Motion and Margins

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Middle
East
Federation of
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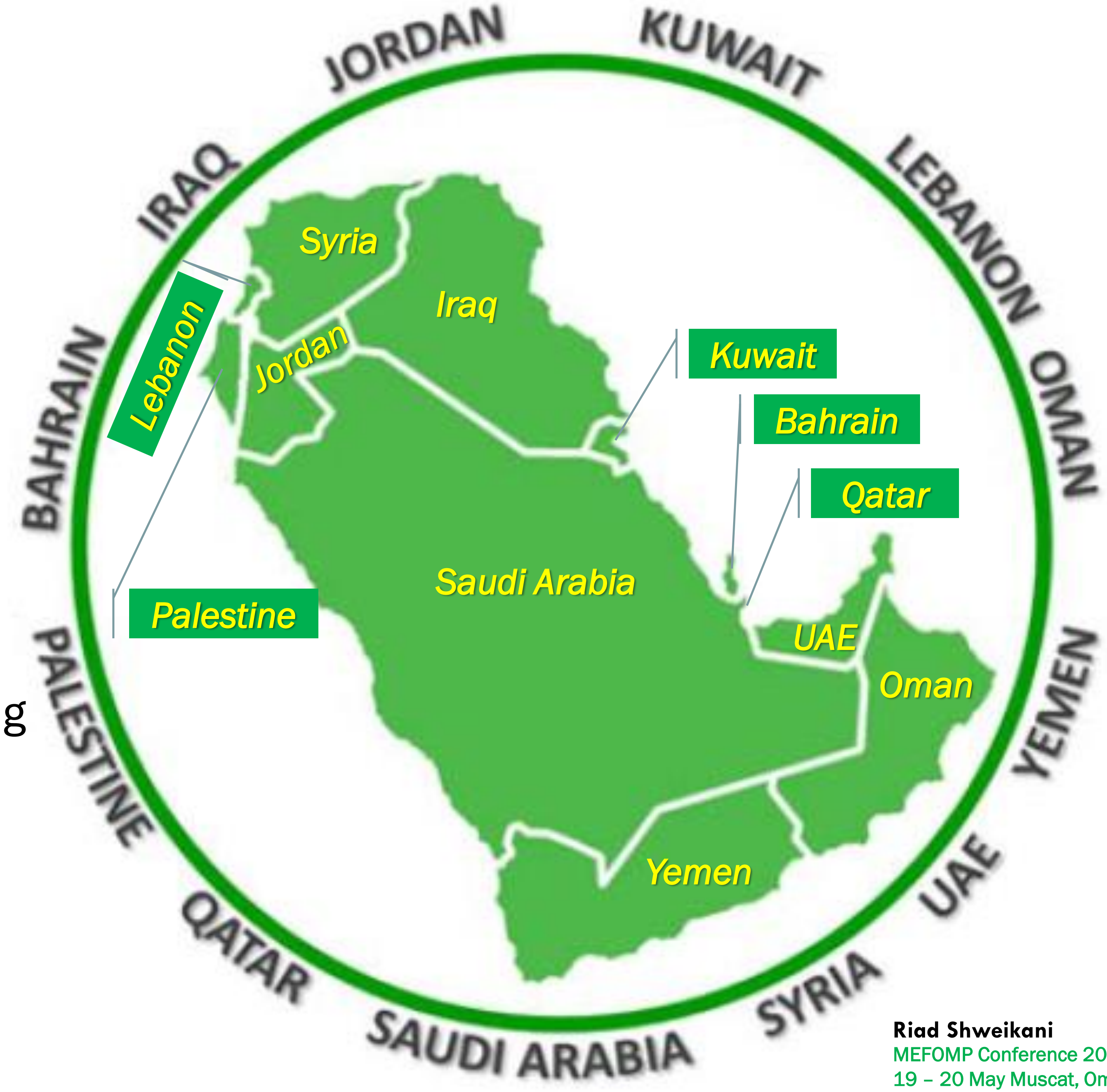
Medical
Physics

Established in 2009 with 12 participating countries

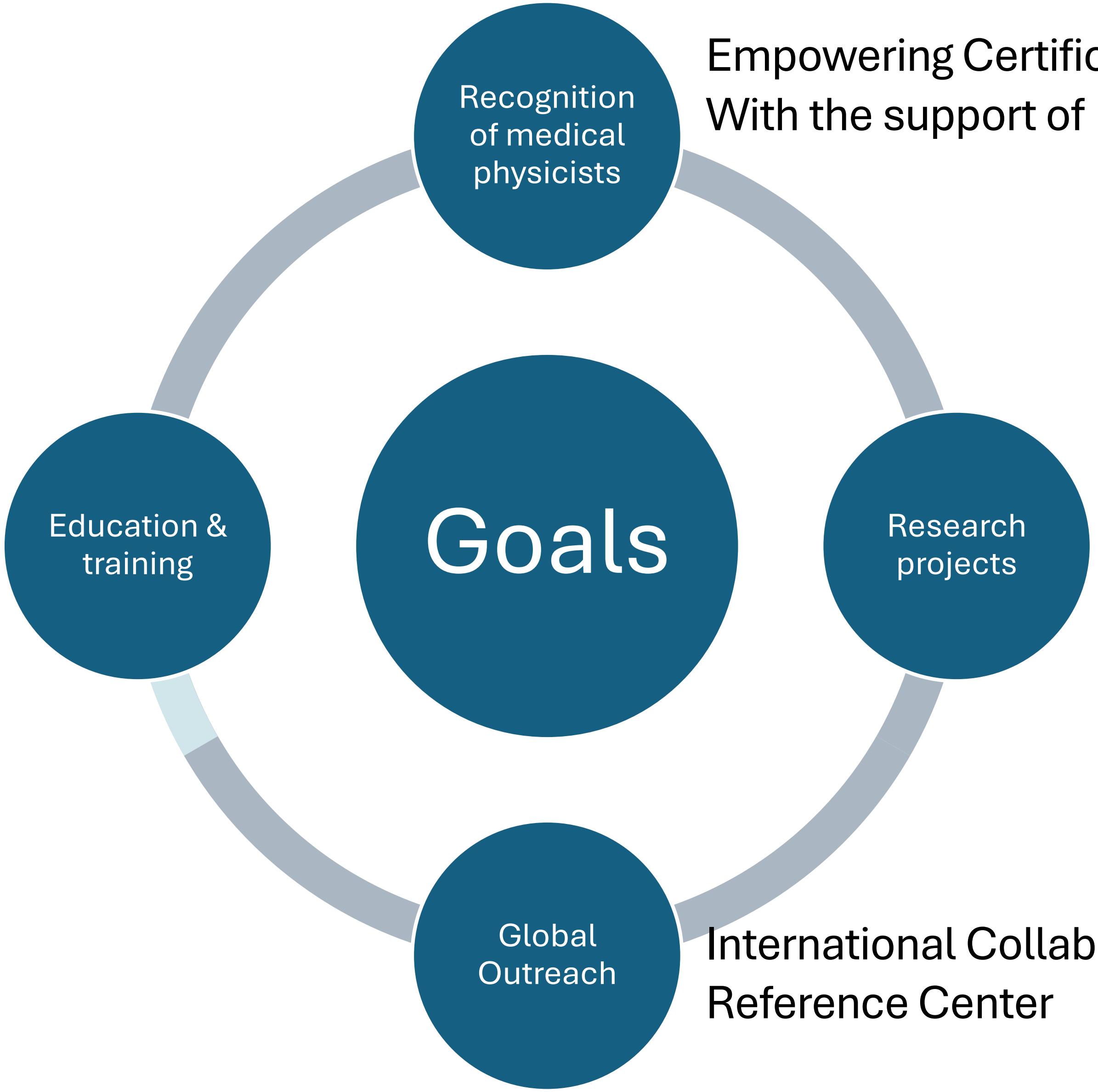
Goal: Enhance medical physics



Goals

Empowering Certification of Medical Physicists
With the support of IMCPB

Conferences
Workshops
Webinars



Recognizing Excellence
National effort
Regional ?

International Collaborations
Reference Center

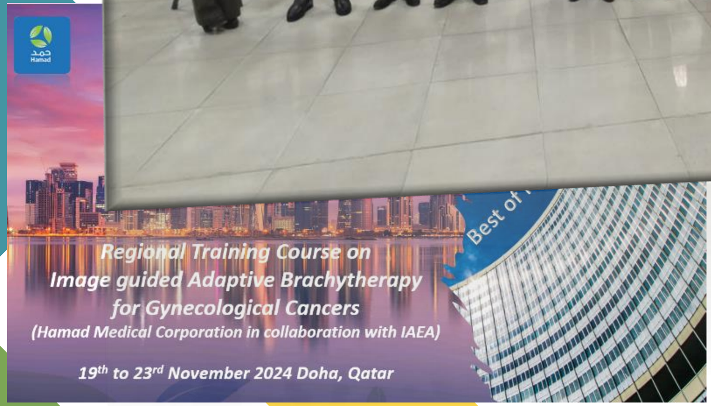
Conferences

- Biennial, Radiotherapy, diagnostic, Nuclear medicine
- Engagement of other medical specialties and allied health professionals

Workshops

- Run or endorsed by MEFOMP
- Radiotherapy, diagnostic, Nuclear medicine
- Different countries

Computed Tomography Workshop and Quality Control in Amman, Jordan



Global Outreach

International Collaborations

IOMP

The Abdus Salam International Centre for Theoretical Physics (ICTP)

MESTRO
Middle East Society for Therapeutic Radiation Oncology

ESTRO
European Society for RADIOTHERAPY & ONCOLOGY

AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE

EFOMP
EUROPEAN FEDERATION OF ORGANISATIONS FOR MEDICAL PHYSICS

IAEA Anchor center

- Experienced cancer centres working with IAEA
- Support their region through training & networking
- Provide mentorship and expertise in RT & imaging

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Rays of Hope Anchor Centres

King Hussein Cancer Foundation
King Hussein Cancer Center

Varian

Reference center

Vision RT

Abu Dhabi – UAE

28^{th} International Conference Medical Physics (ICMP) 2027

Agenda

- Introduction
- Types and Sources of Motion
- Concept of Margins in Radiotherapy
- Motion Management Strategies
- Online Adaptive Radiotherapy(oART): Margin and concepts
- Summary & Take-home Messages

Introduction

- **Goal of Radiotherapy**: Deliver prescribed dose precisely to the target, minimize dose to surrounding healthy tissues.
- **Reality:** The anatomy is not static — patients breathe, organs move and tumors can shift.
- **Consequence:** Motion introduces geometric uncertainties that affect dose delivery accuracy

Motion affects both **target coverage and normal tissue sparing.** Understanding and managing the motion, it is essential to treatment success.

Introduction

- **Margin:**

Margins are a practical solution to manage **uncertainty from motion** and ensure adequate **target dose coverage.**

- Tight Margin → Underdosage of Target

- Loose Margin → Higher dose to surrounding normal tissues

"Margins in radiotherapy always represent a trade-off:

Deliver the dose precisely to the target, minimize dose to surrounding healthy tissues"

Types and Sources of Motions

- Types of Motion in Radiotherapy:

❑ **<u>Patient Setup Errors</u>:**

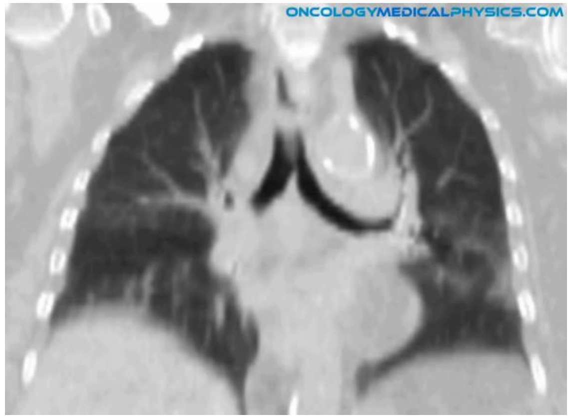
These errors occur when the patient's position during treatment differs from the planned position during imaging and planning.

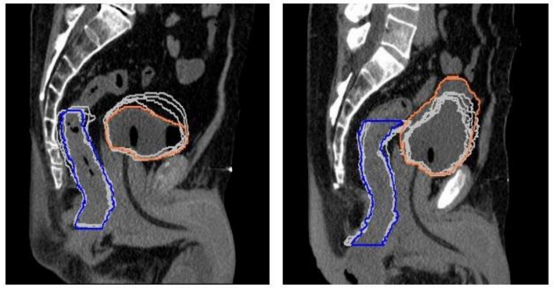
❑ **<u>Intra-fraction Motion</u>**

Such as Respiration, swallowing, involuntary muscle movements and setup shift during the treatment

❑ **<u>Inter-fraction Motion</u>**

This refers to changes in the patient's position or organ position between treatment sessions, such as variations in bowel or bladder filling, body weight, changing in breathing pattern.





Types and Sources of Motions

- Source of Motions in Radiotherapy:

❑ **Respiratory Motion:**

Breathing causes significant motion of organs in the chest and abdomen, particularly the lungs, liver, and kidneys.

❑ **Cardiac Motion:**

The heart's contractions and relaxations can cause motion of surrounding tissues and organs.

❑ **Gastrointestinal Motion:**

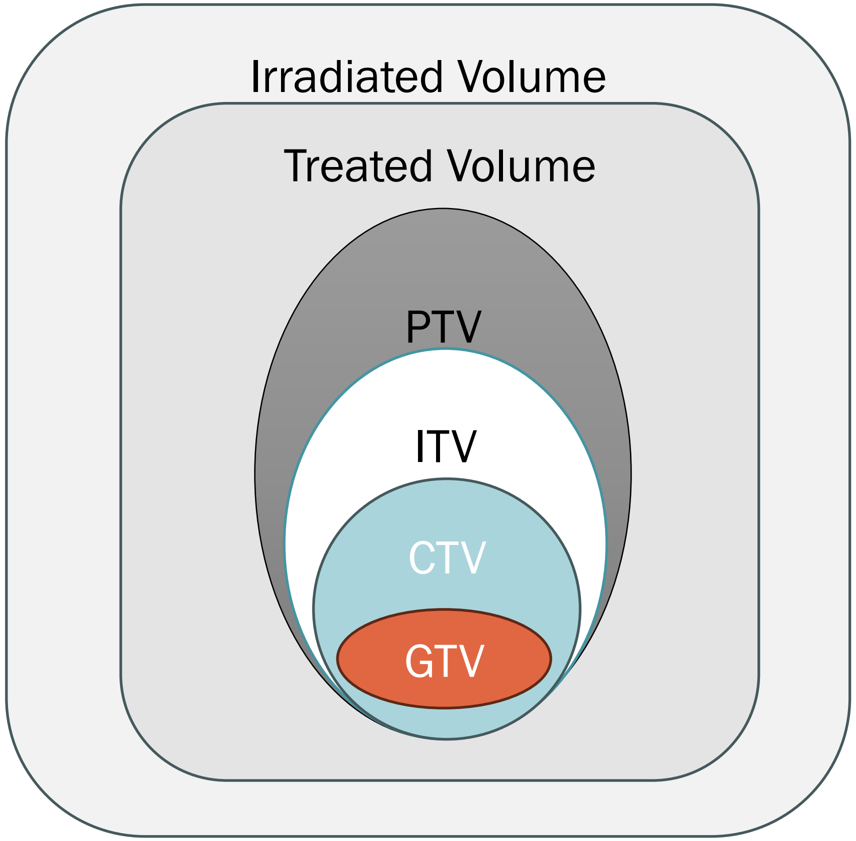
Filling and emptying of the stomach and intestines, as well as bowel movements, can cause movement of adjacent organs.

❑ **Patient Posture and Positioning:**

Changes in patient posture on the treatment table can lead to variations in organ position

Concept of Margins in Radiotherapy

- Volume definition in RT (ICRU-62):
- **Gross Tumor Volume (GTV):** This is the macroscopic extent of the tumor that can be seen or imaged.
- **Clinical Target Volume (CTV):** Encompasses the GTV and any potential microscopic spread of cancer cells.
- **Internal Target Volume (ITV):** Accounts for variations in the CTV's position and shape due to internal organ motion (e.g., breathing).
- **Planning Target Volume (PTV):** This is the CTV plus margins to account for uncertainties in patient positioning and setup during treatment
- **Treated Volume:** Tissue volume that should receive the dose to make sure PTV is receiving the prescribe dose
- **Irradiated Volume:** • Tissue volume that receives a dose that is considered significant in relation to normal tissue tolerance(usually more than 50% of Prescribe dose).
- Organs at Risk & Planning Organ at Risk Volume (PRV): OAR + uncertainty margins
- Remaining Volume at Risk (RVR): OAR not overlapping with PTV, or not receiving high dose, but is still at potential risk of receiving unintended radiation dose due to treatment delivery uncertainties, dose spill, or proximity to the target.

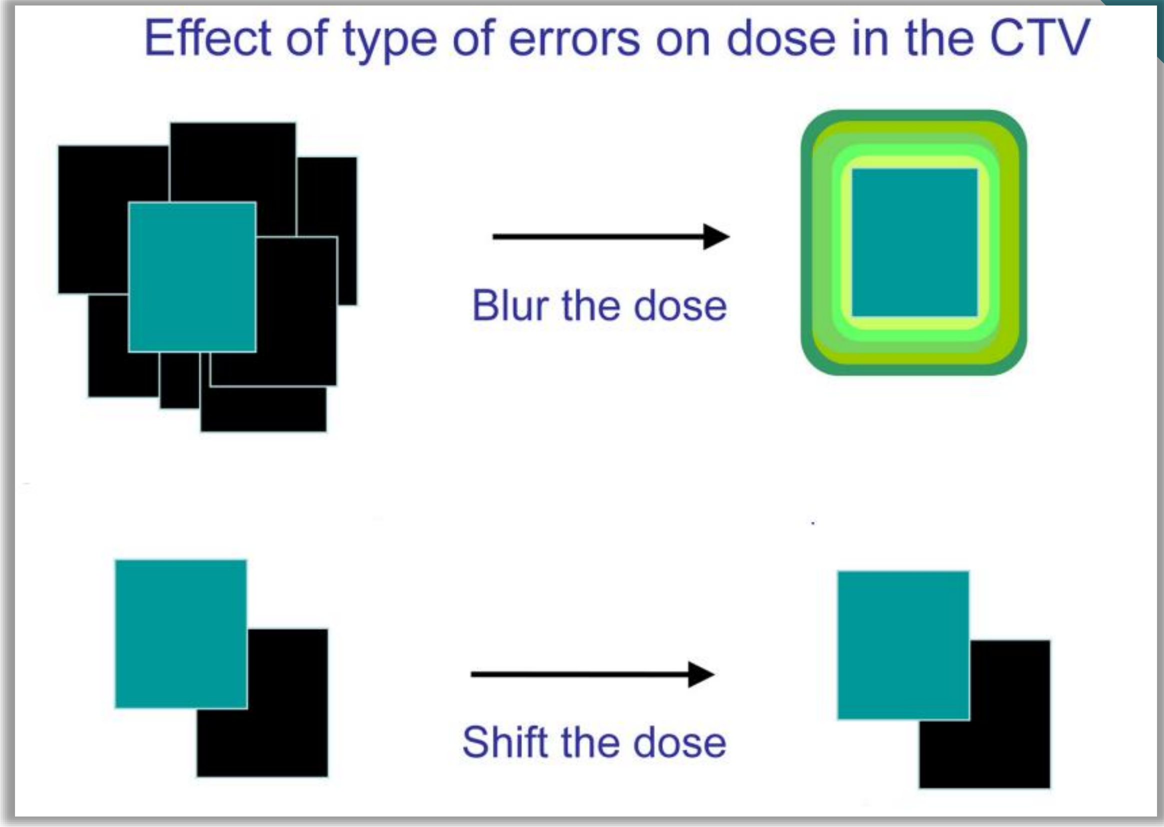


Concept of Margins in Radiotherapy

Each type of Motion can have **Systematic** and **Random error:**

Random error (σ): A random error is a variable deviation that changes in magnitude and direction between treatment fractions. These are day-to-day variations.

Systematic error (Σ): A systematic error is a consistent deviation that occurs in the same direction and magnitude throughout the entire treatment course.



Recipes for margin calculation in RT

- **PTV:** (CTV/ITV) + Setup Margin (SM)

How can we calculate SM ?

The margin should be added to the CTV/ITV to make sure that 90% of the patients will receive the 95% prescribed dose

PTV margin= **2.0** Σ **+ 0.7** σ (Stroom et al, 1999)
PTV margin= **2.5** Σ **+ 0.7** σ (Van Herk et al, 2000)

Σ = Standard Deviation of all systematic error combined quadratically
σ = Standard Deviation of all random error combined quadratically

✓ Van Herk M., Remeijer P., Rasch C., Lebesque J.V. The probability of correct target dosage: Dose-population histograms for deriving treatment margins in radiotherapy. Int J Radiat Oncol Biol Phys. 2000

✓ **stroom JC, de Boer HC, Huizenga H, Visser AG.** *Inclusion of geometrical uncertainties in radiotherapy treatment planning by means of coverage probability.* Int J Radiat Oncol Biol Phys. 1999 Mar 1;43(4):905–919.

Recipes for margin calculation in RT

PRV: (Serial OAR) + Confidence Margine

Margine recipe to spare the OAR for 90% of the patients

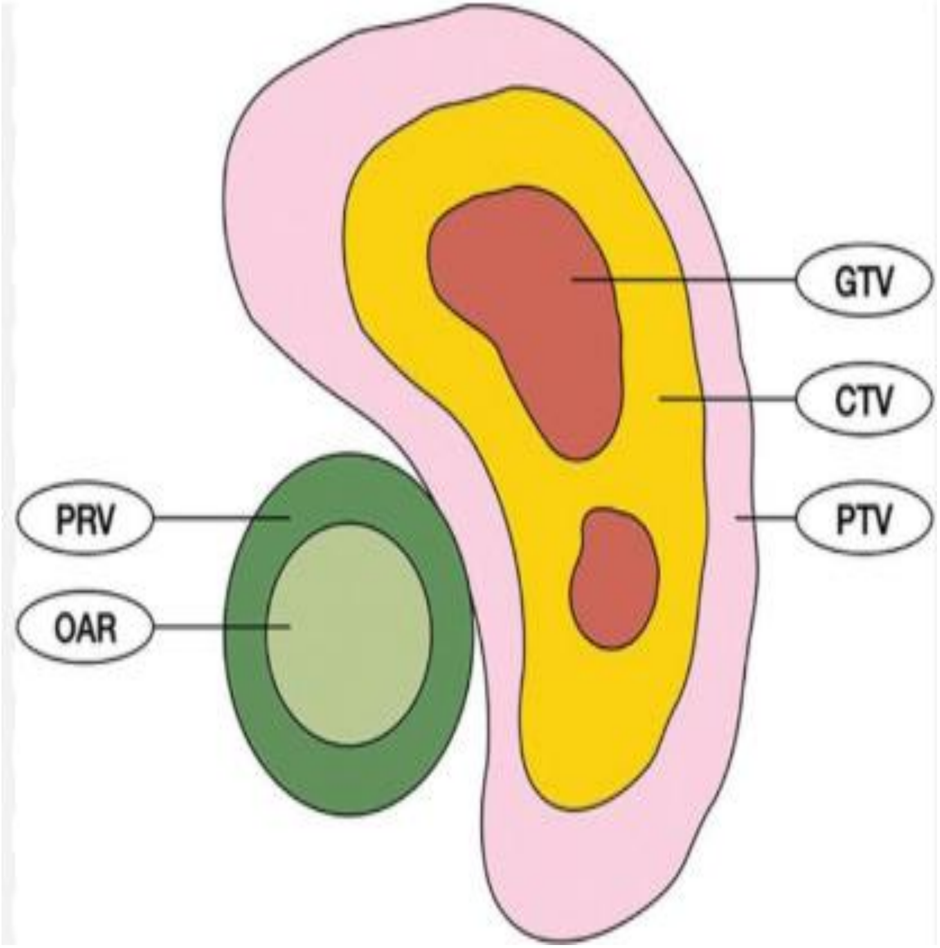
PRV margin= $1.64\ \Sigma + 0.7\ \sigma$

PRV margin often uses statistical Z-score whereas,

PTV Margin uses empirical method based on Monte Carlo simulation

PRV $\longrightarrow$ Aim simple Spatial Avoidance

PTV $\longrightarrow$ Aimimg Dose Coverage Probability



Example of Geometrical Margin Calculation in RT

Fraction	Patient 1	Patient 2	Patient 3	Patient 4
Fraction 1	2 mm	4 mm	1 mm	3 mm
Fraction 2	1 mm	-2 mm	-1 mm	-3 mm
Fraction 3	1 mm	2 mm	2 mm	-2 mm
Fraction 4	1 mm	0	2 mm	1
Mean	1.25 mm	1 mm	1 mm	-0.25 mm
SD	0.75	2.58	1.41	2.75

Mean	0.75
SD (Σ)	0.68

RMS of SDs (σ)	1.36

PTV margin= 2.5 (0.68) + 0.7(1.36) = 2.65 mm

Concept of Margins in Radiotherapy

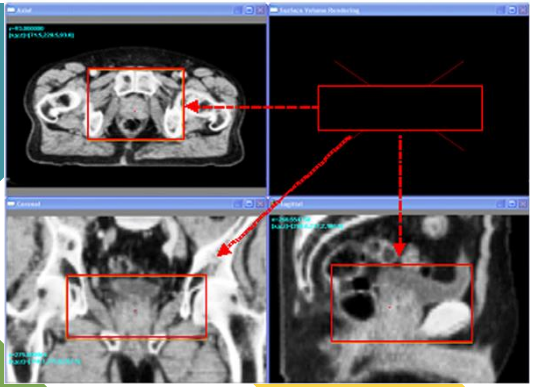
Examining Margin Reduction and Its Impact on Dose Distribution for Prostate Cancer Patients Undergoing Daily Cone-Beam Computed Tomography

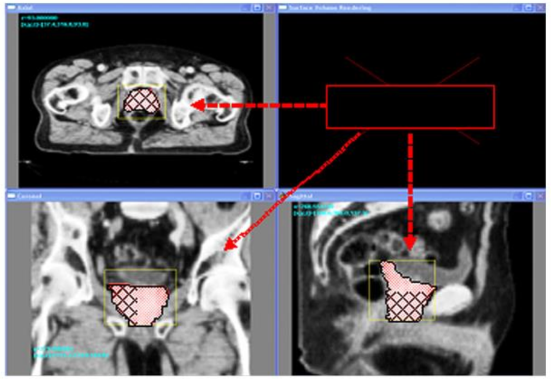
Rabih Hammoud M.S., Samir H. Patel M.D., Deepak Pradhan M.D., Jinkoo Kim M.S., Harrison Guan Ph.D., Shidong Li Ph.D. and Benjamin Movsas M.D.

International Journal of Radiation Oncology, Biology, Physics, 2008-05-01, Volume 71, Issue 1, Pages 265-273,

Materials & Methods

- 5 prostate patients, 140 CBCTs
- Two IMRT margins: 10/6 mm vs 5/3 mm
- Daily CBCT + bony alignment + rectal monitoring
- Dose recalculated on CBCT with inhomogeneity correction
- In-house 3D image registration (Center Of Mass COM & Maximal Border Displacement MBD analysis)





Conclusion

- 10/6 margin is adequate with daily guidance
- 5/3 margin reduces bladder/rectum dose by 30–50% but increases geometric miss risk
- Soft-tissue registration enables smaller margins - Daily CBCT supports precise targeting and toxicity reduction.

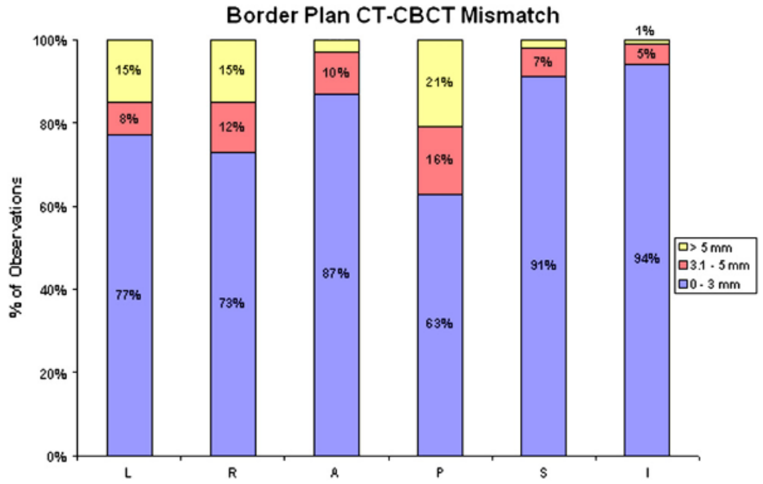


Fig. 7. Percentage of observations of maximal border displacement (MBD) registrations that fall within 0–3 mm, 3.1–5 mm, and >5 mm. CBCT = cone-beam computed tomography.

Margins: Biological Considerations

Biological Margin: Extra margin added based on **tumor biology**, such as cell density, hypoxia, and radio resistance

Why Biological Margine needed: To Ensure the tumor receives the **biologically effective dose** needed to achieve **tumor control**

In Addition To Physical Margin, We need Biological Margine As well:

CTV + Physical Margin ⟶ PTV
CTV + Biological Consideration ⟶ "Biological PTV" (bioPTV)

Final margin should ideally combine both **geometric** and **biological** factors for optimal treatment.

Margins: Biological Considerations

There is no any specific formula to determine the Biological Margin

Study	Consideration	Recommendation
Van Herk et al. (2000, 2002) – Prostate Cancer Example	Developed a margin recipe based on TCP and EUD analysis.	They recommended 3mm margin as biological Margine ($2.5\Sigma + 0.7\sigma + 3$ mm)
Bentzen et al. (2003)	Hypoxia Considerations	CTV has hypoxic subregion, expand margin around it by 3–5 mm to ensure control
Guckenberger et al. (2011) – SBRT and Tumor Control	Studied lung SBRT and effect of tumor cell density gradients	Found that a 2 mm increase in margin can compensate for biological uncertainties

Concept of Margins in Radiotherapy

- Influence of margins on volume:

Given the volume of sphere:

$$V= \frac{4}{3} \pi r^3$$

Reduction of CTV-PTV margin from 2.0 cr … n around a spherical CTV with a diameter of 5.0 cm results in a dec… e of the irradiated surrounding healthy issue from 316cm^3 t…

How can we reduce the CTV-PTV Margin ??

Motion Management Strategies to Reduce Margin

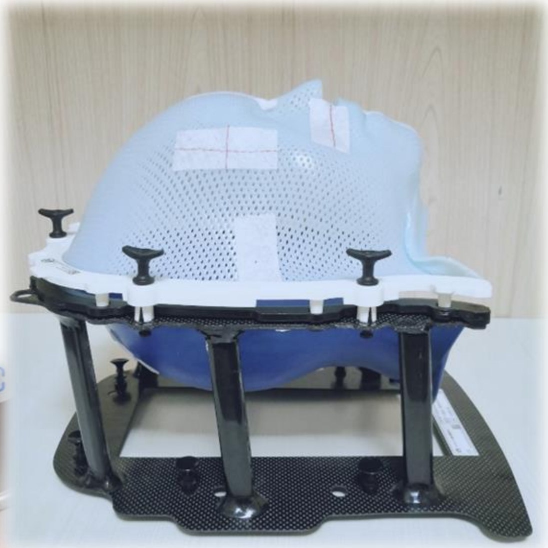
1- Immobilization System and Patient positioning:

One of the most important potential sources of variation is positional changes in the target or surrounding tissue (inter and intra-fraction).

- ❑ **Using Body frame, Brain frame, Vacuum Bags and .....**

- ❑ **Comfortable and reproducible positioning.**

- ↓ Setup uncertainty, ↑ Reproducibility → Less setup margin needed

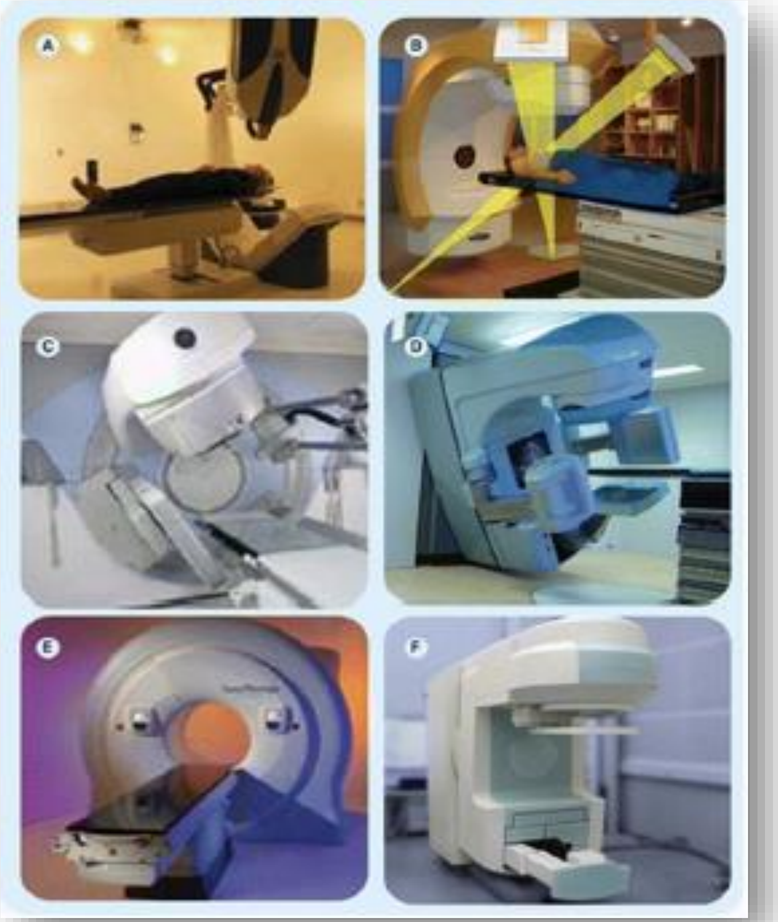


Motion Management Strategies to Reduce Margin

2- Image Guided Radiation Therapy (IGRT):

Setup Margine Can be reduced by using in-room imaging tools such:

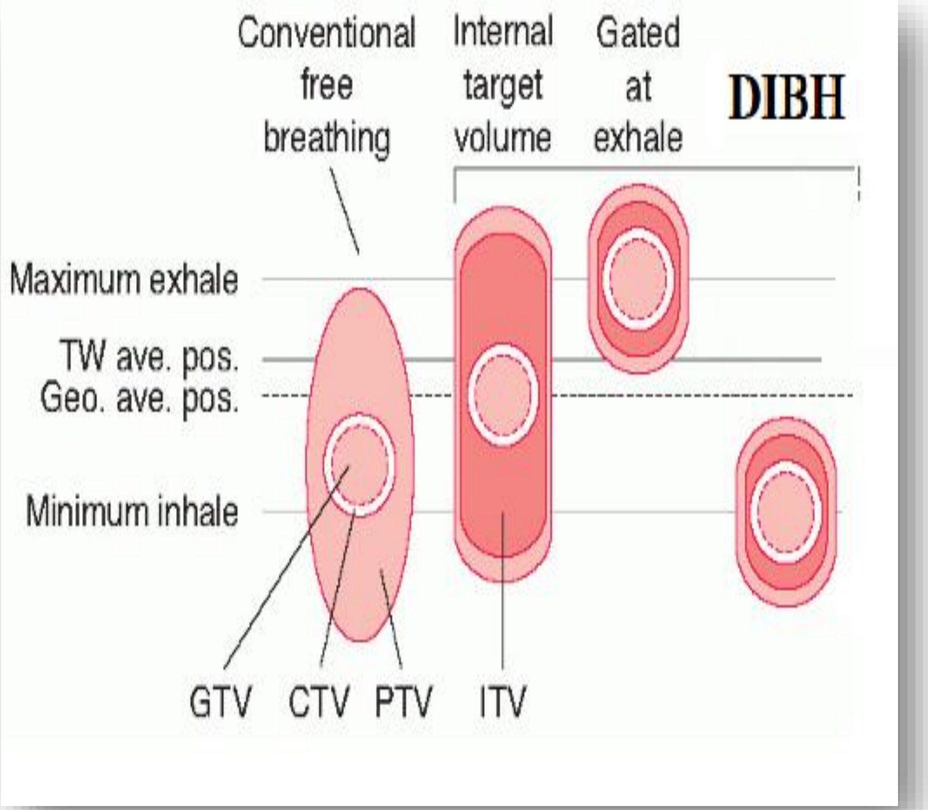
- 2-D/3-D and 4-D System(e.g, EPID, CBCT and 4D CBCT)
- External Fiducial (e.g, Exac Trac)
- Internal fiducial (e.g, Calypso)



Motion Management Strategies to Reduce Margin

3- Respiratory Motion Management technique

- 4-DCT
- Respiratory gating systems (ABC, RPM, SGRT systems)
- Tracking system (CK)
- Abdominal compressor



Online Adaptive Radiotherapy(oART): Margine and concepts

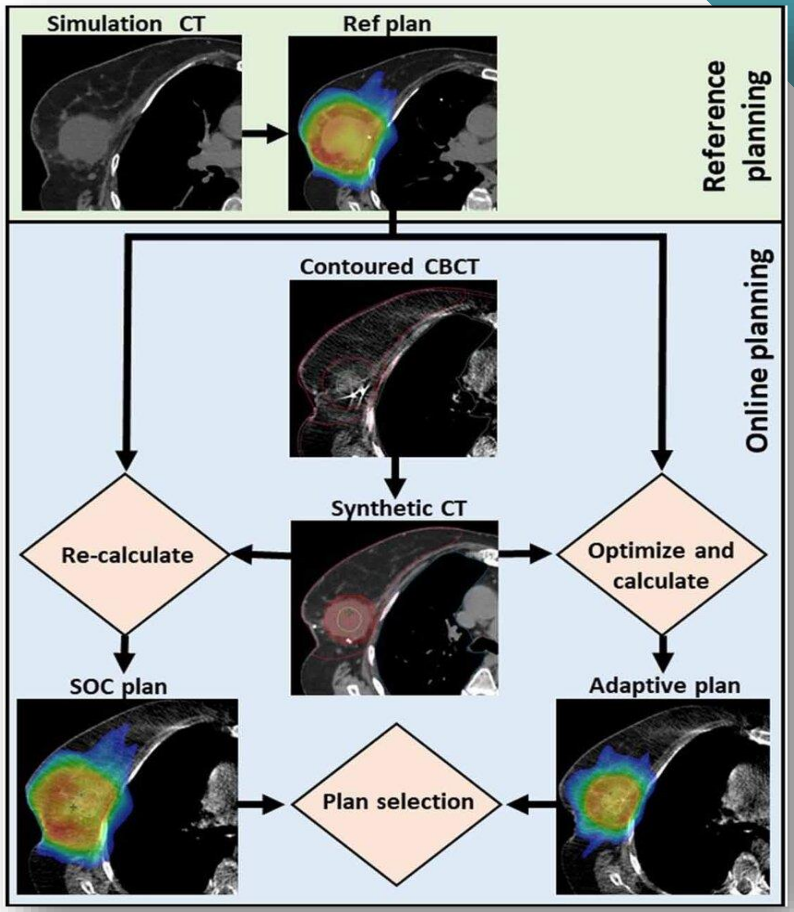
What is oART?

- **Daily adaptation of the treatment plan** based on the patient's anatomy of the day**.**

- Ethos (Varian) and MR-LINAC(Elekta) and Recently EVO (Elekta)

- Quik overview of online adaptive radiot...

oART Aims to **account for anatomical changes** such as tumor shrinkage, organ motion, and variations in filling (bladder, rectum, etc.)



Online Adaptive Radiotherapy(oART): Margine and concepts

Intrafraction Motion and Margin Assessment for Ethos Online Adaptive Radiotherapy Treatments of the Prostate and Seminal Vesicles

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- Study Example:
- Analyzed 65 treatment fractions from 13 patients using Varian Ethos.
- On-board CBCT scans before and during each fraction were used to assess intrafraction motion.
- Established that with verification imaging, PTV margins of **4 mm (prostate)** and **5 mm (seminal vesicles)** provided ≥95% coverage in over 90% of fractions— outperforming traditional IGRT with **7 mm margins.**
- Simulated adapted Ethos protocol showed better CTV coverage than a non-adaptive workflow using larger margins

Online Adaptive Radiotherapy(oART)

Impact on Margins:

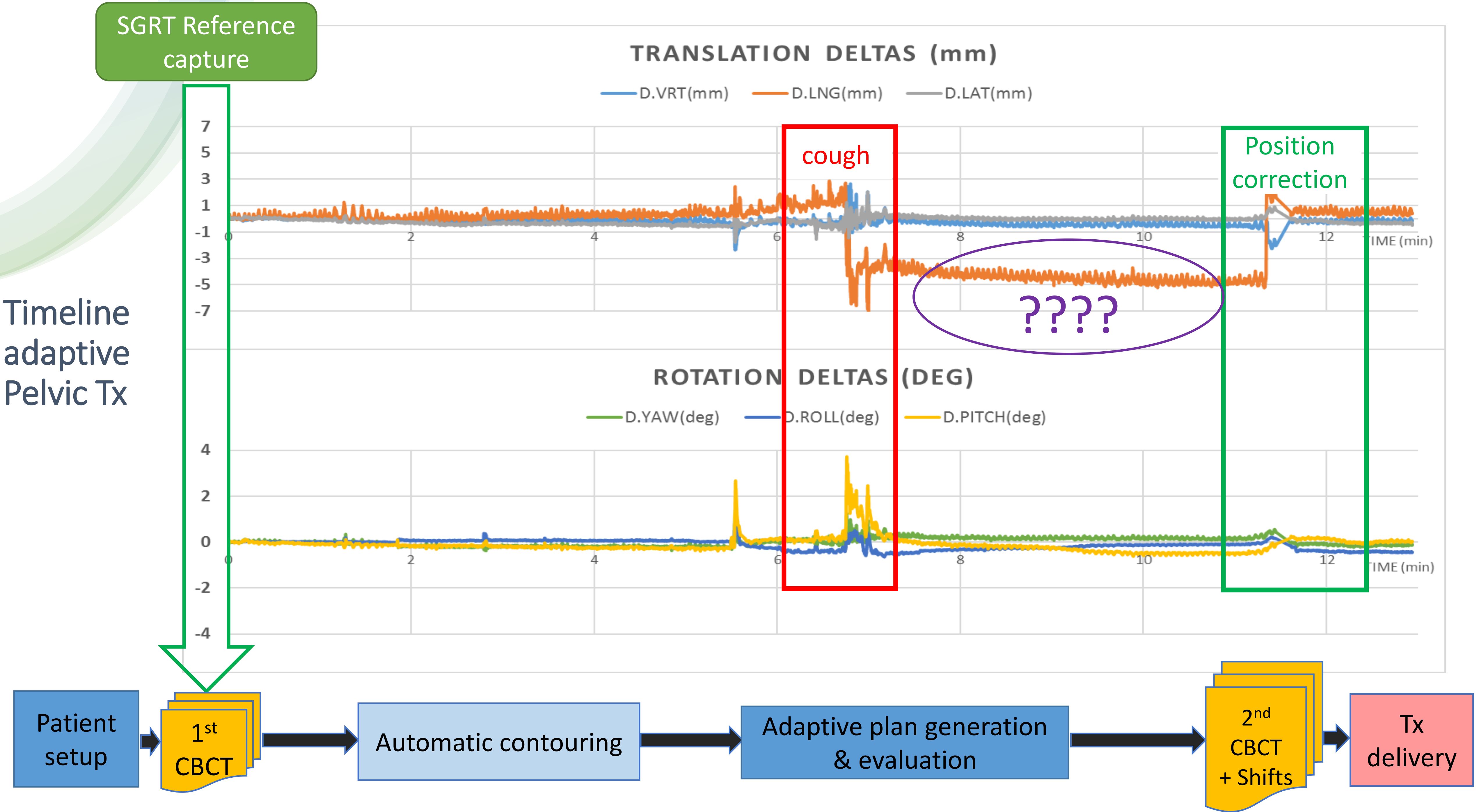
Traditional Planning	OART
Larger PTV margin	Reduced PTV margin
Account for inter-fraction variability	Account for daily anatomy
Relies on population-Based margin	Patient-specific daily adaptation
Less Precise dose to target and OAR	Increase sparing of OARs, Better target conformity

Result:
Smaller margins ➔ Better OAR sparing ➔ Potential dose escalation / toxicity reduction

Maintaining Accuracy with SGRT during oART

- SGRT ensures accurate setup and continuous monitoring on bore-based linacs (e.g., Ethos)
- It can help detect patient drift during extended adaptive workflows
- Potential reduction for repeated imaging

Timeline adaptive Pelvic Tx



Maintaining Accuracy with SGRT during oART

- SGRT ensures accurate setup and continuous monitoring on bore-based linacs (e.g., Ethos)
- It can help detect patient drift during extended adaptive workflows
- Potential reduction for repeated imaging

Conclusion

- ✅ **Margins remain essential** to account for geometric uncertainties in radiotherapy.
- ✅ **Systematic errors** contribute most significantly to required margins.
- ✅ **Traditional approaches** require larger margins to safeguard against setup and anatomical variations.
- ✅ **Motion management strategies** (e.g., IGRT, immobilization, gating) can effectively reduce margins.
- ✅ **Online Adaptive Radiotherapy (oART)** allows:

  - Daily adaptation to patient anatomy.
  - Significant **margin reduction**
  - Improved **target coverage** and **OAR sparing.**
  - Potential for **dose escalation** or **toxicity reduction**

Thank you

- AhaSlides - The power of engagement

💡 *"If the link fails, don't panic… we'll just continue the quiz old-school, right here on the slides!"*

QUIZ TIME

Q1. Which of the following is a main consequence of motion during radiotherapy?

a) Increased patient comfort

b) Reduced treatment time

c) Geometric uncertainties affecting dose delivery

d) Improved tumor visualization

Q2. In radiotherapy margins, what is the risk of using a tight margin?

a) Underdosage of the target

b) Higher dose to normal tissues

c) Better OAR sparing

d) Improved setup reproducibility

QUIZ TIME

Q3. Which type of motion refers to variations between treatment sessions?

a) Patient setup error

b) Respiratory motion

c) Intrafraction motion

d) Interfraction motion ✓

Q4. According to Van Herk's margin recipe, the PTV margin equals:

a) $2.0\,\Sigma + 0.7\,\sigma$

b) $2.5\,\Sigma + 0.7\,\sigma$ ✓

c) $3.0\,\Sigma + \sigma$

d) $1.64\,\Sigma + 0.7\,\sigma$

QUIZ TIME

Q5. Which is a respiratory motion management technique?

a) CBCT

b) Immobilization with vacuum bags

c) Fiducial markers

d) 4D-CT

Q6. In Ethos oART prostate workflows, what margin change was observed?

a) Elimination of imaging

b) Higher treatment time without dosimetric gain

c) Margin reduction from 7 mm to ~4 mm

d) Increased systematic error

QUIZ TIME

Q7. Why might a biological margin be added?

a) To increase setup reproducibility

b) To account for hypoxia/radioresistance and cell-density factors

c) To compensate for equipment malfunction

d) To reduce imaging frequency