Adaptive SBRT for Prostate Cancer

Experience with Ethos: Where Prostate SBRT Stands to Gain?

C-M Charlie Ma, Ph.D.

Department of Radiation Oncology

FCCC, Philadelphia, PA 19111

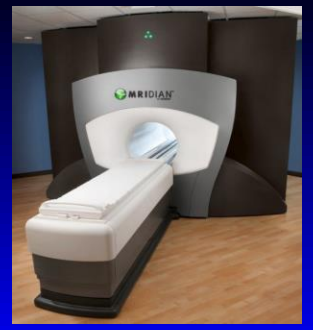
Educational Objectives

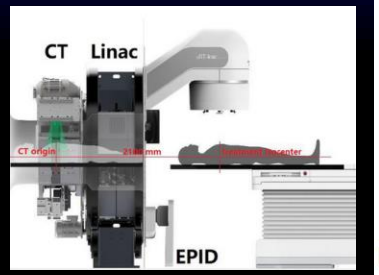
- Adaptive radiotherapy (ART) machines
- ART workflows and techniques
- Fox Chase experience with CBCT-based ART
- Preliminary results of adaptive SBRT for prostate
- Technical challenges and clinical considerations

Adaptive Radiotherapy Systems

Available ART machines

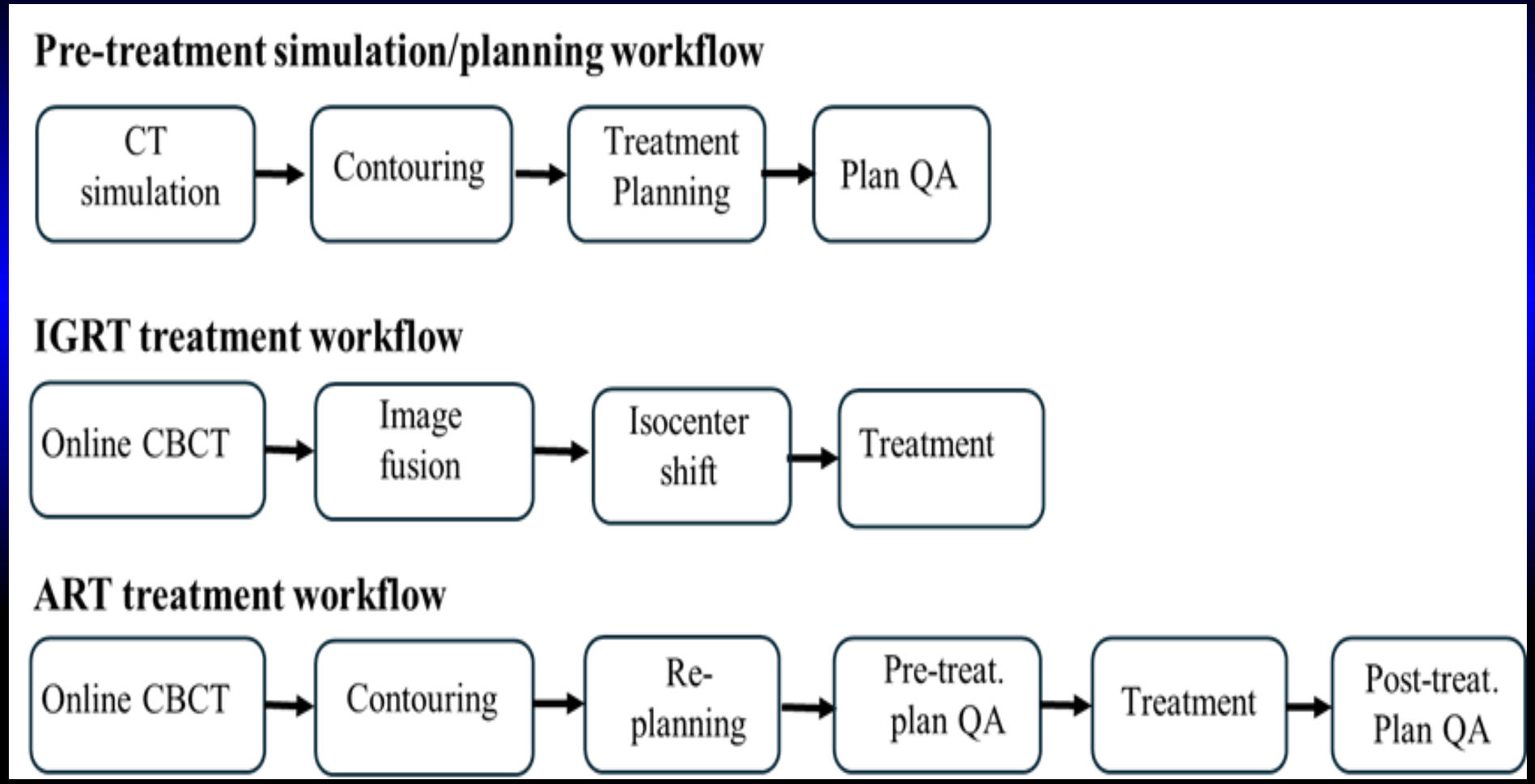
- ViewRay: MR-linac
- Elekta Unity: MR-linac
- MagnetTx Aurora-RT: MR-linac
- Varian Ethos: CBCT-linac
- Accuray Radixact/Cenos: CBCT-linac
- Elekta Evo: CBCT-linac
- United Imaging: CT-linac
- Akesis/Prowess adaptive workstation: CBCT-linac





Workflows for IGRT and ART

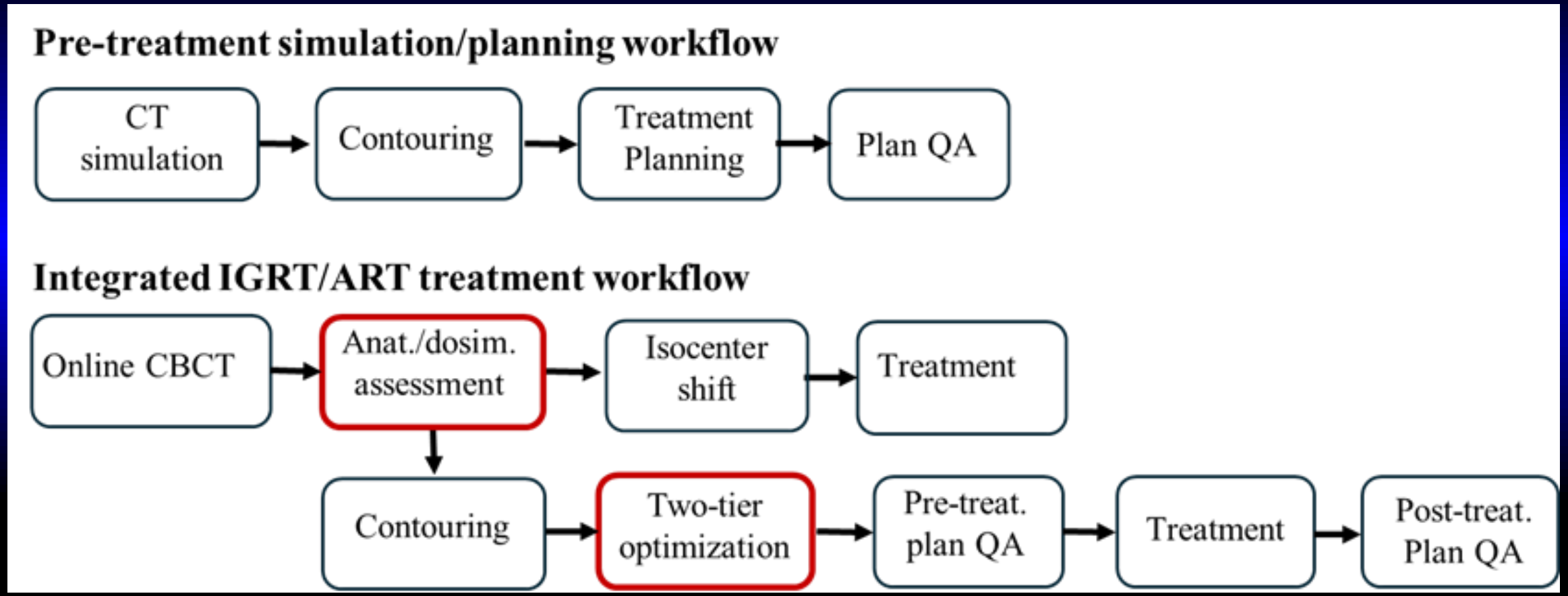
Make a decision first!



Questions about Adaptive RT

- Why not to perform ART only for large anatomy changes?
- Why are adaptive plans worse than scheduled plans sometimes?

An Integrated Workflow for IGRT/ART



Ma et al (2025) MJCS 10(1): 53.

Two Strategies for ART

- **Better target localization to reduce the need for ART**

  Dose guided target localization

- **Better optimization method**

  A two-tier optimization process:

  1st tier: simple DAO optimization - MLC segment shape/weight change

  2nd tier: full optimization - objective function/dose parameter change

Dose Guided Localization

- **Anatomy (contour) based target localization**

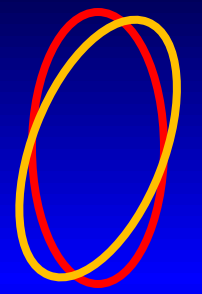
  Large uncertainty due to organ deformation/rotation

- **Isodose based target localization**

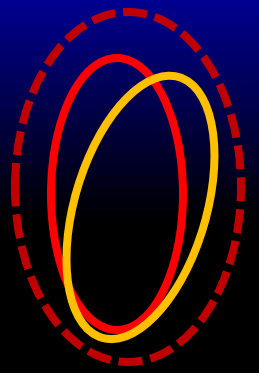
  Improved target coverage and/or OAR sparing:

  More accurate to enclose the treatment volume

  Optical avoidance of critical structures

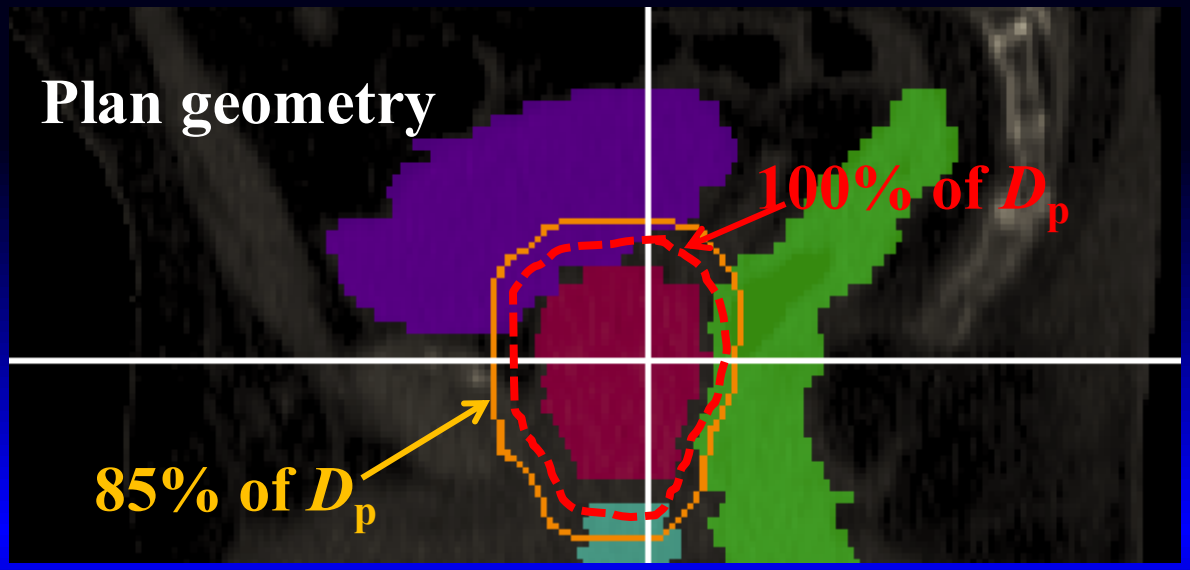


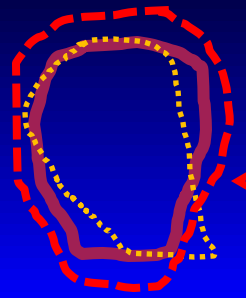
Contour match



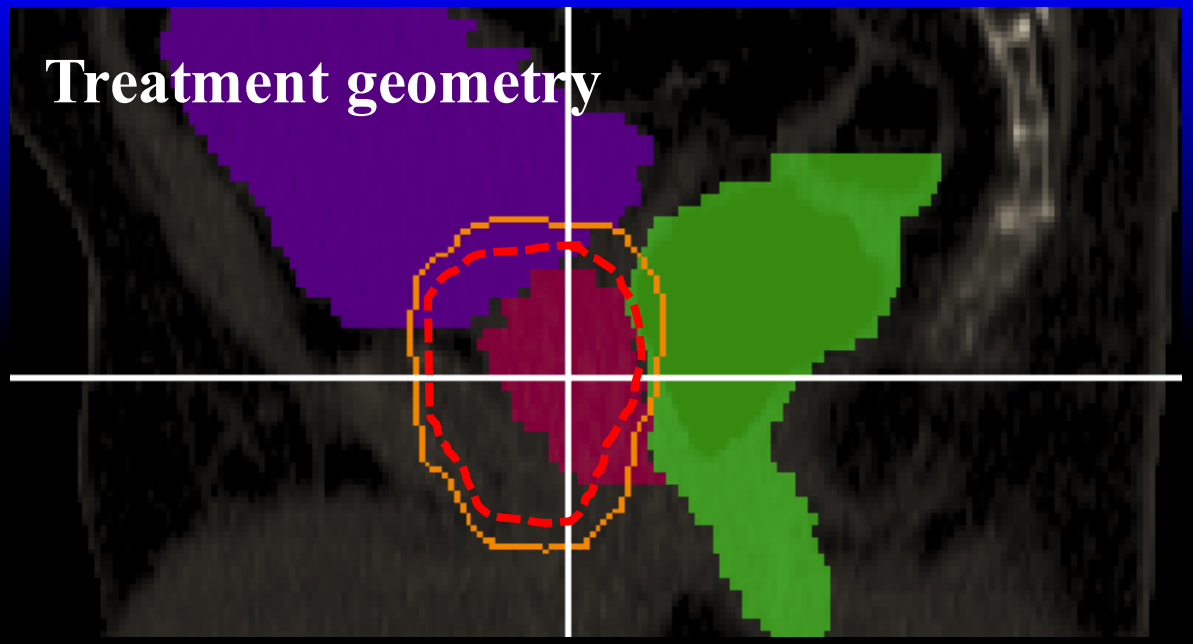
Isodose match

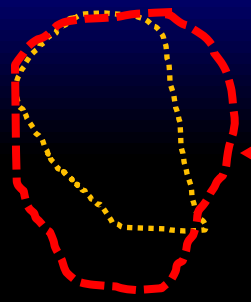
Fractional Dose Distribution





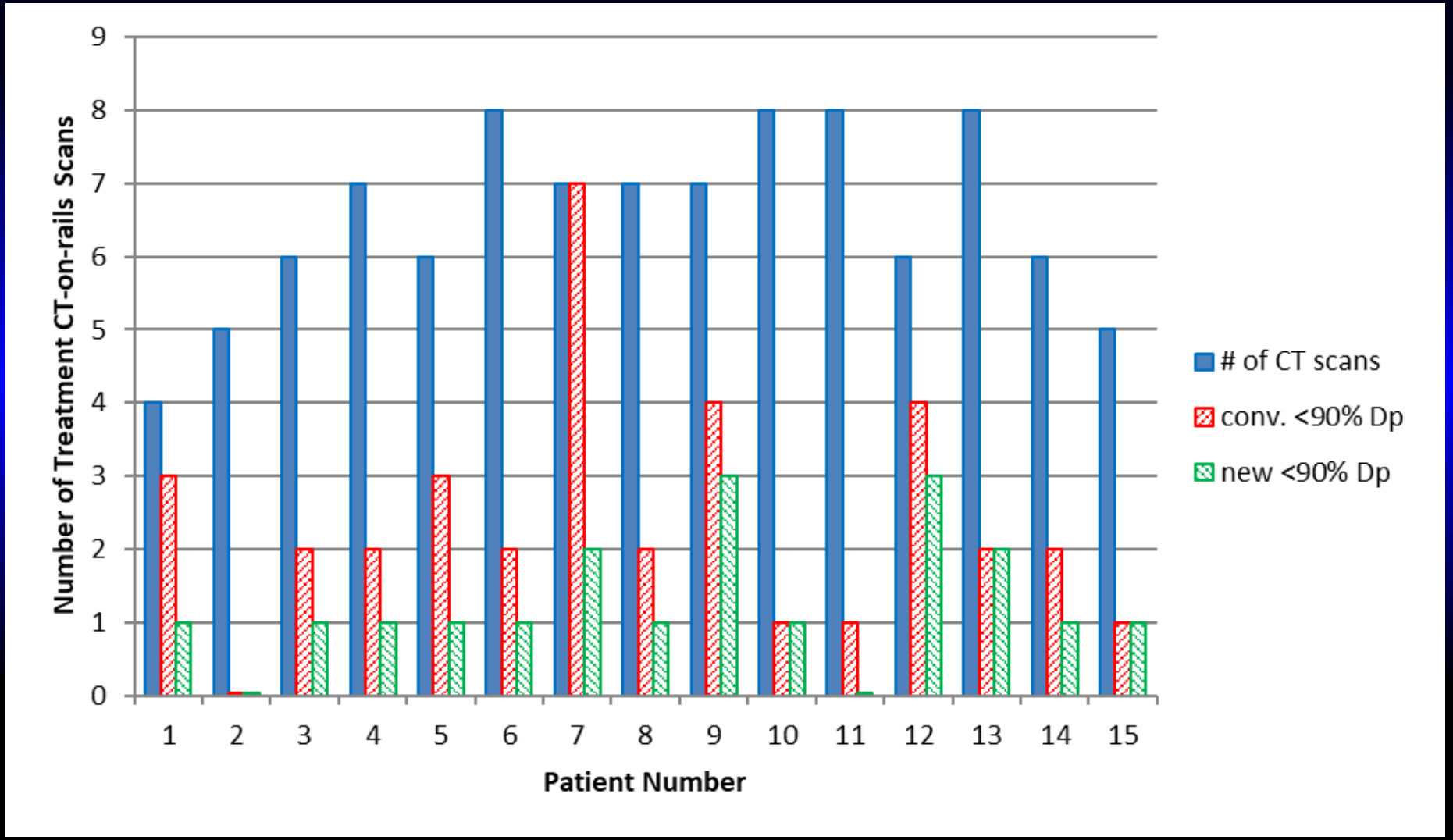
Align with anatomy





Align with isodose

Anatomy- vs. Isodose-Based Localization



Ma et al (2023) Phys Med 107: 102550

Two-tier ART Optimization

- 1st tier: DAO optimization for easy (most) cases

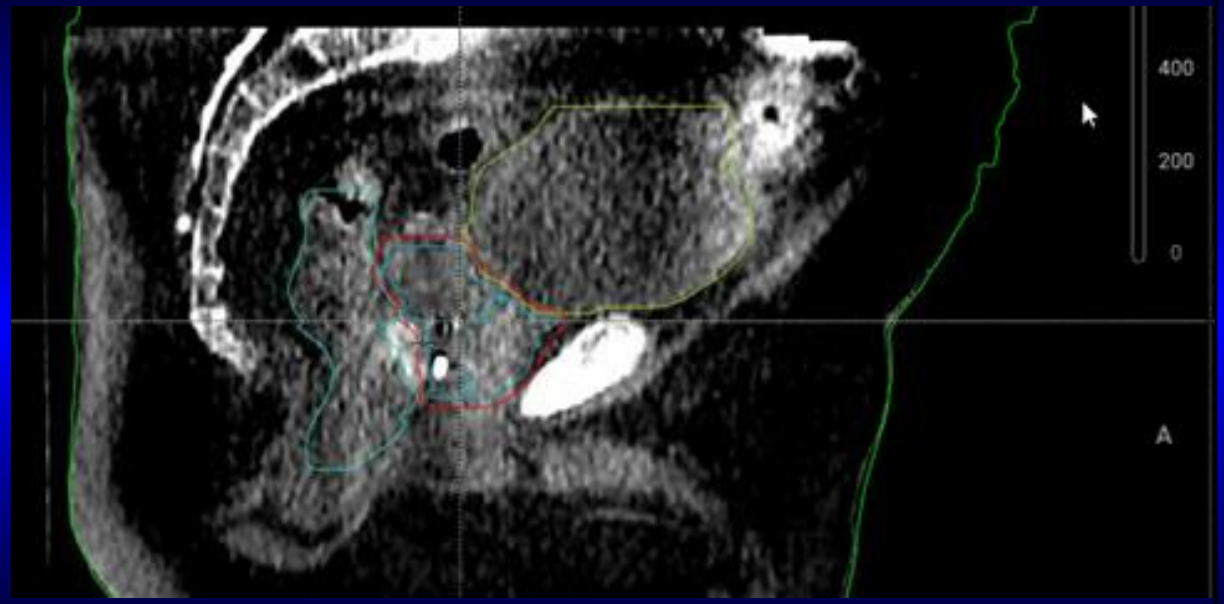
  Fast optimization by adjusting MLC shape/weight

- 2nd tier: optimization for large (few) anatomy changes

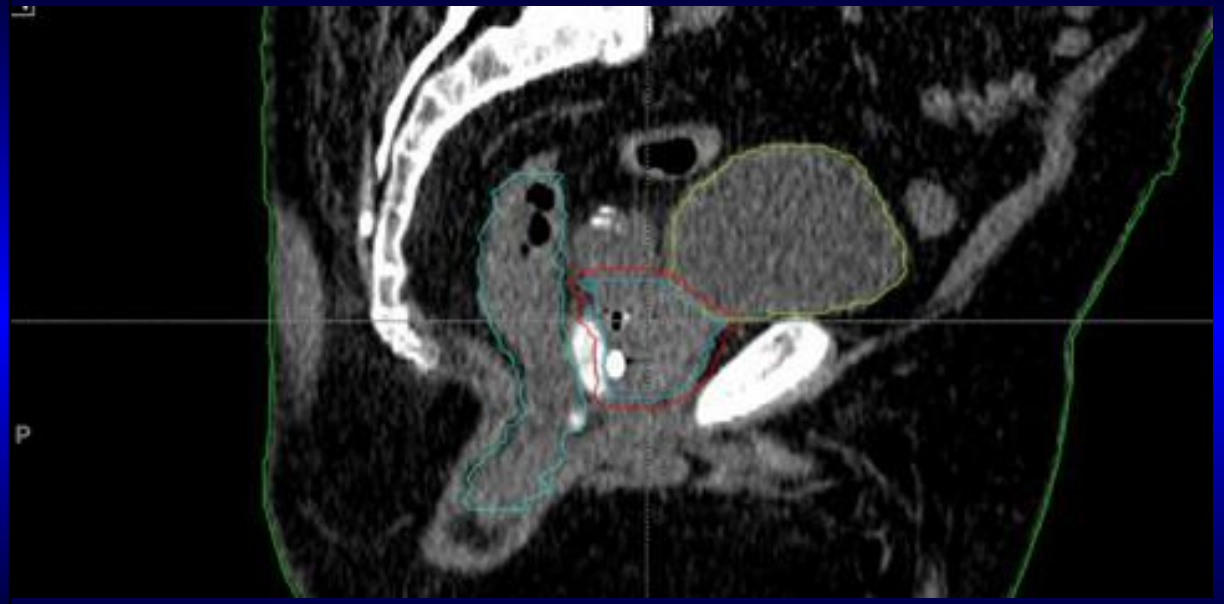
  Modification of objective function/optimization parameters

  Better optimization results due to change of solution space

Fast Optimization (MLC Shape/Weight)



CBCT



Simulation CT

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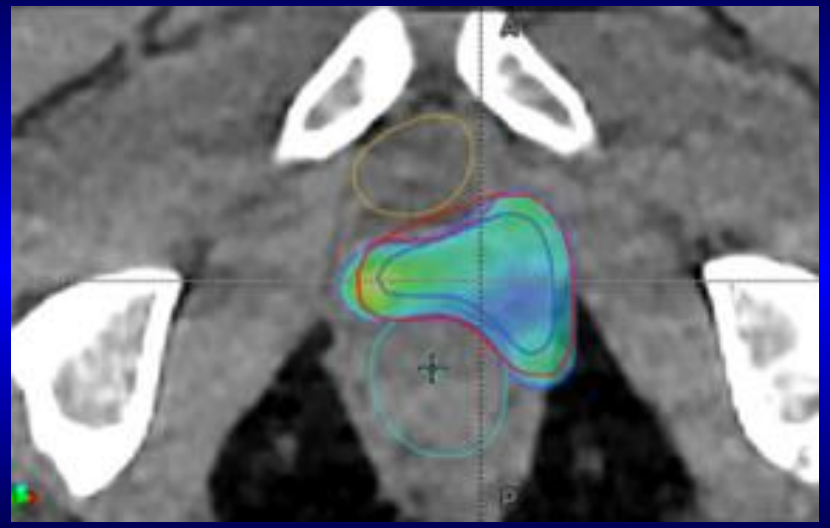
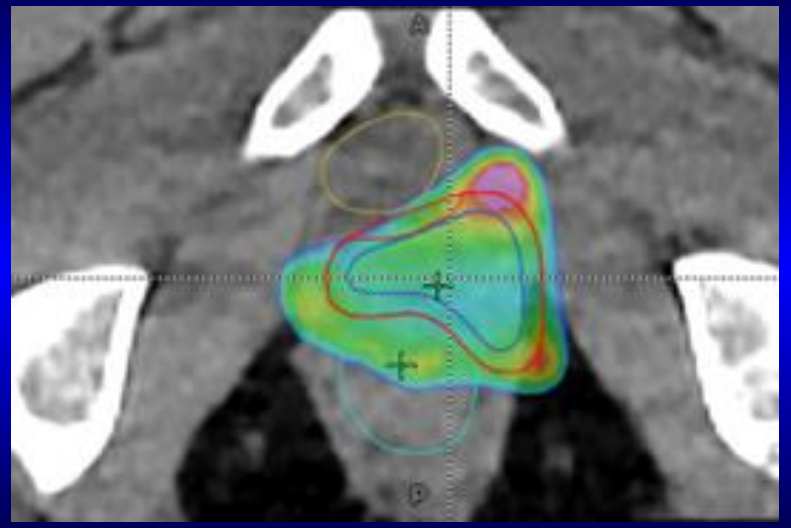
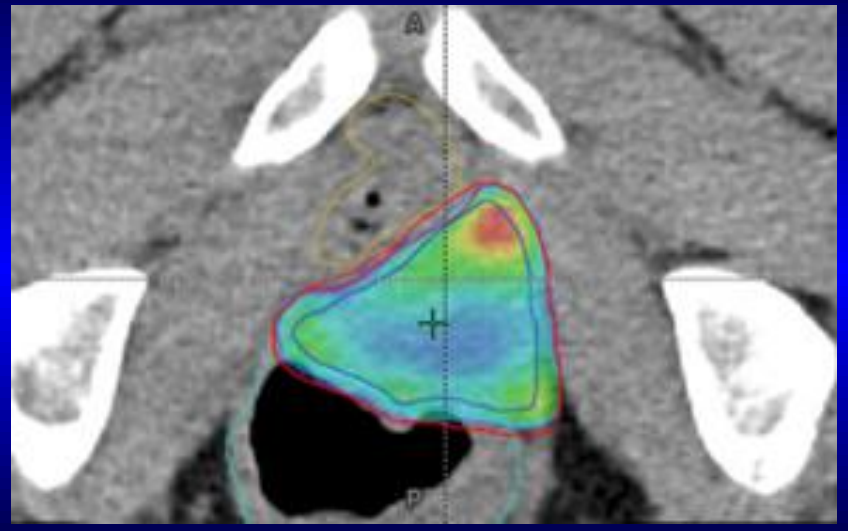
Full Optimization (New Solution Space)



Adaptive plan



Scheduled plan

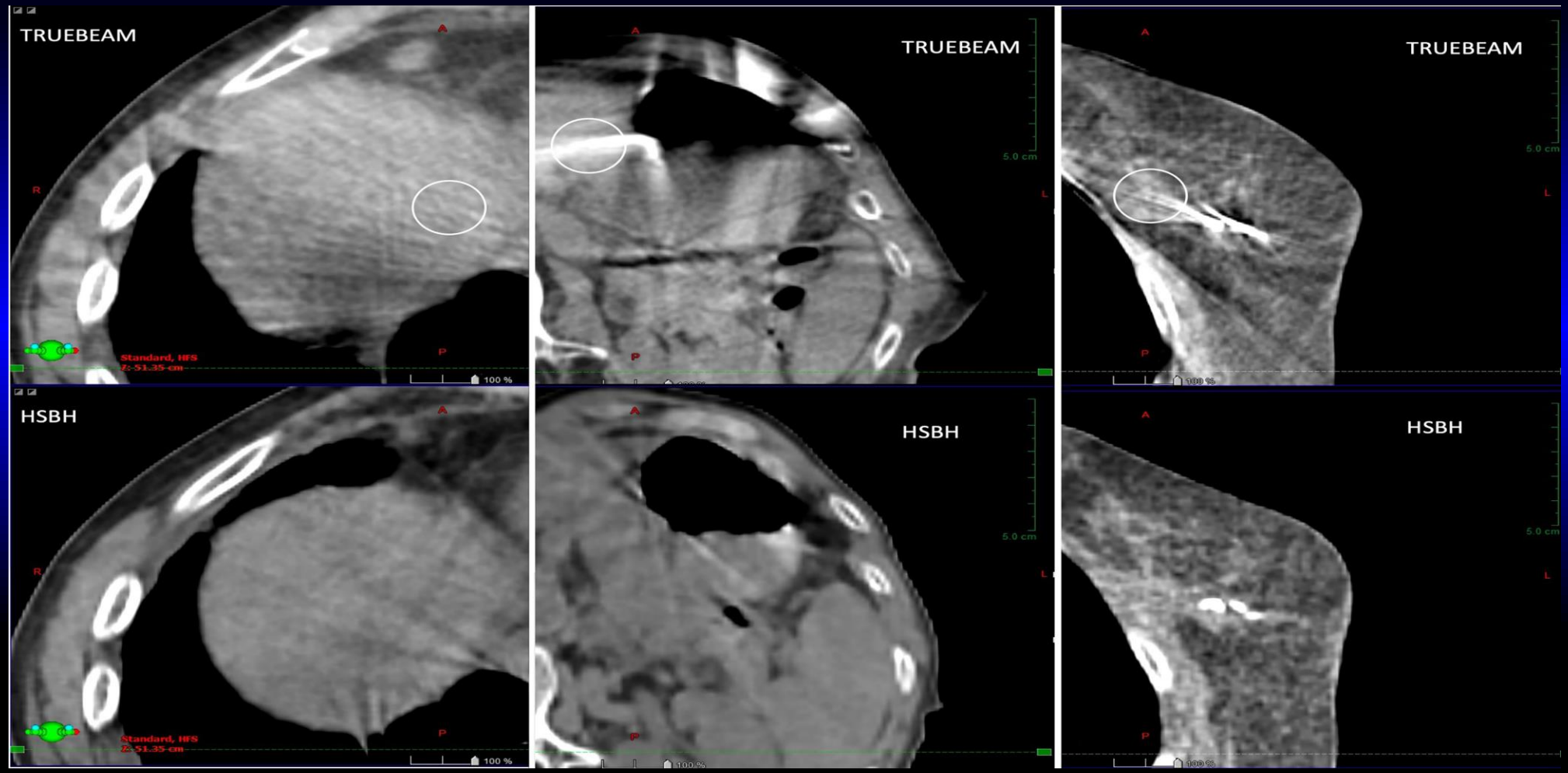


Reference plan

Initial ART Experience with Ethos

- Ethos ART system installed in Feb 2023
- HyperSight CBCT installed in Sept 2023
- Ethos 2.0 upgrade completed in 2025
- ~ 1000 patients treated with ART
- > 90% ART treatments for SBRT patients

Imaging Quality Improvement with HyperSight



Rapid imaging in 6.9 seconds (good for breath hold with Identify)

ART Treatment Sites

- Prostate (Varian ARTIA-Prostat NCT05804318 2023, FCCC IIT)
- Cervix (Varian ARTIA-Cervix NCT05197881 2023)
- Bladder/Rectum (FCCC IIT NCT07221058 2025)
- Pancreas/biliary tree (FCCC IIT NCT06984562 2025)
- Oligomets – lymph nodes and bone (FCCC IIT NCT05880667 2023)
- Breast (APBI, FCCC IIT)
- Lung/mediastinum
- Head and neck
- Almost any candidate for SBRT
- Some IMRT patients – prostate bed

A Dosimetric Study on Adaptive Prostate SBRT

- 50 prostate cases investigated (250 adaptive fractions)
- Workflow/treatment time evaluated
- Treatment plans compared (scheduled vs. adaptive)
- Typical cases/dosimetric issues analyzed
- Challenges and potential gains/improvements

Average Time for Each ART Step

Procedure	Description	Average Elapsed time (minute)
Patient Setup	Patient check-in and couch setup	8.42
Segmentation	CBCT, auto-segmentation and physician edits	8.45
Optimization	IMRT optimization and Dose calculation	1.6
Approval	Plan evaluation, approval and Mobius QA	5.75
Treatment	2nd CBCT and dose delivery	8.33

24.1 min

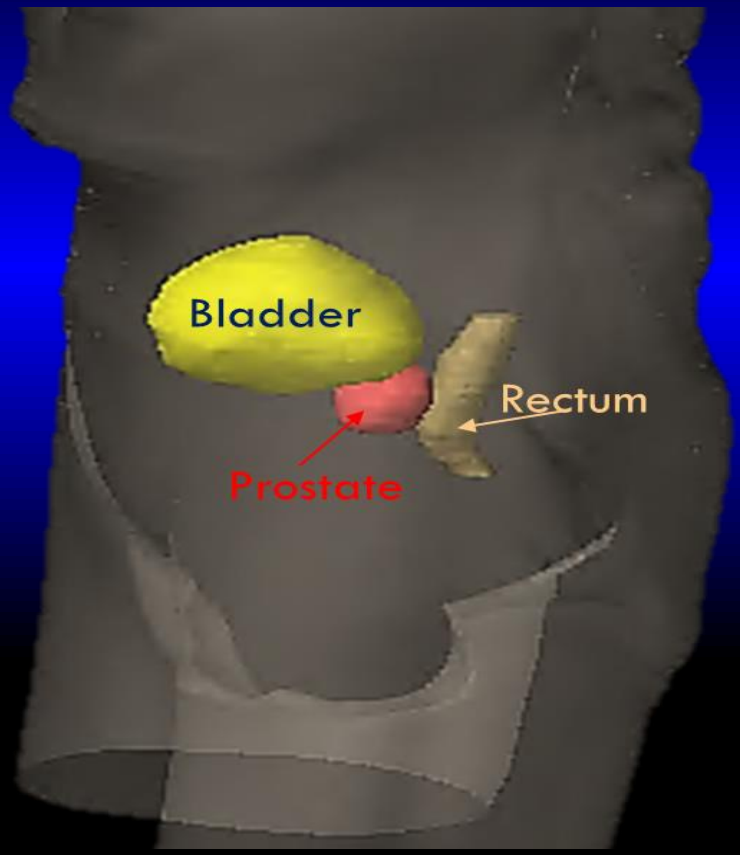
Clinical Goals for Prostate SBRT

PTV D95% ≥ 37 Gy (7.4 Gy/fraction)

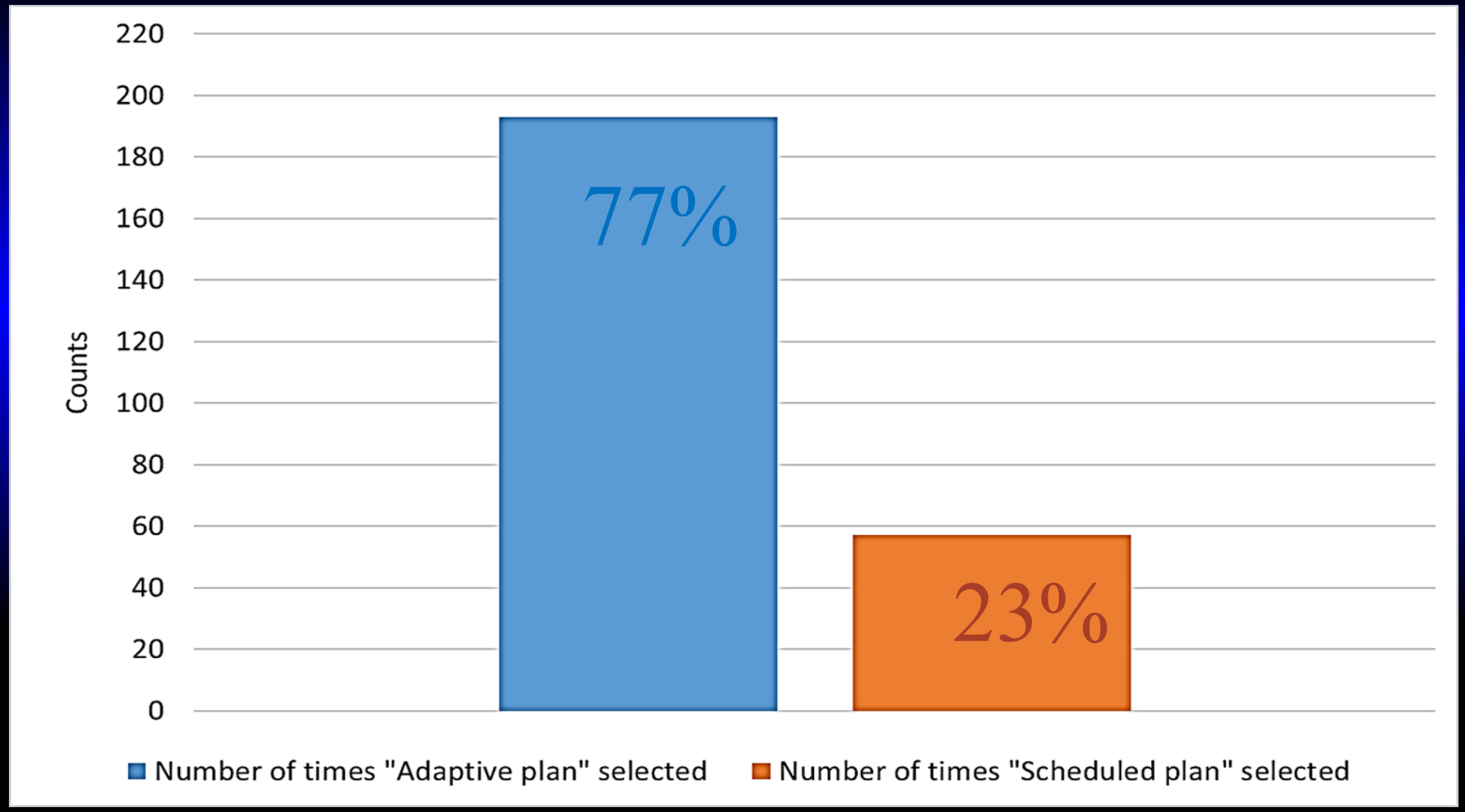
Main OARs:

Rectum	Dose Limit (Gy)
Max dose (point)	≤39.3 Gy
<2cc	>37 Gy
≤ 10% of rectum	≥ 33 Gy
≤ 20% of rectum	≥ 30 Gy
≤ 50% of rectum	≥ 18 Gy

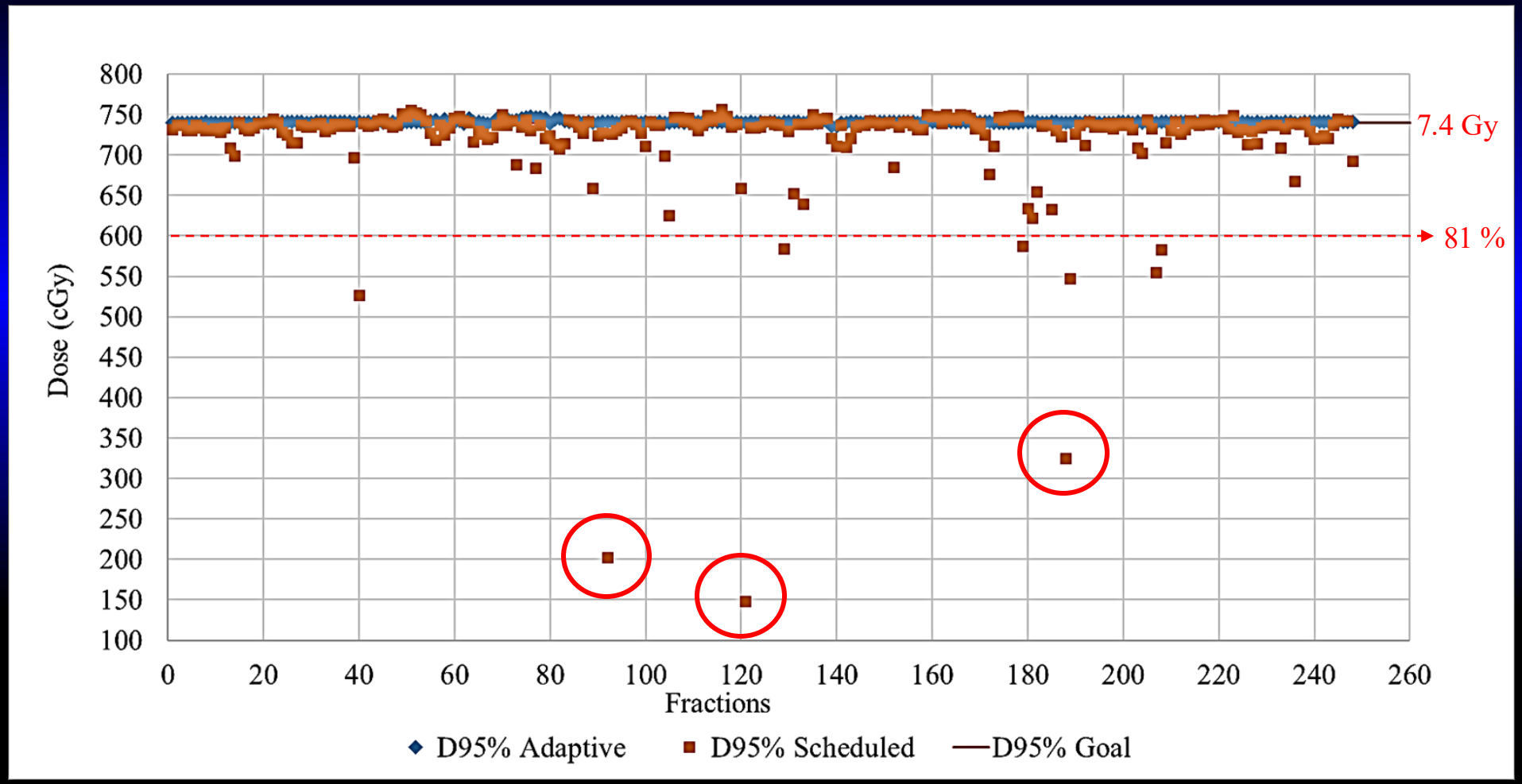
Bladder	Dose Limit (Gy)
Max dose (point)	40.7 Gy
<25% or <50cc (use smaller)	>24 Gy



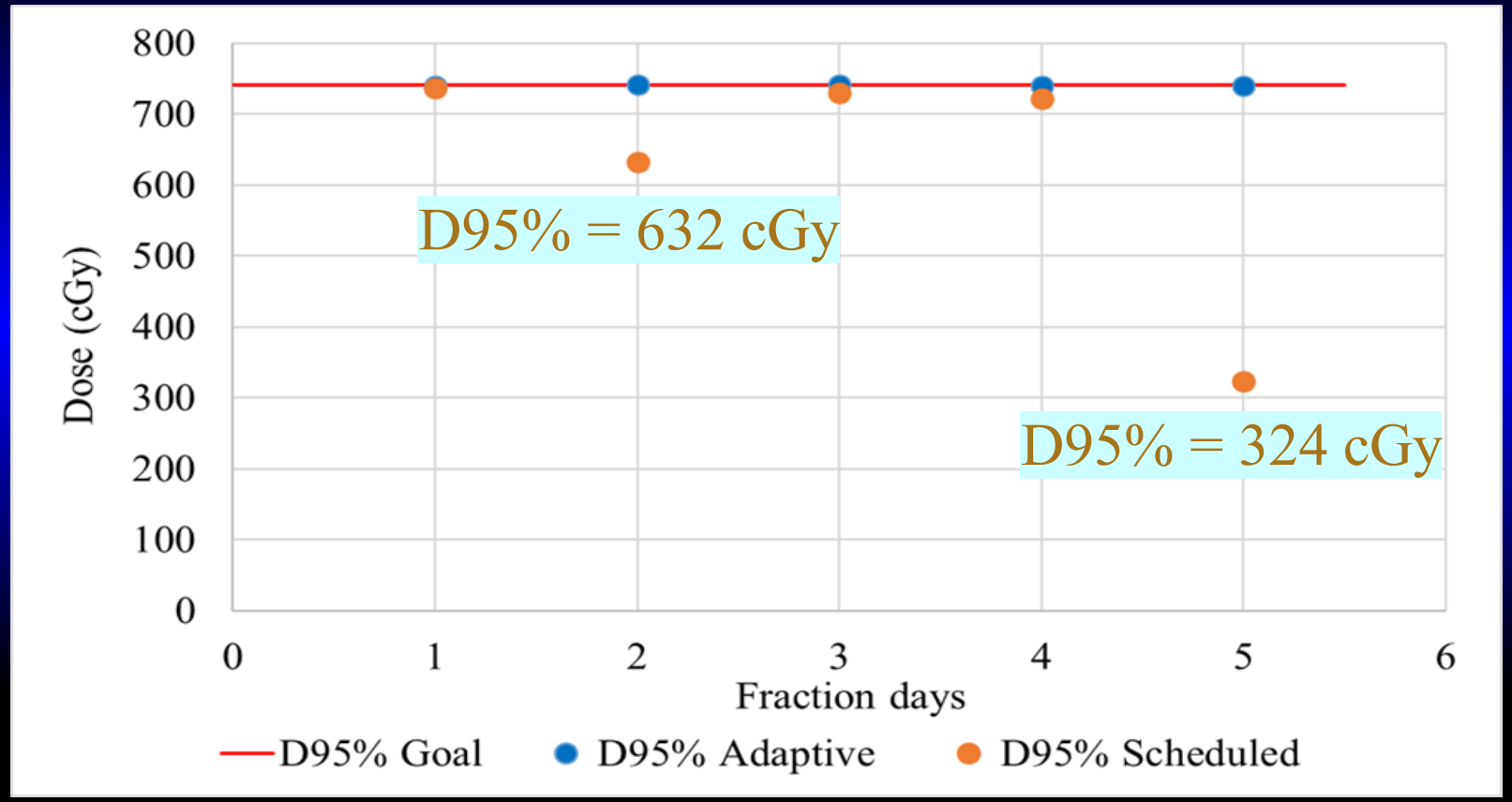
Adaptive Plan vs. Scheduled Plan



PTV Coverage – D95%



Case 1: PTV Coverage/Fraction

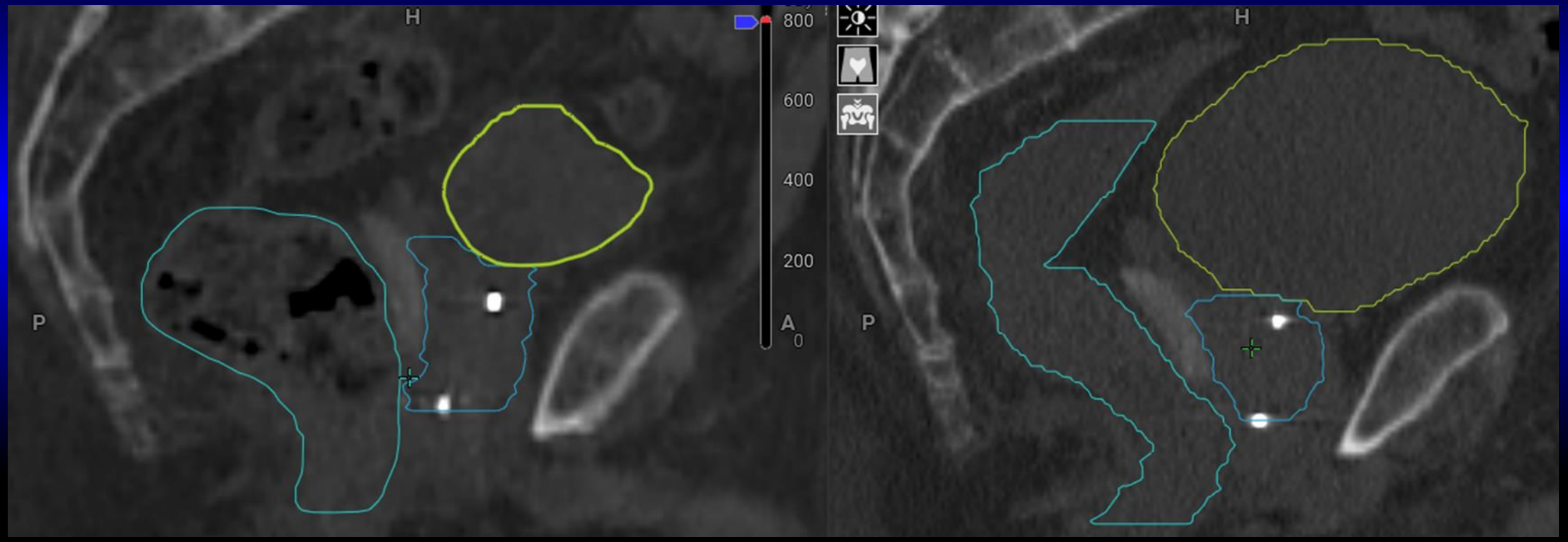


OARs met all dose constraints in both adaptive and scheduled plans.

Case 1: Fraction 5 Geometry Changes

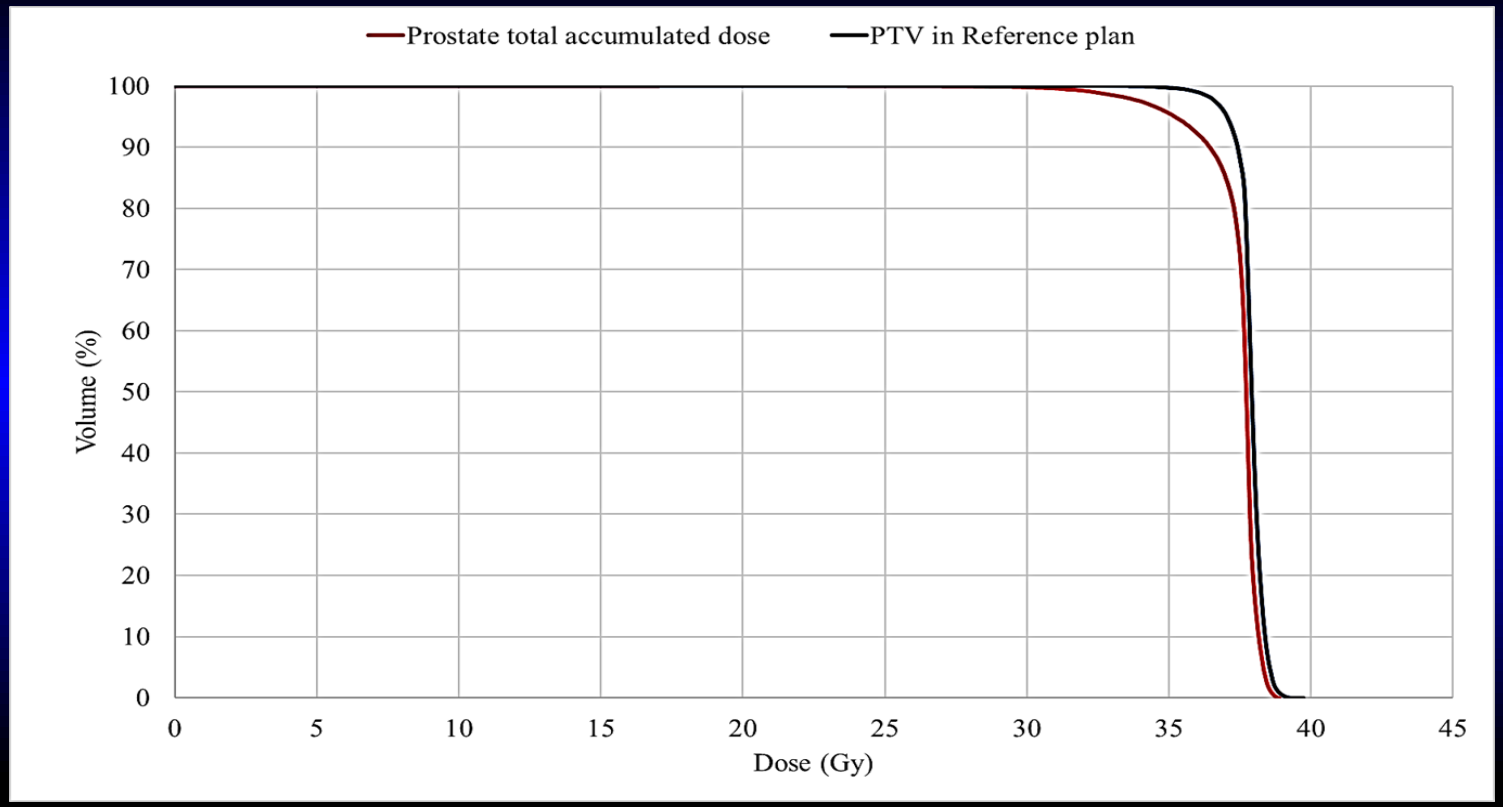
CBCT

Simulation CT



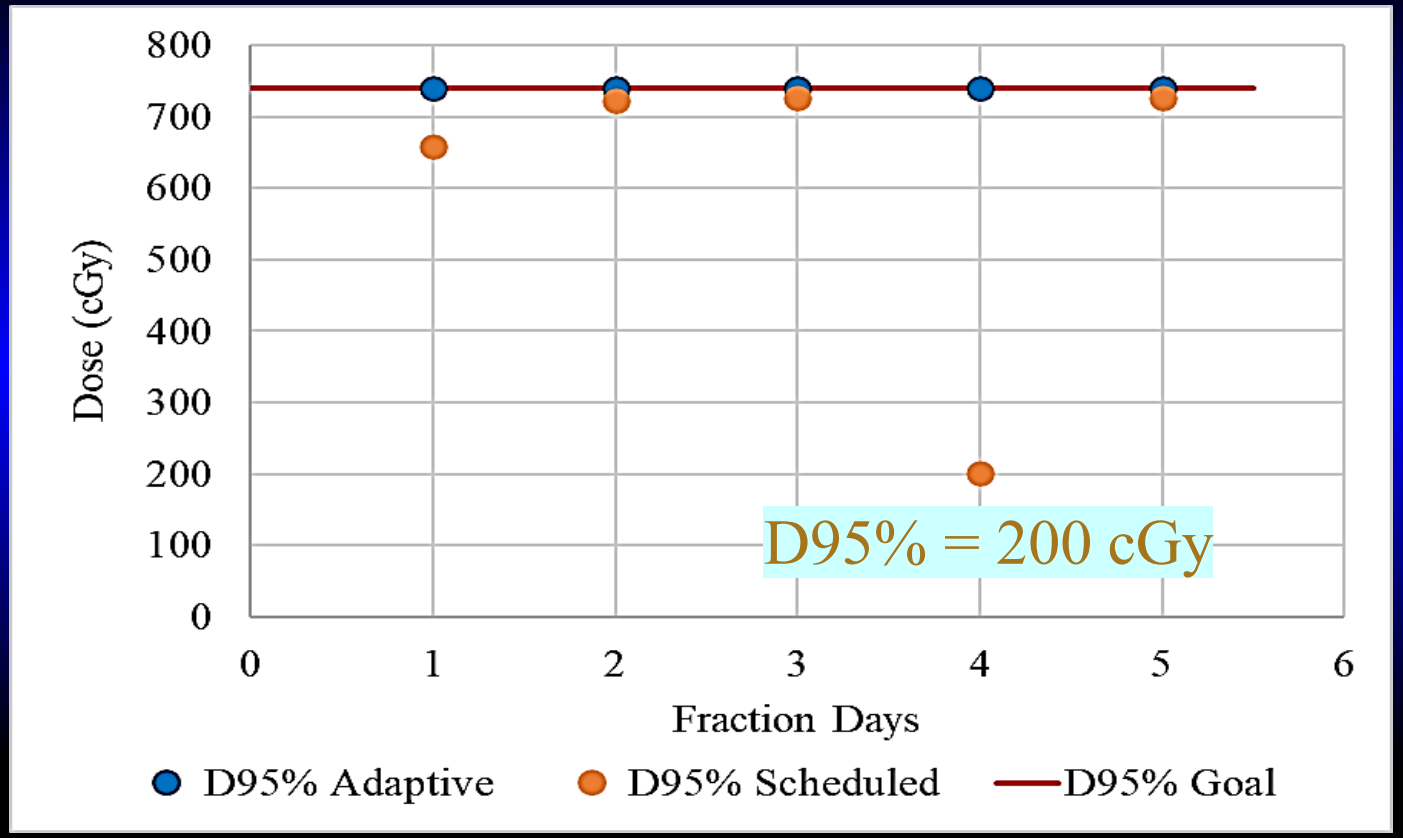
Note the changes in rectum/bladder volume and fiducial separation!

Case 1: Planned vs. Cumulative Dose



Planned D95% = 37 Gy vs. cumulative (scheduled) D95 = 35.2 Gy (= 95.1% of Dp)

Case 2: PTV Coverage/Fraction

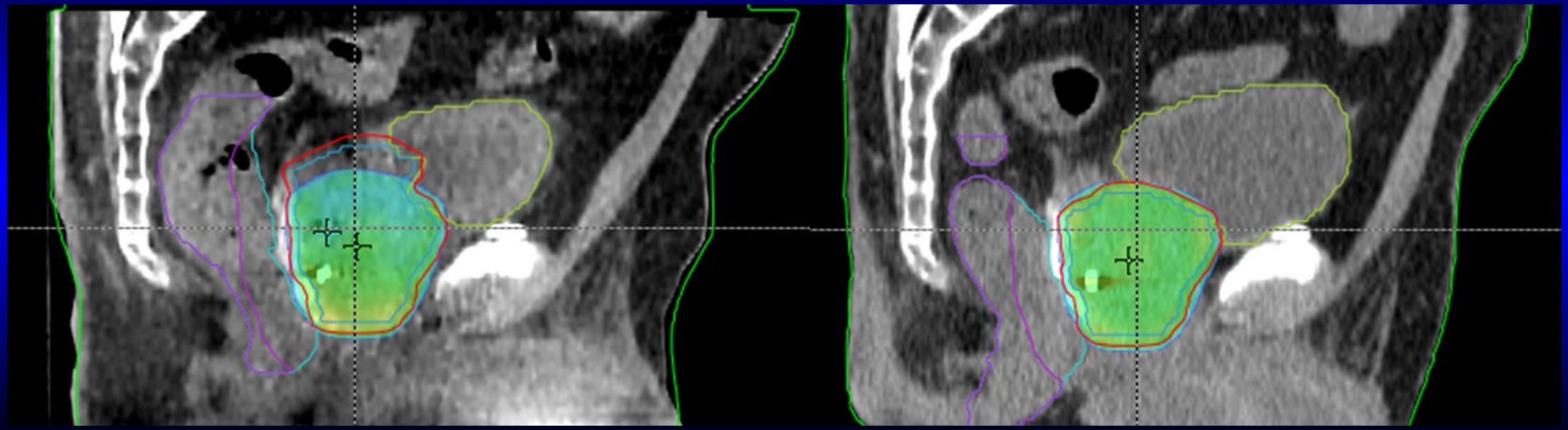


OARs met all dose constraints in both adaptive and scheduled plans.

Case 2: Fraction 4 Contour Changes

CBCT

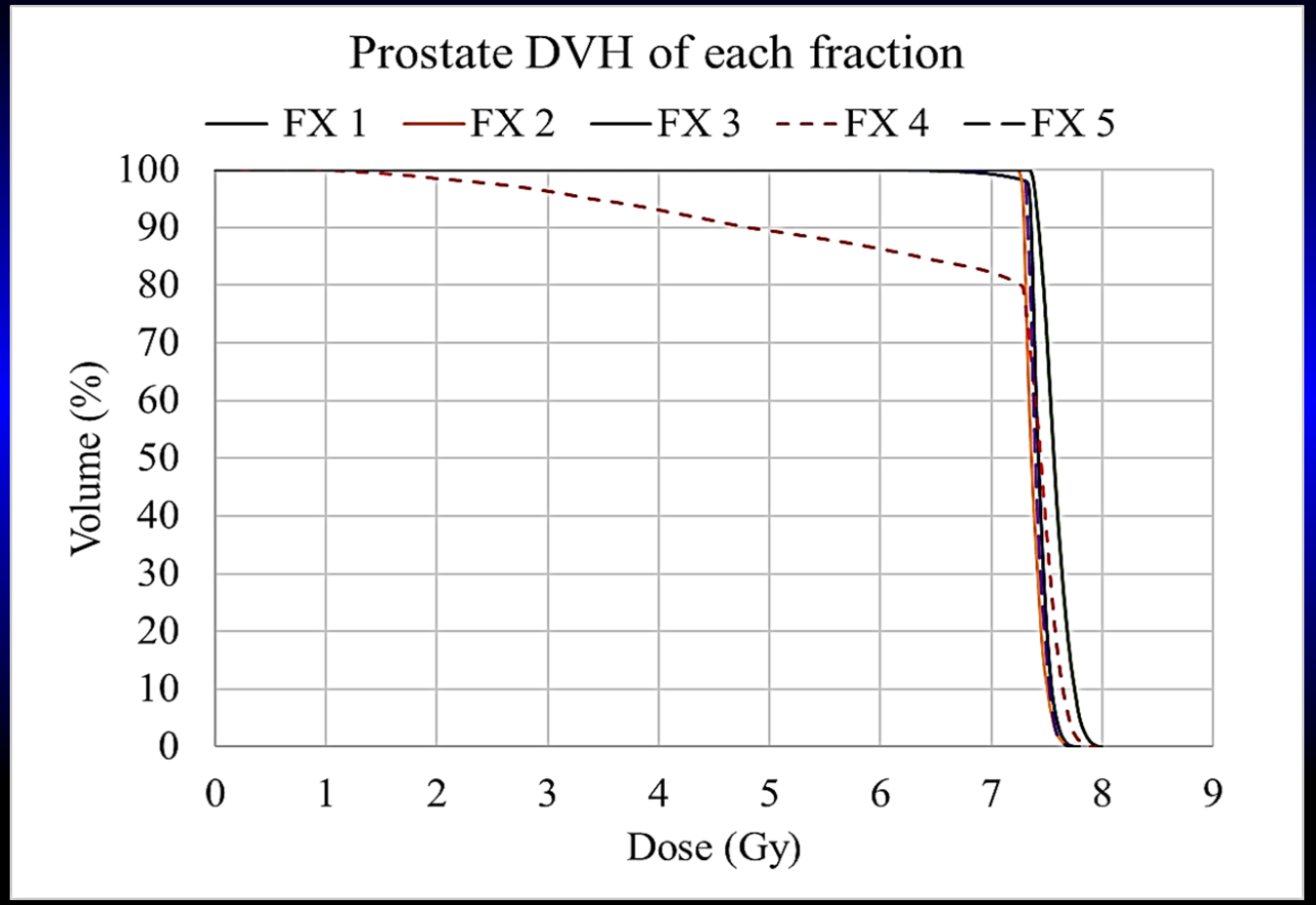
Simulation CT



Is this a true anatomical change or a contouring variation?

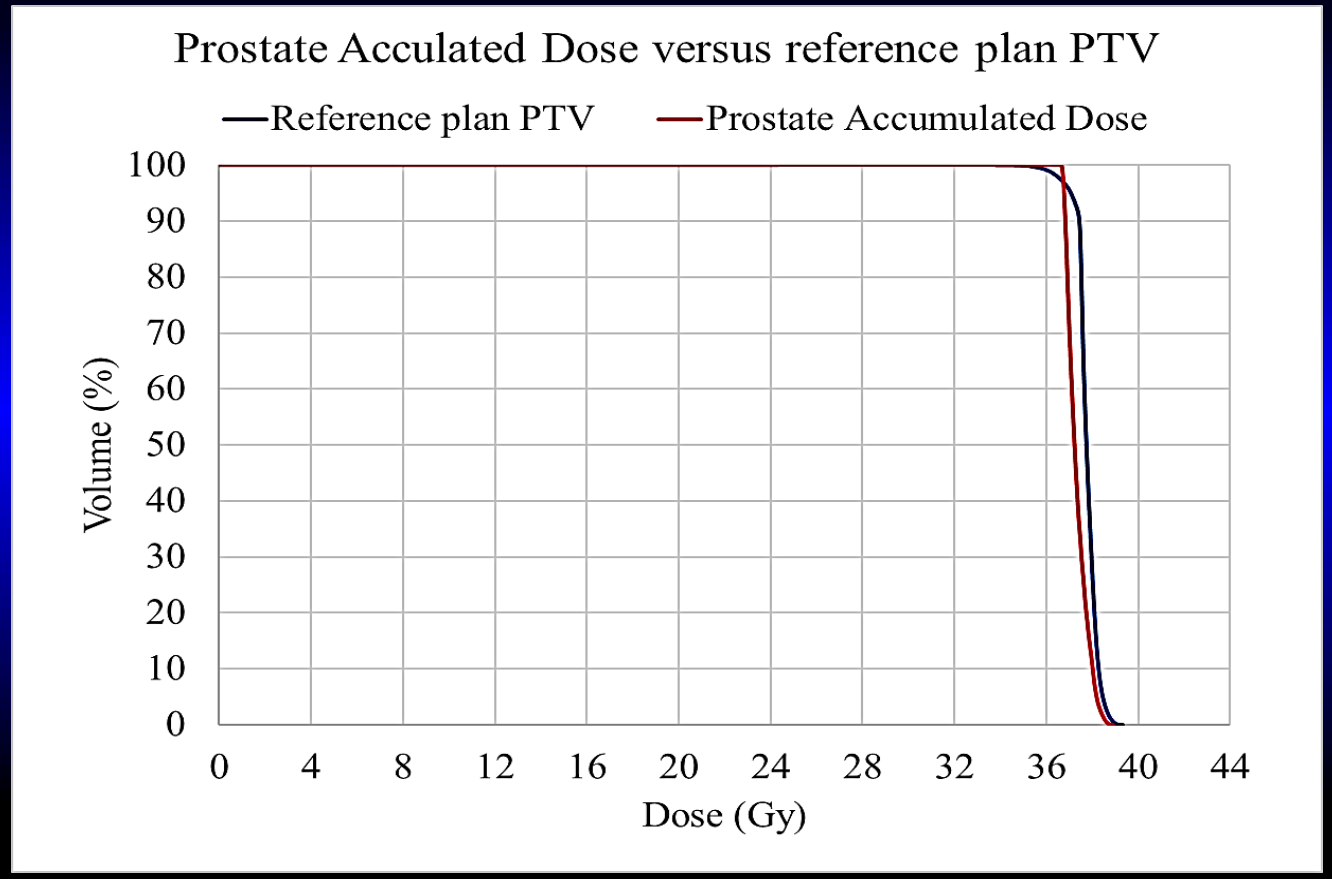
Planning CT	FX 1	FX 2	FX 3	FX 4	FX 5
67.8 cc	72.9 cc	67.8 cc	69.3 cc	87.6 cc	66.3 cc

Case 2: Target DVH – Scheduled Plan



Target underdosing due to changes in prostate contouring!

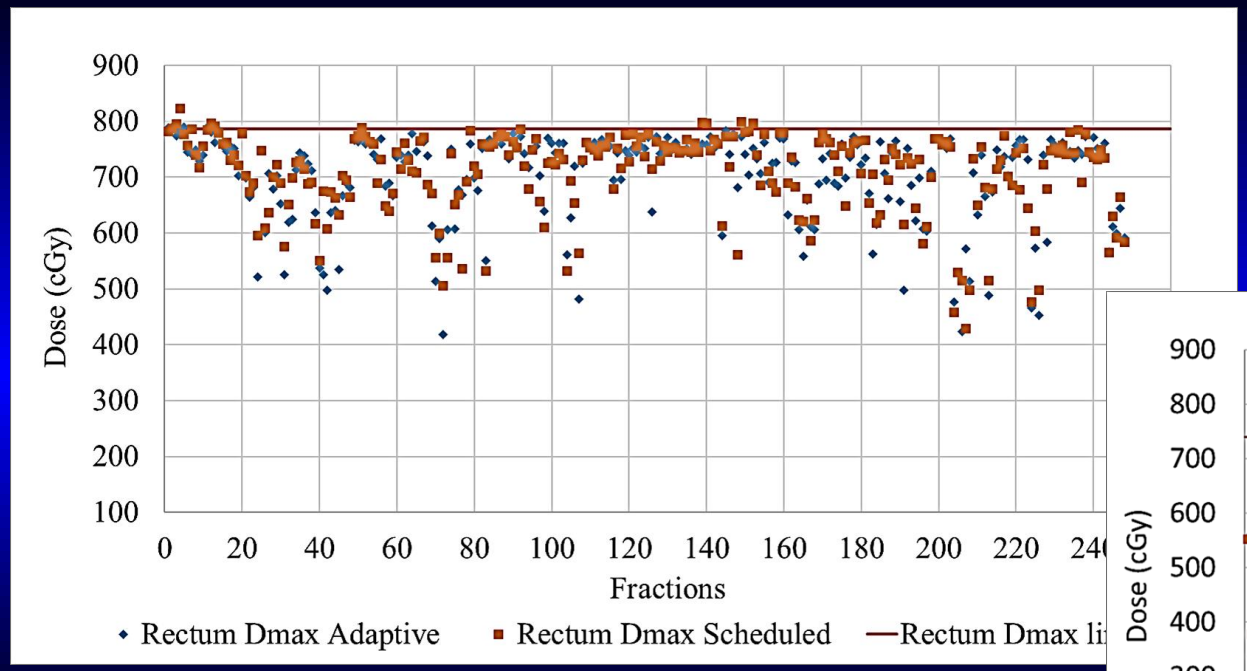
Case 2: Planned vs. Cumulative Dose



Velocity dose summation removed the contouring effect !!!

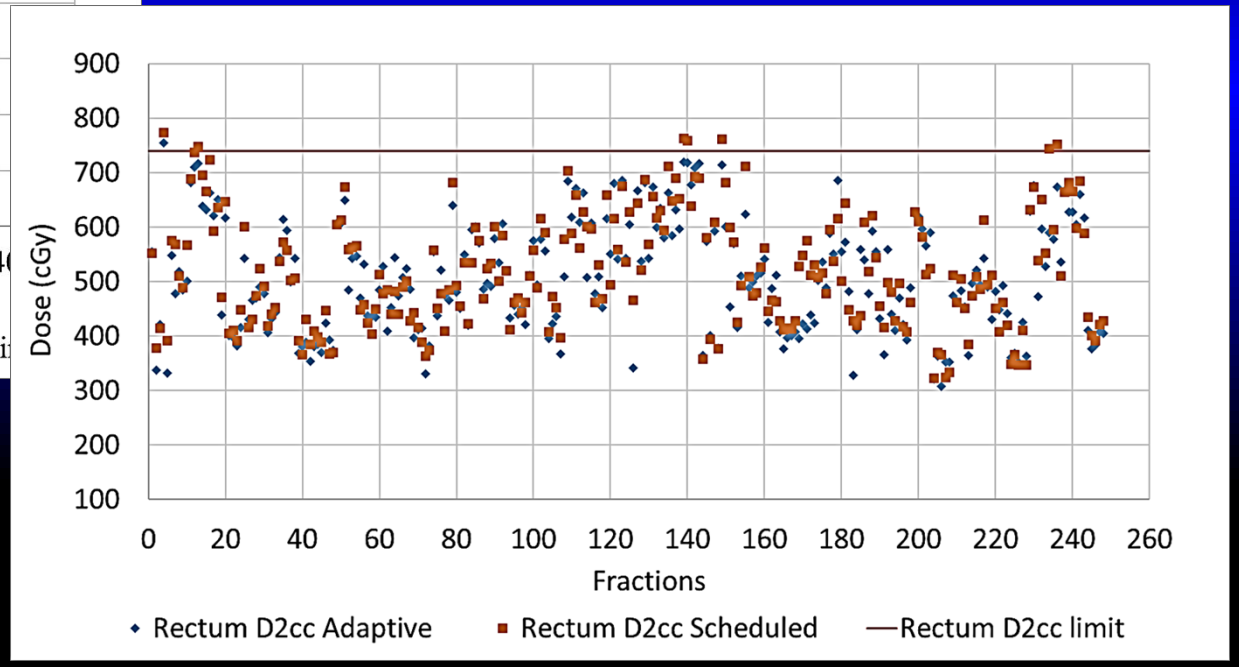
Planned D95% = 37 Gy vs. cumulative D95 = 36.8 Gy (= 99.5% of Dp)

OAR Comparison – Rectum

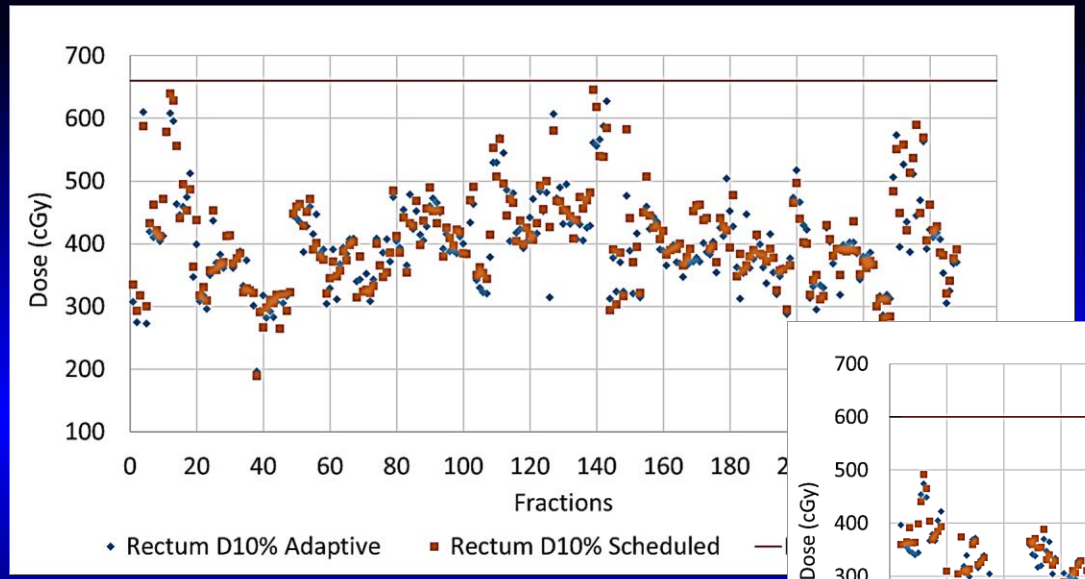


Dmax

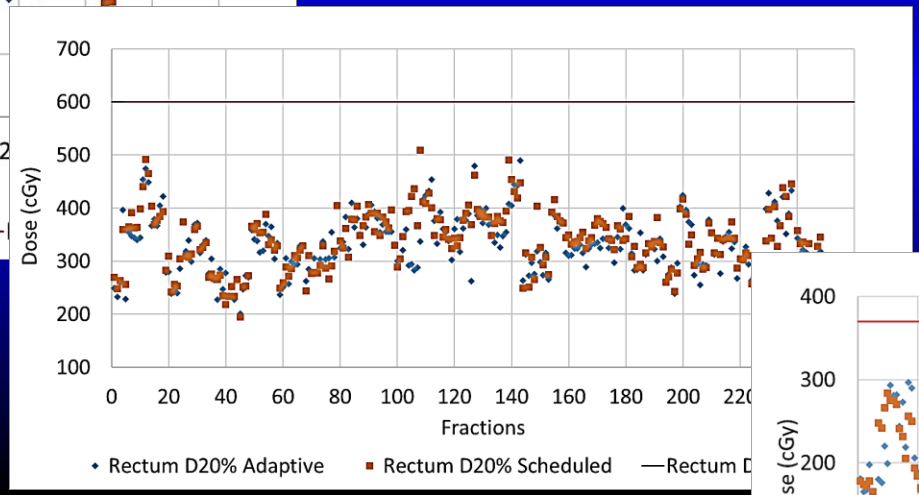
D2cc



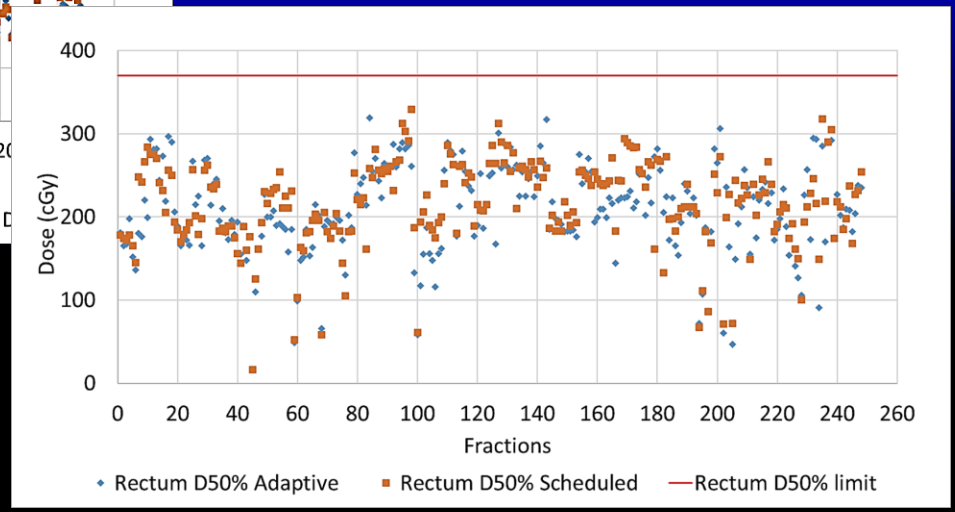
OAR Comparison – Rectum



D10%



D20%

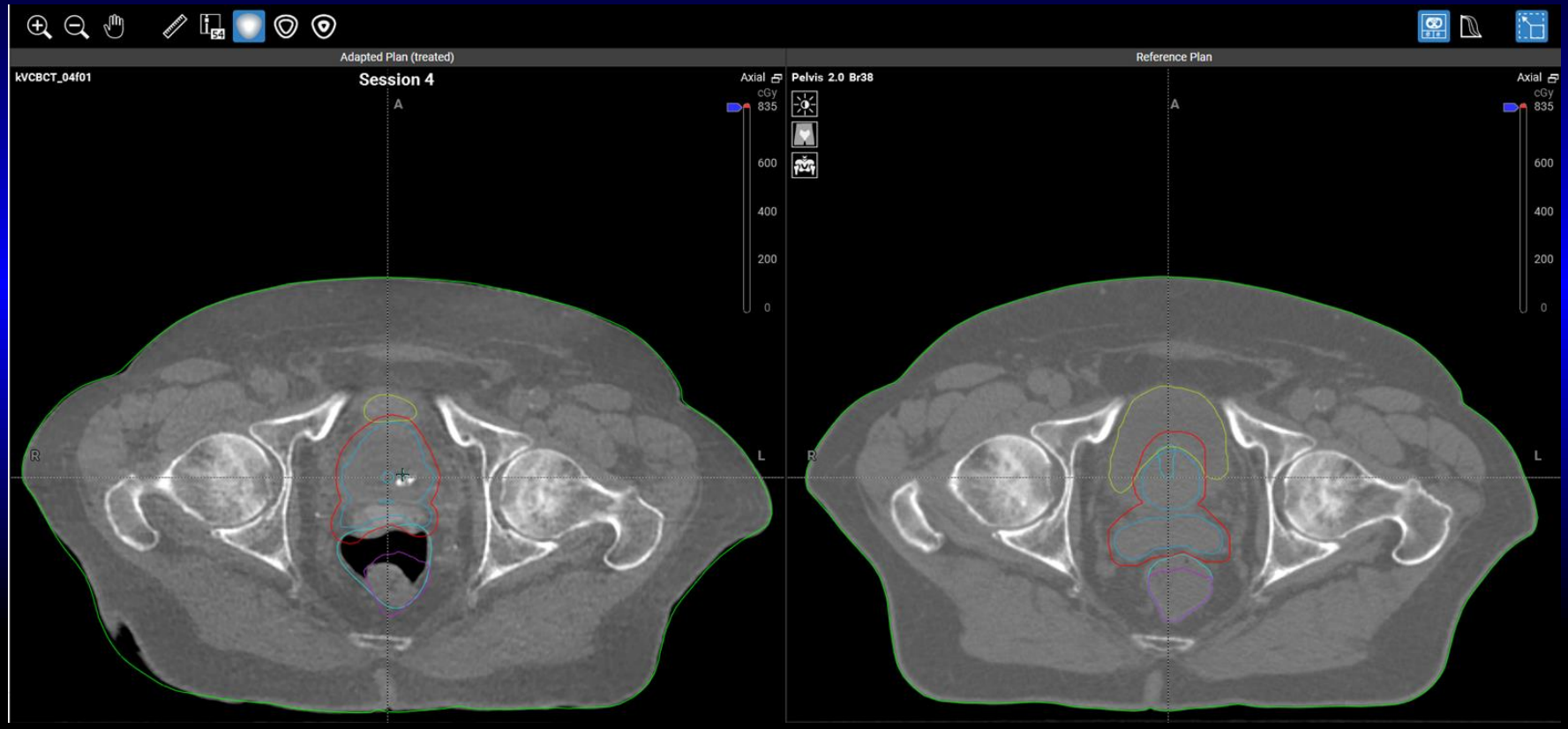


D50%

Case 3: Rectal Volume Variation

CBCT

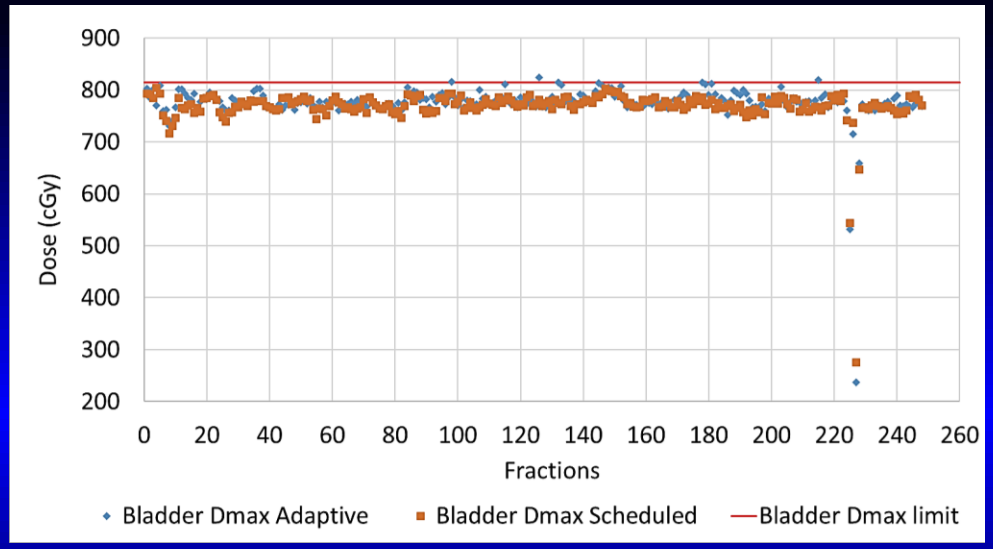
Simulation CT



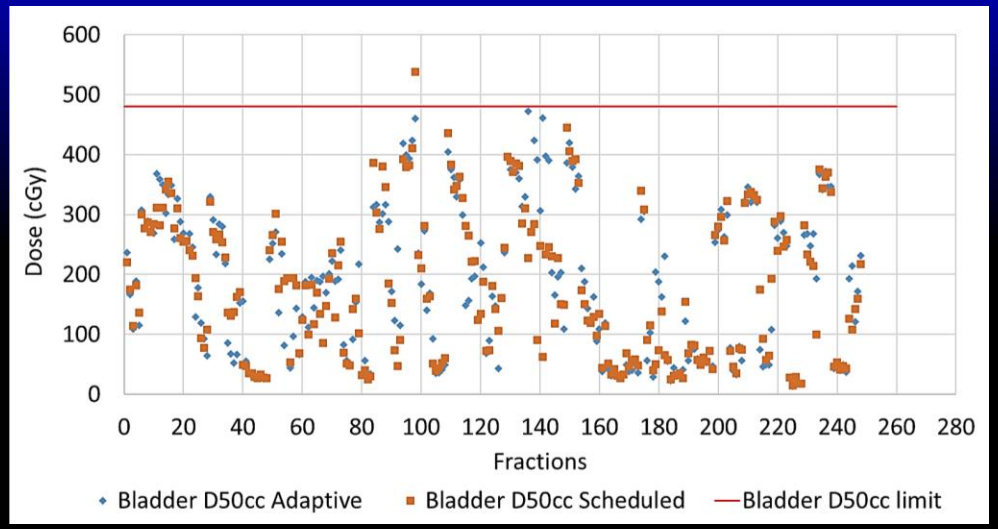
Rectum appeared larger together with CTV contour changes.

OAR Comparison – Bladder

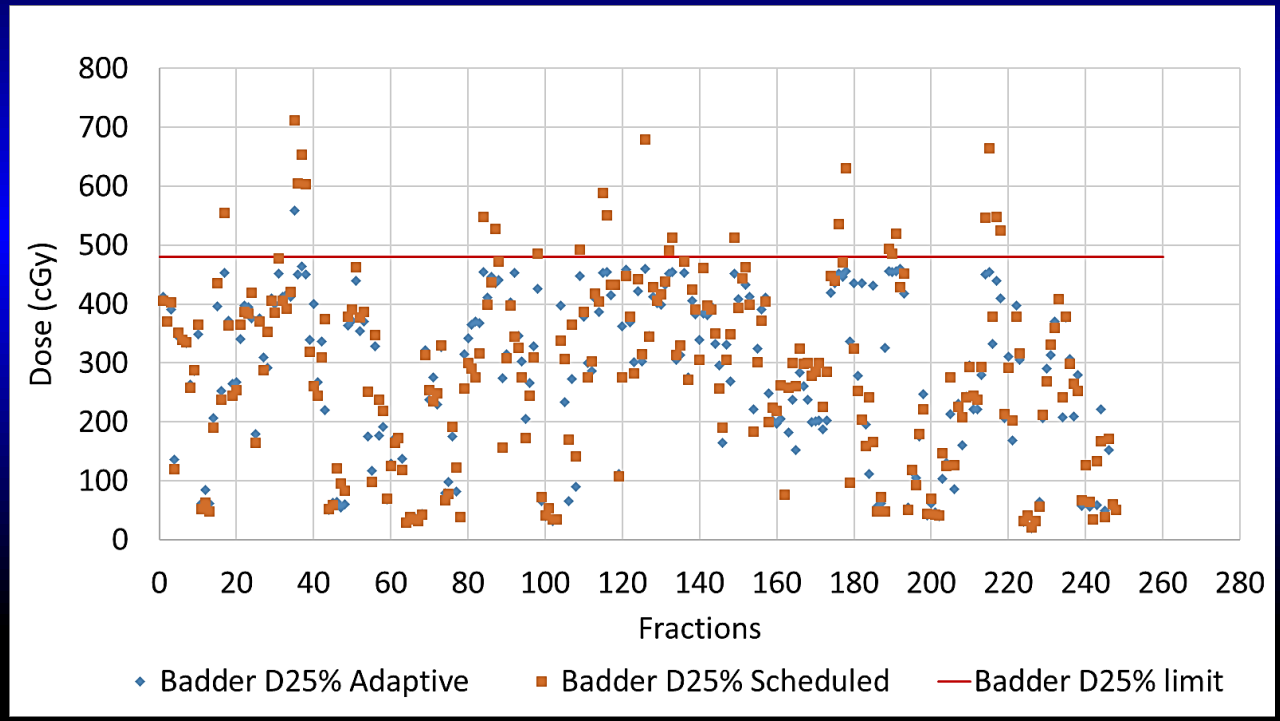
Dmax



D50cc



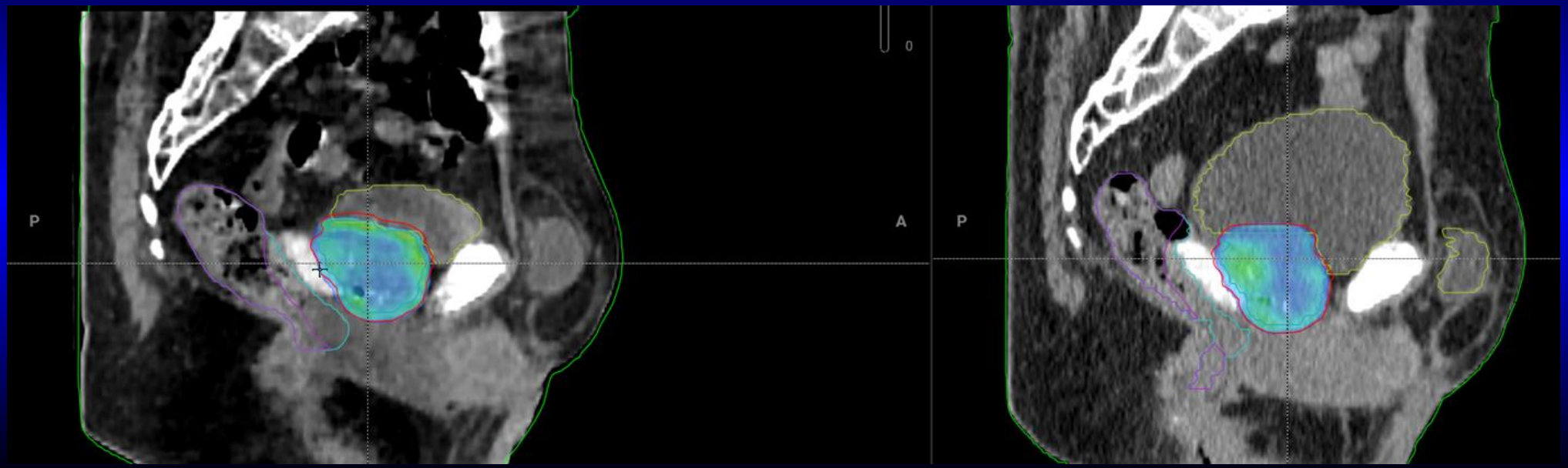
D25%



Case 5: Bladder Volume Variation

CBCT

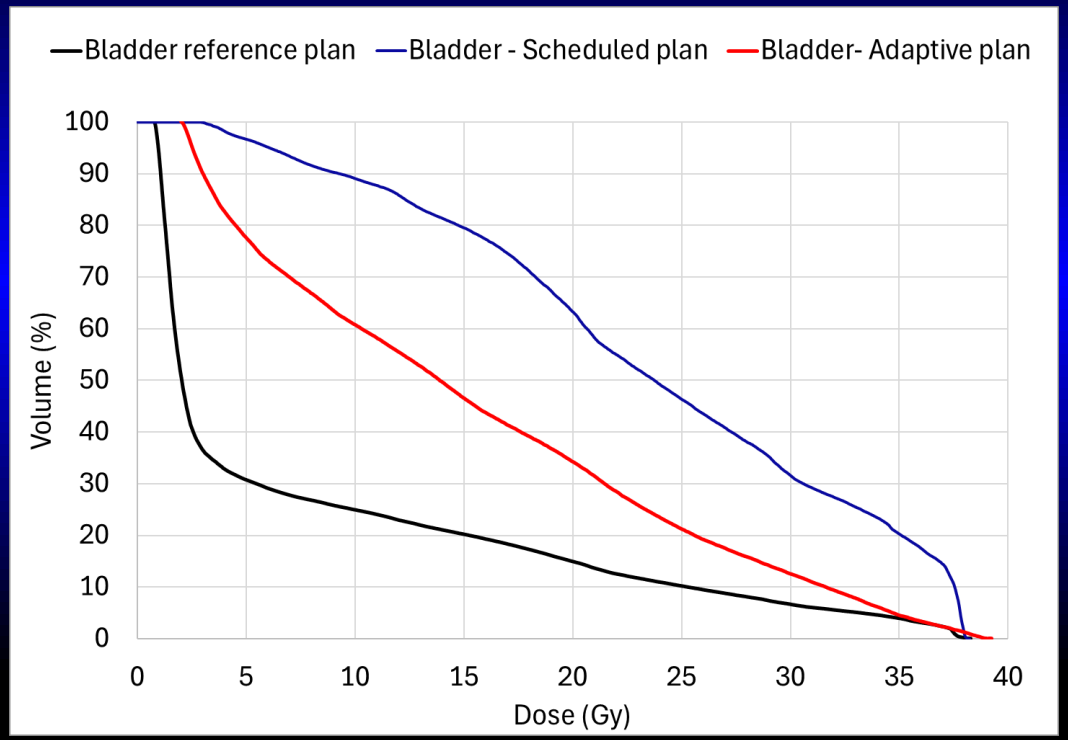
Simulation CT



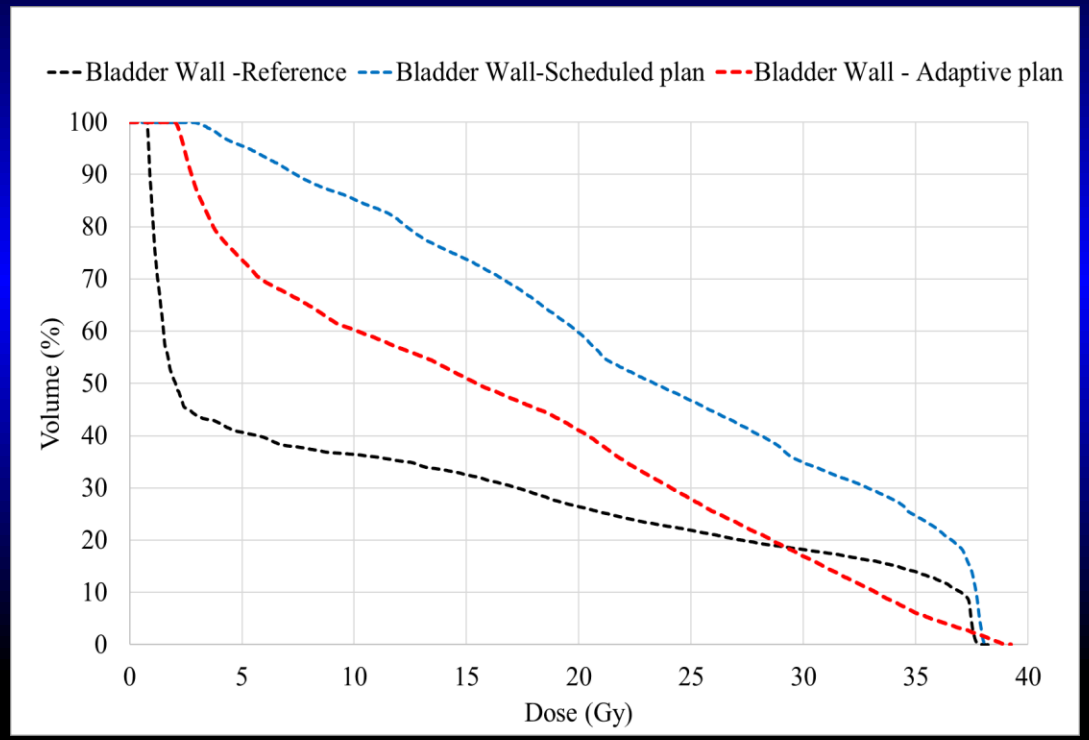
Bladder appeared smaller and overlapping with target volume.

Bladder Volume Control Still Necessary?

Whole bladder (solid organ)



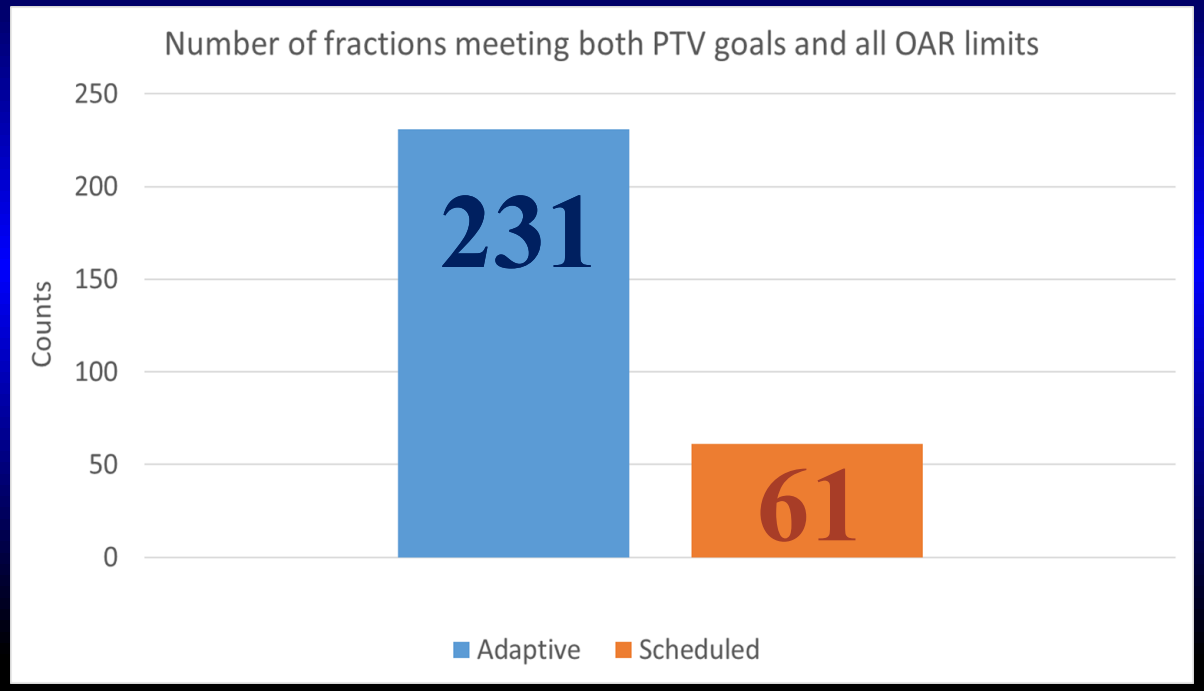
Bladder wall



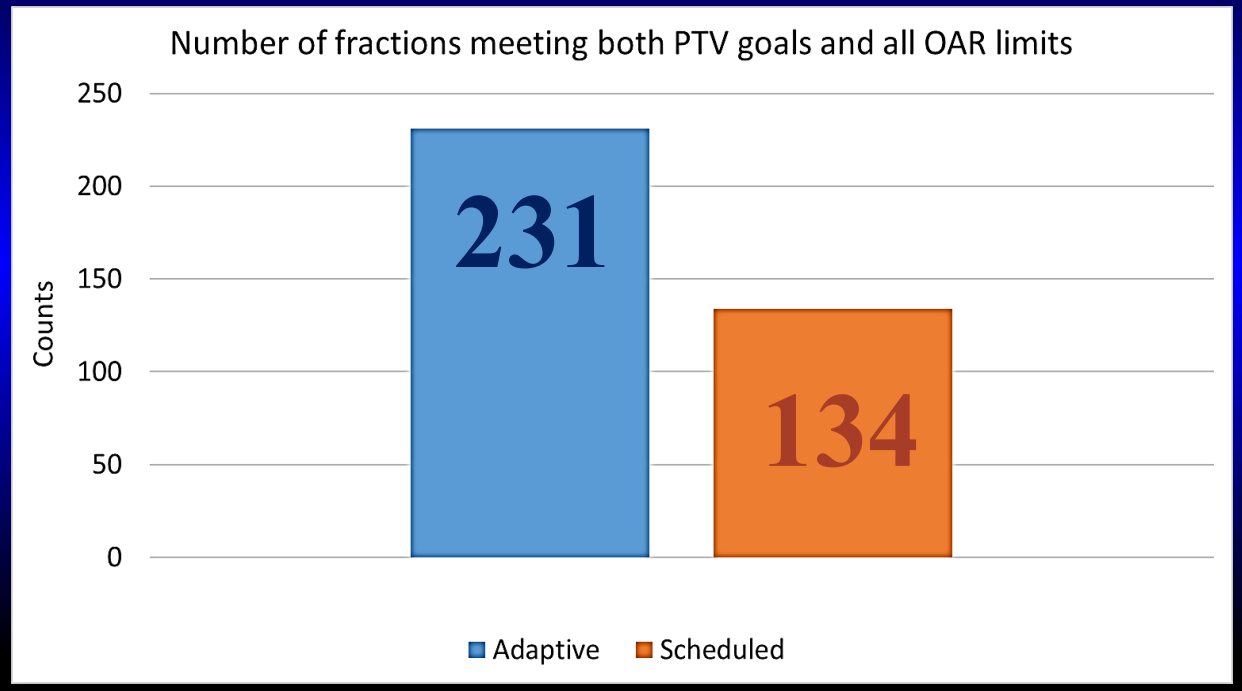
Full bladder is better than empty bladder!

Further Technical Improvement

Original Ethos plans



Re-normalize dose by 1.6%



Focus on 5-10% fractions with significant anatomical changes!

Conclusions

- **ART is beneficial to patients with large prostate rotation/deformation**
- **Adaptation to changes of anatomy as well as technique/workflow**
- **An integrated IGRT/ART workflow to improve effectiveness/efficiency**

Acknowledgment to FCCC ART/GU team