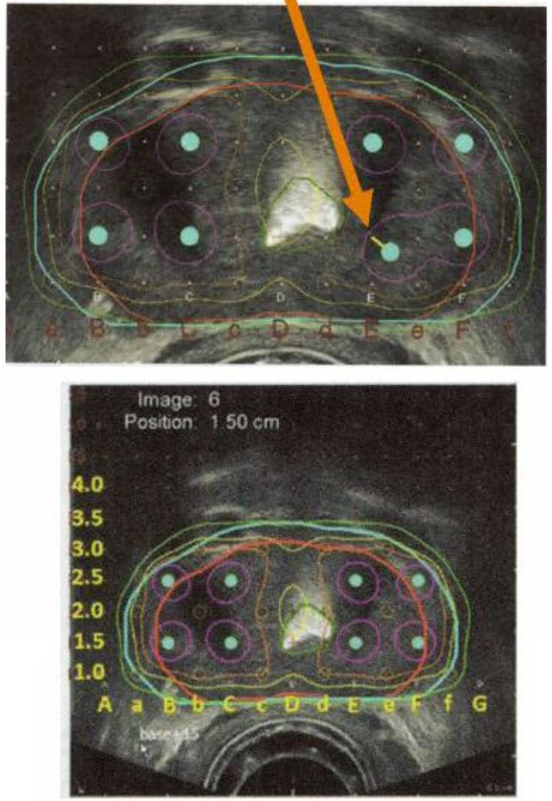


Image: Clinical Brachytherapy Physics Monograph, 2017 ABS-AAPM Summer School

Applicator Placement

- Internal "dummy" wire

Courtesy Matt Harkenrider, MD

Color Keys

‘ Standard or in widespread clinical use

O Optional available modality

E Experimental or research-oriented modality

- not applicable

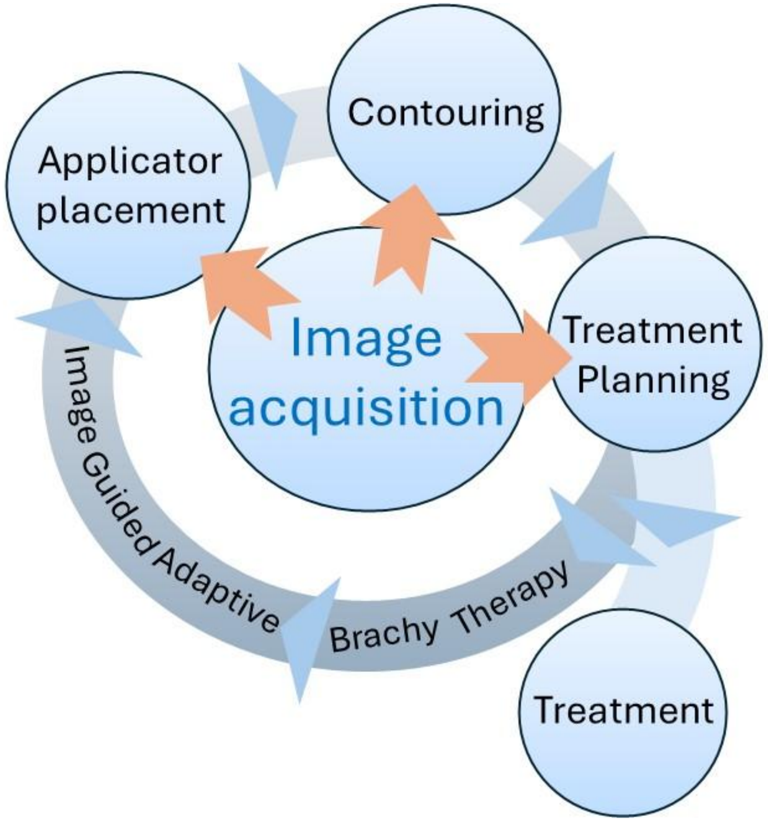
Treatment site	Applicator insertion /guidance						Implant/Image verification						Treatment Planning					
	CT	Fluoroscopy / radiographs	MRI	Ultrasound	Visual	Endoscopy	CT	Fluoroscopy / radiographs	MRI	Ultrasound	Visual	Endoscopy	CT	Fluoroscopy / radiographs	MRI	Ultrasound	Visual	Endoscopy
Cervix (limited stage)	o	‘	o	o	-	-	‘	‘	o	o	-	-	‘	‘	o	e	-	-
Cervix (advanced stages)	o	‘	o	‘	-	e	‘	‘	o	‘	-	e	‘	‘	o	e	-	-
Endometrium (post op.)	-	‘	-	-	‘	-	o	‘	o	-	-	-	‘	‘	o	-	‘	-
Endometrium (definitive)	-	‘	-	o	-	-	‘	‘	o	-	-	-	‘	‘	o	-	-	-
Vagina	o	‘	o	‘	o	-	‘	‘	o	‘	o	-	‘	‘	o	e	-	-
Vulva	-	‘	-	-	‘	-	-	‘	-	-	‘	-	o	‘	-	-	‘	-

3. INTEGRATION OF IGRT INTO THE BRACHYTHERAPY WORKFLOW

Integration of IGRT into the Brachytherapy Workflow

•**Key Workflow Stages**:

- **Applicator Insertion**: Real-time imaging (ultrasound, fluoroscopy) for precise placement.
- **Treatment Planning**: 3D imaging (CT, MRI) to create personalized plans.
- **Verification**: Imaging confirms accurate dose delivery and applicator position.



Integration of IGRT into the Brachytherapy Workflow

Levels of Complexity	IMAGING MODALITY
Level 1	No imaging or simple planar imaging.
Level 2	2D imaging with anatomical landmarks (planar radiographs).
Level 3	3D imaging (CT, MRI) for precise treatment planning.
Level 4	Image-guided adaptive brachytherapy (IGABT) with complex applicators.

4. CLINICAL APPLICATIONS OF IGRT IN BRACHYTHERAPY

Cervical Cancer: MRI-Guided Brachytherapy and the EMBRACE Trial

MRI-Guided Brachytherapy:

- Provides superior soft tissue contrast, allowing for better tumor delineation.
- Enables dose escalation to the tumor while sparing organs at risk (OARs).

Workflow Challenges:

- Timing of imaging in the workflow.
- Requirement for MRI-compatible applicators.

- **The EMBRACE Trial**:
  - **Objective**: A multicenter prospective study evaluating MRI-guided adaptive brachytherapy in cervical cancer.
  - **Key Findings**:
    - Improved local control rates.
    - Significant reduction in severe side effects.
    - Enhanced tumor targeting, leading to better overall survival and quality of life.
  - **Impact**: The trial has set a new standard for MRI-based brachytherapy, supporting its integration into clinical practice.

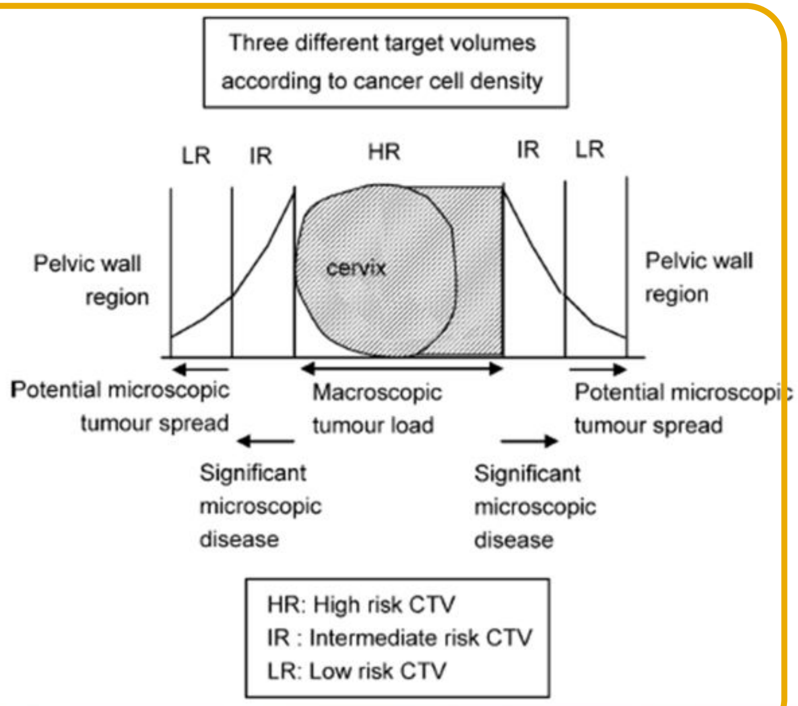
Cervical Cancer: MRI-Guided Brachytherapy and the EMBRACE / II Trials

Recommendations from Gynaecological (GYN) GEC-ESTRO Working Group☆ (I): concepts and terms in 3D image based 3D treatment planning in cervix cancer brachytherapy with emphasis on MRI assessment of GTV and CTV

Reproducible MRI-based volumes

- intermediate-risk CTV (IR CTV)
- high-risk CTV (HR CTV)

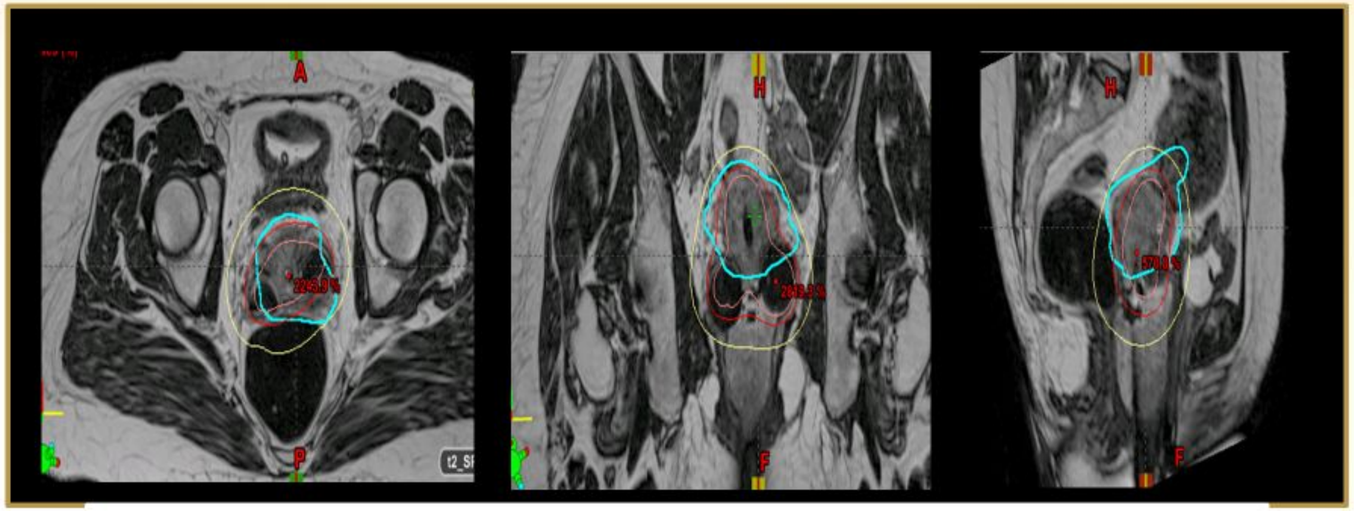
Foundation for Image-based dose specification volumes

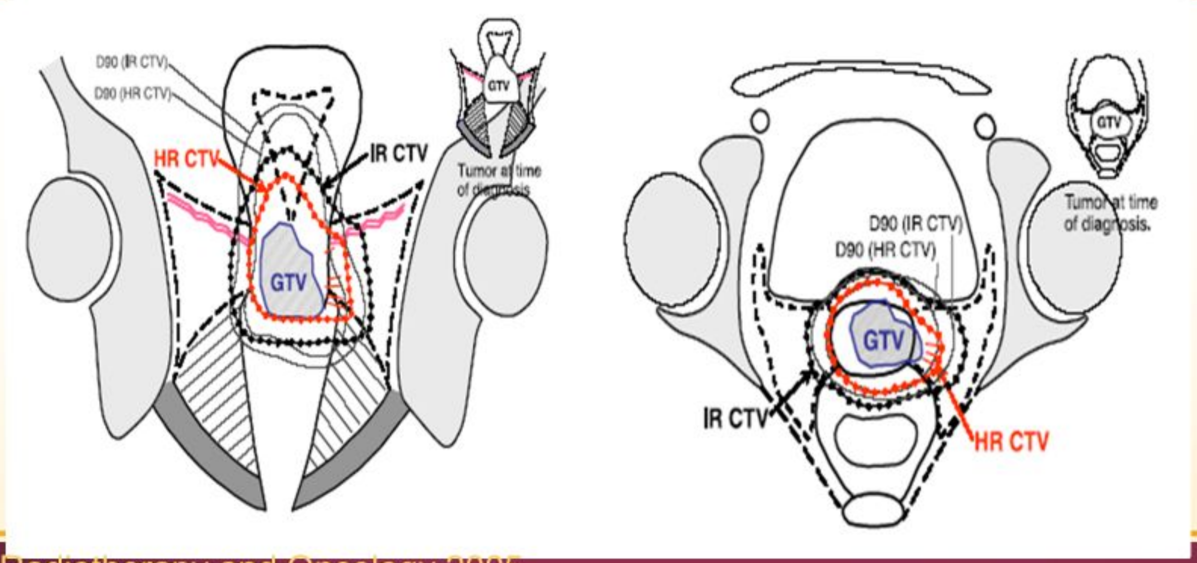


Courtesy Matt Harkenrider, MD

C. Haie-Meder et al. / Radiotherapy and Oncology 74 (2005) 235–245

MRI for Image Guided Brachytherapy





Courtesy
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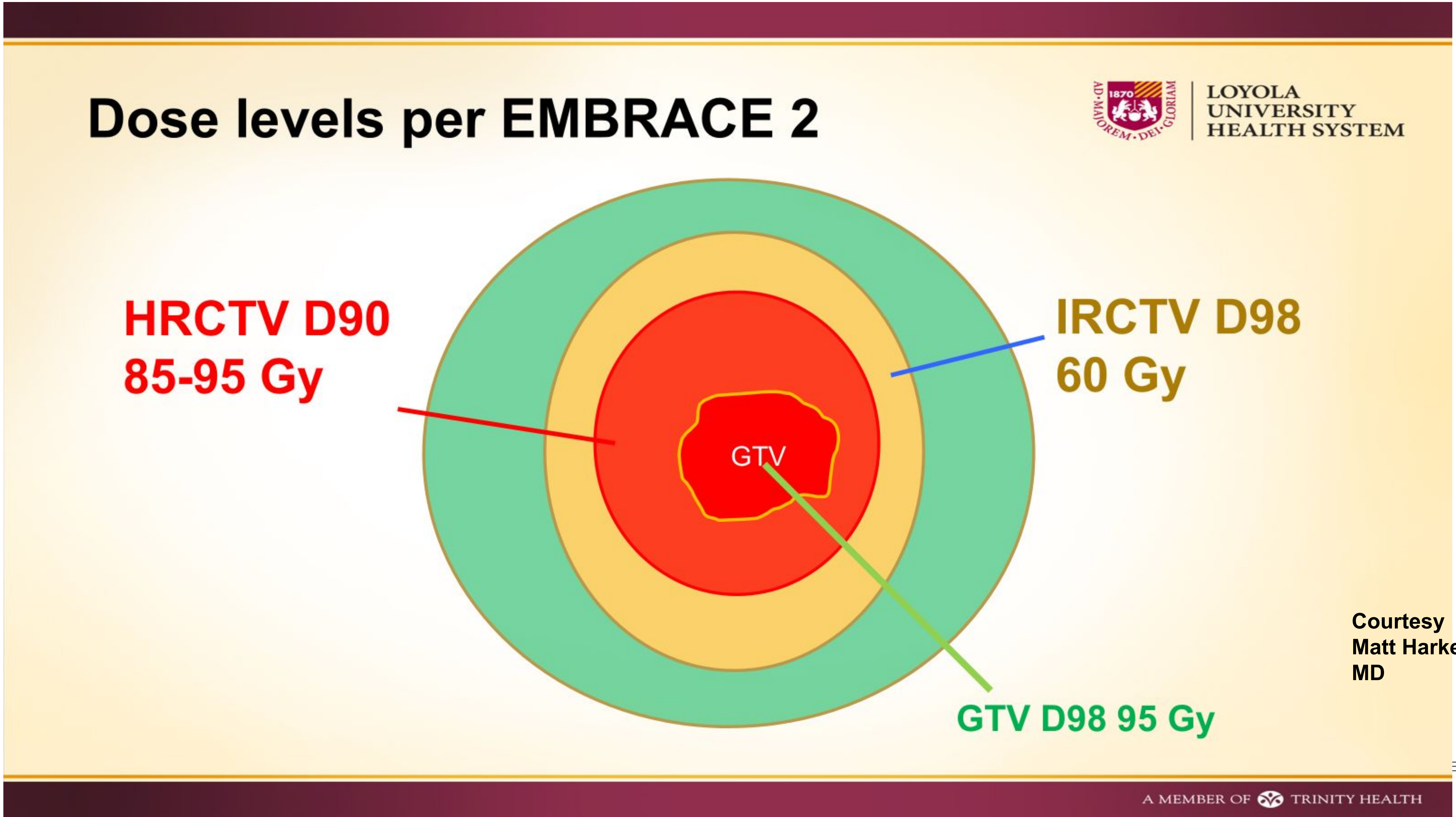
Cervical Cancer: MRI-Guided Brachytherapy and the EMBRACE / II Trials

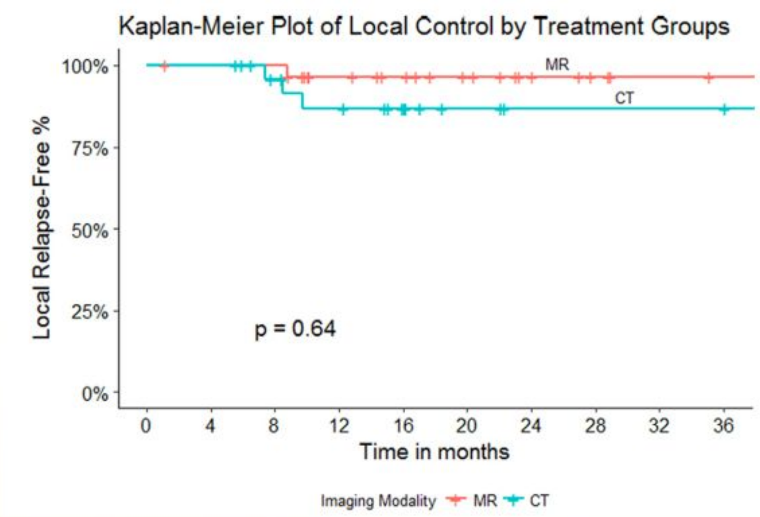


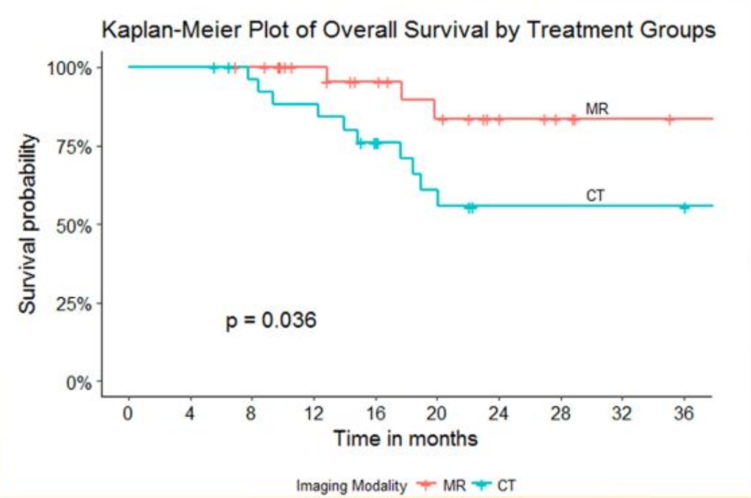
Courtesy
Matt Harkenrider, MD

Cervical Cancer: MRI-Guided Brachytherapy – MR vs CT

Comparison of outcomes for MR-guided versus CT-guided high-dose-rate interstitial brachytherapy in women with locally advanced carcinoma of the cervix☆

Sophia C. Kamran [a,*], Matthias M. Manuel [b,c,e], Linda P. Cho [b,c,f], Antonio L. Damato [b,c,g], Ehud J. Schmidt [d], Clare Tempany [d], Robert A. Cormack [b,c], Akila N. Viswanathan [b,c,h,**]





Courtesy
Matt Harkenrider, MD

Prostate Cancer: LDR and HDR Brachytherapy

LDR Brachytherapy (Low-Dose-Rate):

- Permanent seed implants, typically used for early-stage prostate cancer.
- **Imaging**: **Ultrasound or CT** used for real-time seed placement during treatment.

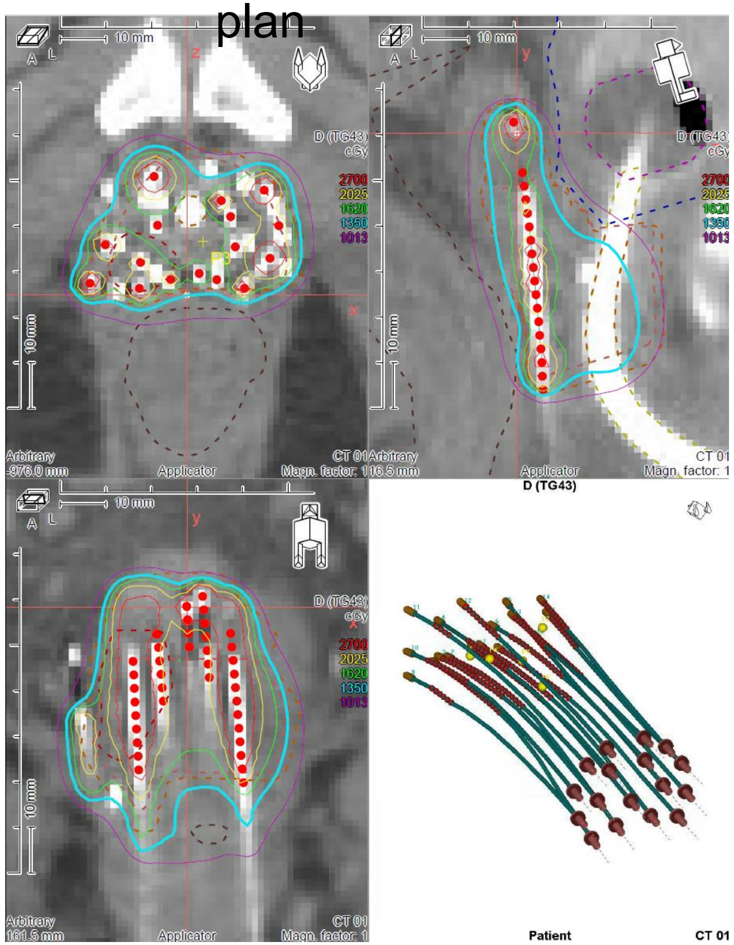
HDR Brachytherapy (High-Dose-Rate):

- Temporary placement of radioactive sources for high-dose precision.
- **Imaging**: **MRI, ultrasound, or CT** for applicator guidance and detailed treatment planning.

Role of Imaging:

- Ensures accurate placement of seeds or applicators, reducing complications and improving treatment outcomes.

HDR prostate plan



Prostate Cancer: Key Clinical Trials in Brachytherapy

- **ASCENDE-RT Trial**:
  - Combined HDR brachytherapy boost with EBRT.
  - **Imaging**: **MRI or CT** used for precise treatment planning and dose delivery in HDR.
  - **Outcome**: Improved progression-free survival in high-risk patients with imaging-guided HDR boost.
- **RTOG 0232 Trial**:
  - Compared LDR brachytherapy alone with LDR + EBRT.
  - **Imaging**: **Ultrasound and CT** guided accurate seed placement in LDR brachytherapy.
  - **Outcome**: Effective outcomes with brachytherapy alone in intermediate-risk patients.
- **FLAME Trial**:
  - Focal boost HDR brachytherapy for high-risk prostate cancer.
  - **Imaging**: **MRI-guided boost** allowed precise targeting of high-risk areas.
  - **Outcome**: Improved local control with no added toxicity from MRI-guided focal boosts.

Clinical Applications of IGRT in Brachytherapy

Head and Neck Cancers:

- Complex anatomy requires advanced imaging for precise applicator placement and dose distribution.

Breast Cancer:

- Partial breast irradiation using brachytherapy, often guided by ultrasound for applicator placement.

Skin Cancer:

- Surface brachytherapy is commonly used, with minimal imaging required, though ultrasound may be used for depth assessment.

Benefits of brachytherapy

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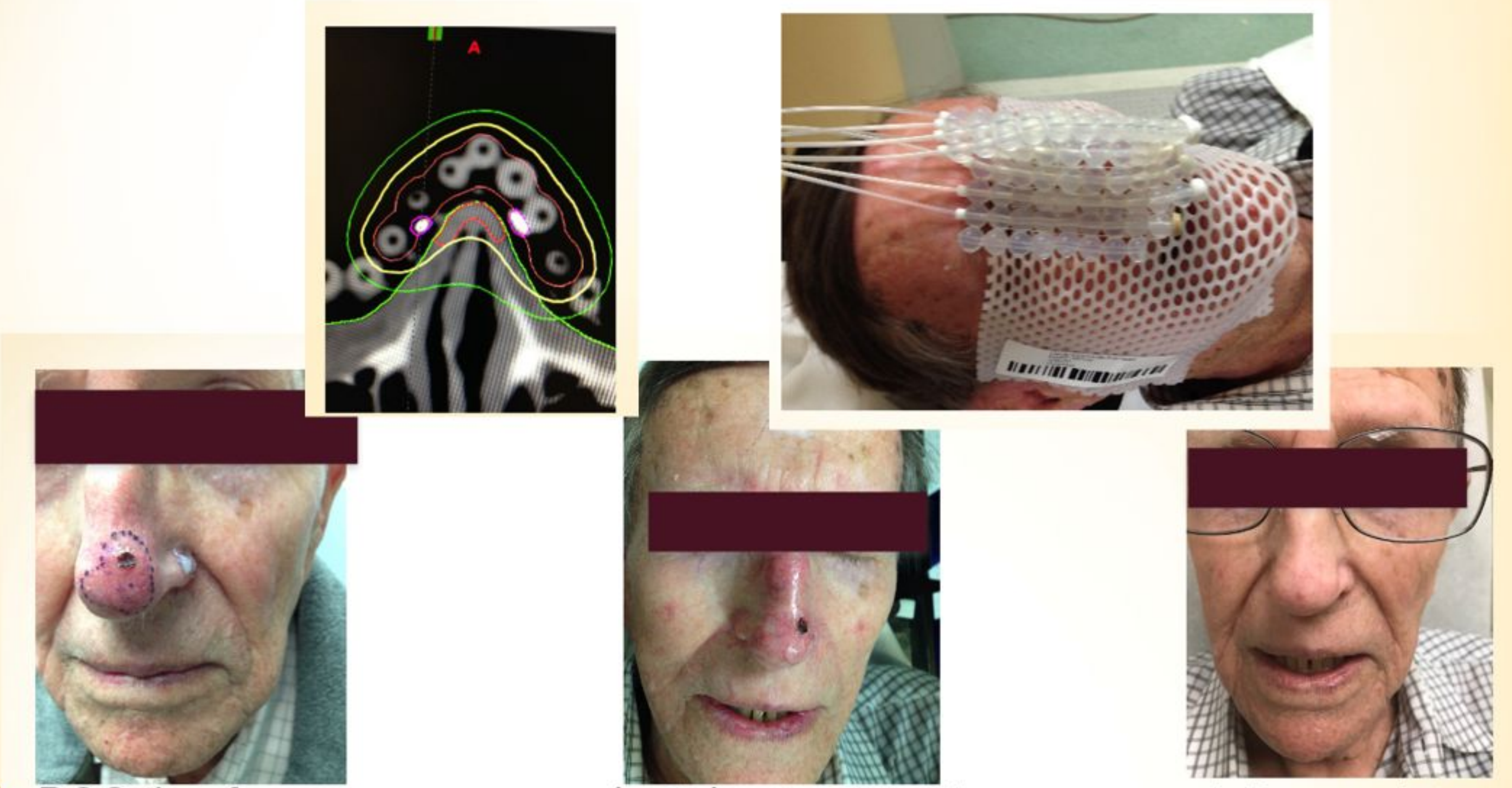
Skin cancer

- Excellent local control with organ preservation for non-melanomatous **skin cancer**



BCC tip of nose | last day treatment | 1.5 years later

Courtesy
Matt Harkenrider, MD

5. RADIATION PROTECTION AND DOSE REDUCTION

Radiation Protection and Dose Reduction in IGRT

Justification of Imaging:

- Imaging should be used only when clinically necessary to avoid unnecessary radiation exposure.

Key Factors for decision process on imaging use in brachytherapy:

- **Resources**: Availability and access to imaging modalities.
- **Feasibility**: Ability to visualize target and OARs accurately.
- **Operationality**: Integration of imaging into clinical workflow.
- **Benefits vs. Risks**: Balancing clinical benefits of imaging with radiation exposure risks.

Dose Optimization Techniques:

- Minimize radiation exposure by using non-ionizing modalities (MRI, ultrasound).
- Optimize imaging protocols to reduce frequency without compromising accuracy.

6. FUTURE DIRECTIONS IN IGRT FOR BRACHYTHERAPY

Future Directions in IGRT for Brachytherapy

Personalized Medicine:

- Adaptive treatments based on patient-specific anatomy and tumor response.
- Use of imaging data to continuously adjust the treatment plan.

Enhanced Imaging Modalities:

- Development of MRI-compatible applicators and advanced ultrasound technologies.
- Improved soft tissue visualization and dose accuracy.
- AI: development of synthetic MRI from CT for patients who cannot undergo MRI studies

Dose Calculation Models:

- **TG-43**: The standard for dose calculation assuming homogenous tissues and uniform geometry.
- **Advanced Models**: Incorporation of patient-specific anatomy using 3D imaging to account for tissue heterogeneity.
- **AAPM TG-186**: Introduction of heterogeneity corrections to improve dose accuracy in complex anatomical regions, considering different tissue densities.

Future Directions in IGRT for Brachytherapy

Enhanced Imaging Modalities:

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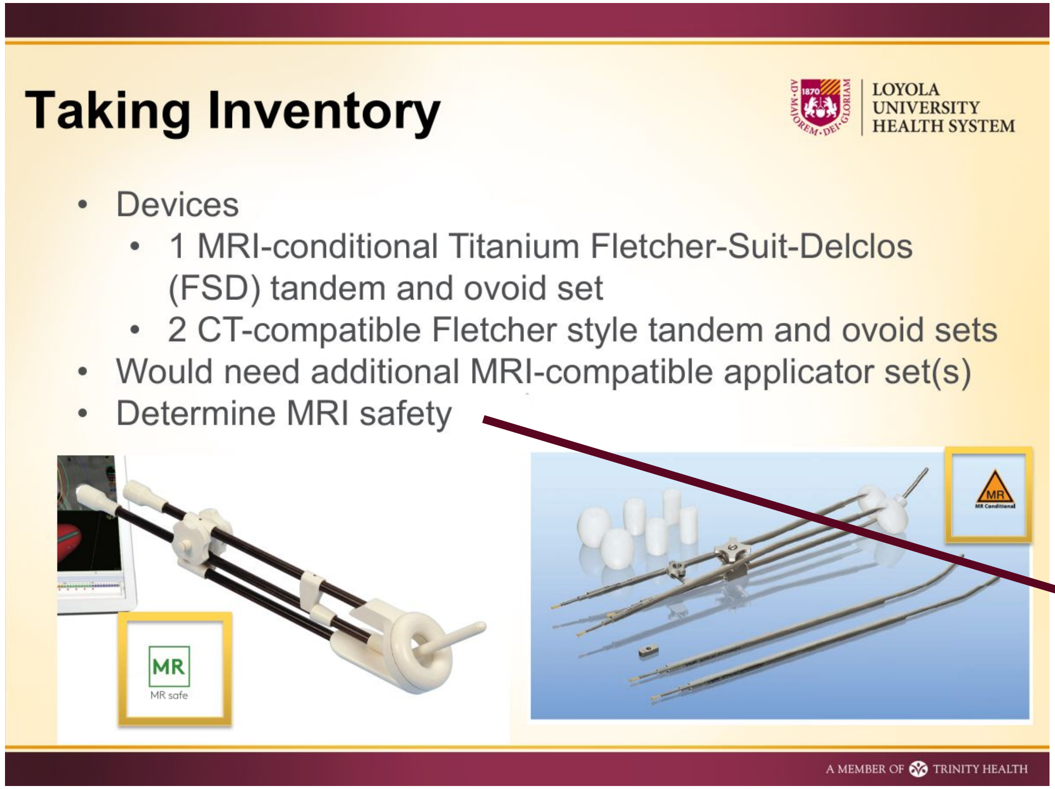

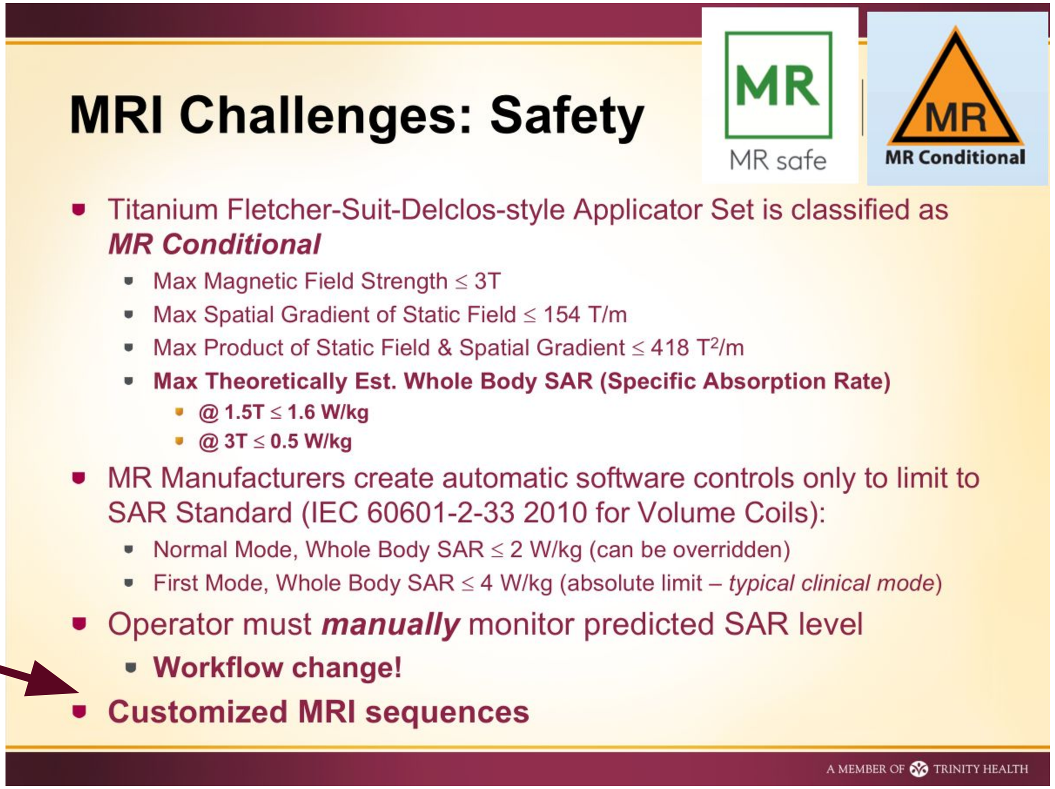

EMBRACE II Trial – Advancing MRI-Guided Brachytherapy for Cervical Cancer

Objective: The EMBRACE II trial builds on the success of the first EMBRACE trial, aiming to refine and optimize MRI-guided adaptive brachytherapy.

Key Focus:

- Standardizing MRI-based treatment protocols across centers.
- Improving local tumor control with optimized dose escalation □ ***ART element.***
- Reducing treatment-related toxicities by refining OAR sparing techniques.

Preliminary Findings:

- Continued improvements in local control.
- Significant progress in reducing severe side effects through optimized treatment planning.

STARPORT Trial – Exploring Stereotactic Adaptive Radiation for Prostate Cancer

Objective: The STARPORT trial is investigating the use of stereotactic adaptive radiation therapy (SABR) combined with brachytherapy for high-risk prostate cancer.

Key Focus:

- Combining stereotactic adaptive radiation with brachytherapy to improve tumor control.
- Use of advanced imaging techniques (e.g., MRI, CT) for real-time adaptation of treatment.
- Exploring the benefits of delivering higher radiation doses in a more targeted manner, with fewer treatments.

Preliminary Findings:

- Promising early data on tumor control and reduced toxicity.
- Enhanced precision with the integration of adaptive imaging techniques.

Challenge: combining doses from EBRT, BT, CT, Fluoro, etc…

7. CONCLUSION

Conclusion: Precision, Safety, and the Role of IGRT in Brachytherapy

IGRT Enhances Precision:

- Improves applicator placement and dose accuracy.
- Ensures treatment is adapted to patient anatomy and tumor response.

Balancing Imaging and Safety:

- Use imaging only when clinically necessary.
- Prioritize non-ionizing modalities where possible.

Key Takeaways and Future Directions in Brachytherapy

Brachytherapy's pivotal role in cancer treatment continues to evolve with advancements in imaging, dose calculation models, and clinical trials.

- **Imaging advancements** (e.g., MRI, CT, ultrasound) are key in ensuring accurate dose delivery and enhancing adaptive approaches in both **external beam radiotherapy (EBRT)** and brachytherapy.
- **Future directions** include refining dose models, as seen in the shift from **TG-43 to heterogeneous tissue models (TG-186)**, and further exploring the impact of clinical trials like **EMBRACE II** and **STARPORT** on broader cancer treatment strategies.
- Clinical trials like **EMBRACE II** and **STARPORT** highlight the importance of personalized, image-guided treatments to optimize outcomes and reduce toxicity.

THANK YOU ☺

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