Workflow Optimization in Proton Therapy

Z. Li
University of Florida Proton Therapy Institute

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Clinical

Nancy Price Mendenhall, MD

Randy Henderson, MD

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Amy Sapp, RN

Connie Patillo, RN

Kristi Helow, RN

Karen, Bunk, RN,

Gail Sarto, RN

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Research

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Cindy Carroll
Chris Morris, MS
Jessica Kirwan, MA

Administrative

Stuart Klein, MHA
Holly Mostoller
Dwanda Smith
Shirley Tomlinson
Katie Rannow
Christina Leone
Kevin Hammonds
Tim Buist
Dawin Daise
Kathy McIntyre
Wendy Lawson
Sonya Williams
Thomas Allen
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Stephanie Williams
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Michelle Boychuck
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Outline

- Clinical workflow of radiotherapy
- Clinical workflow of proton therapy
- Workflow of prostate proton therapy
- Workflow of thoracic/abdomen proton therapy
- Summary

Clinical Workflow

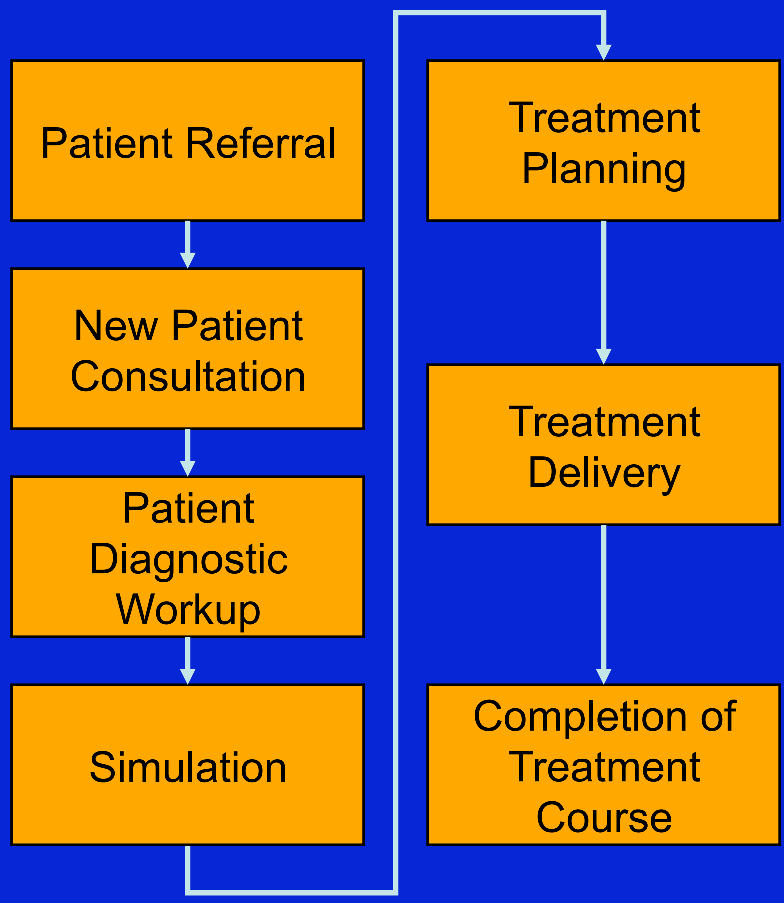
- Definition of workflow:
  - A series of activities performed by one or more users acting in a predefined role to complete a business process. (http://msdn.microsoft.com/en-us/library/bb246417.aspx)

Clinical Workflow

- Elements of workflow
  - Start and finish points
  - Events with variables and outcomes (goals, documentation)
  - Sequence of and relation between events
  - Timeline of events
  - Decision and bifurcation points
  - Responsible personnel
- Workflow may be represented by flowcharts, diagrams, or sequential descriptions

Radiotherapy Clinical Workflow

- A clinical workflow may be defined for each aspect of radiotherapy clinical operations
- A traditional clinical flow may include a sequence of events as shown

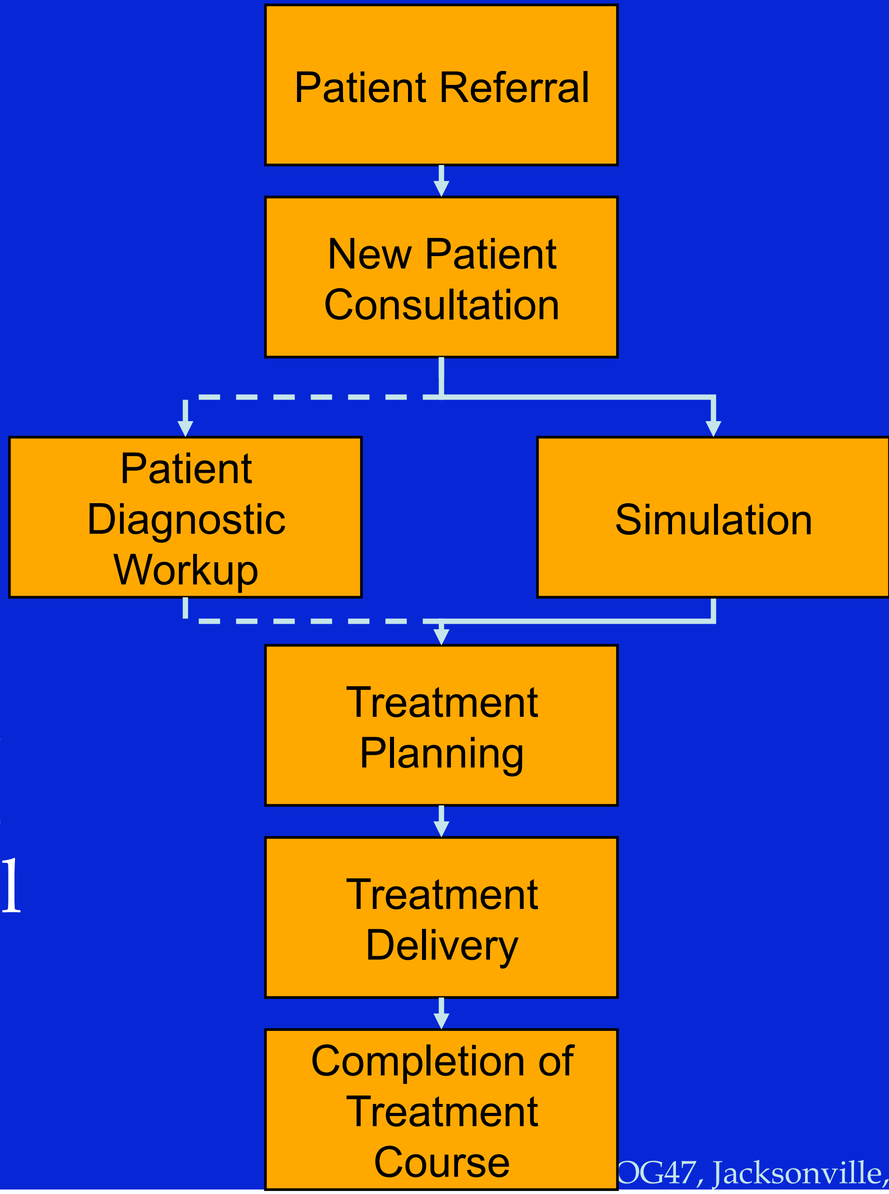


Need for Optimized Workflow in Proton Therapy

- Proton therapy remains a rare and expensive resource
  - Concurrent occurrence of diagnostic workup and simulation/treatment planning
  - Optimized treatment room scheduling to minimize unused beam time

Proton Therapy Clinical Workflow

- Proton therapy may have altered clinical flow due to the long distance that patients need to travel to a proton therapy facility
- Accurate final patient diagnosis must be available prior to completion of treatment planning to avoid waste of resources, or potential error in treatment plan and delivery



Need for Optimized Workflow in Proton Therapy

- Dose calculation and delivery of proton therapy is highly sensitive to various sources of uncertainties
  - CT HU –stopping power conversion
  - Increased RBE at distal falloff region of SOBP
  - Dose calculation uncertainties
  - Physiological changes
  - High-Z metal implant artifacts
  - Organ motion
  - Tumor regression or progression

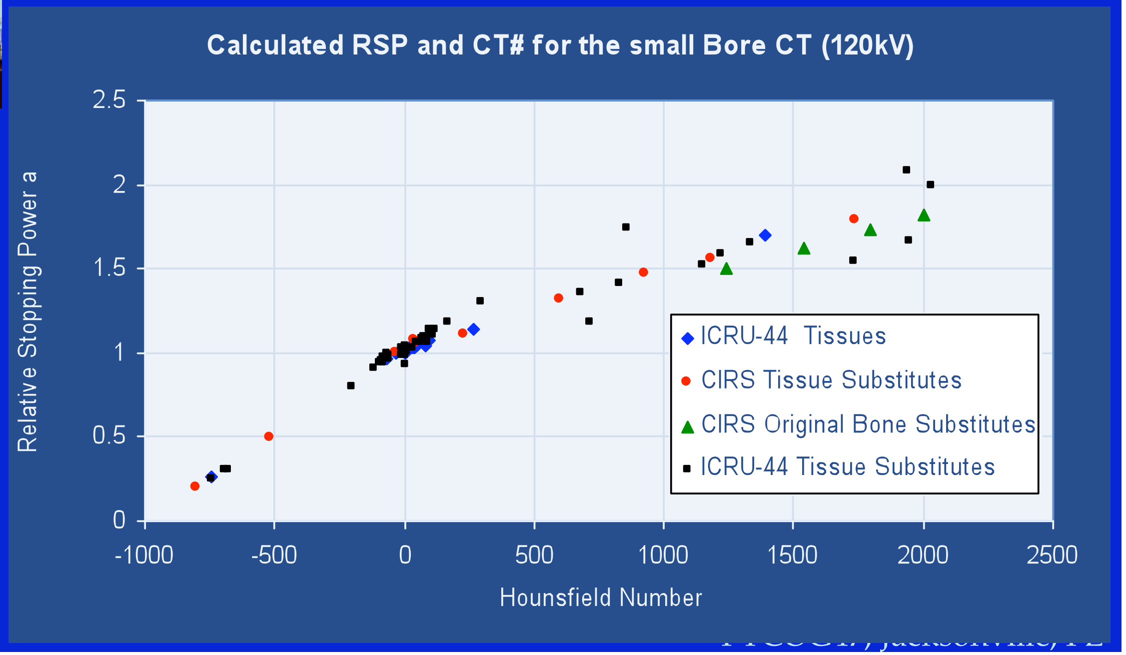
Uncertainties in Proton Therapy

- Range uncertainties due to CT HU – stopping power conversion
  - Conventional electron density phantom material differences from ICRU recommendations
  - Phantom size
  - High-Z material location in phantom (periphery vs center)
  - Reconstruction algorithm

Effect of Phantom Material

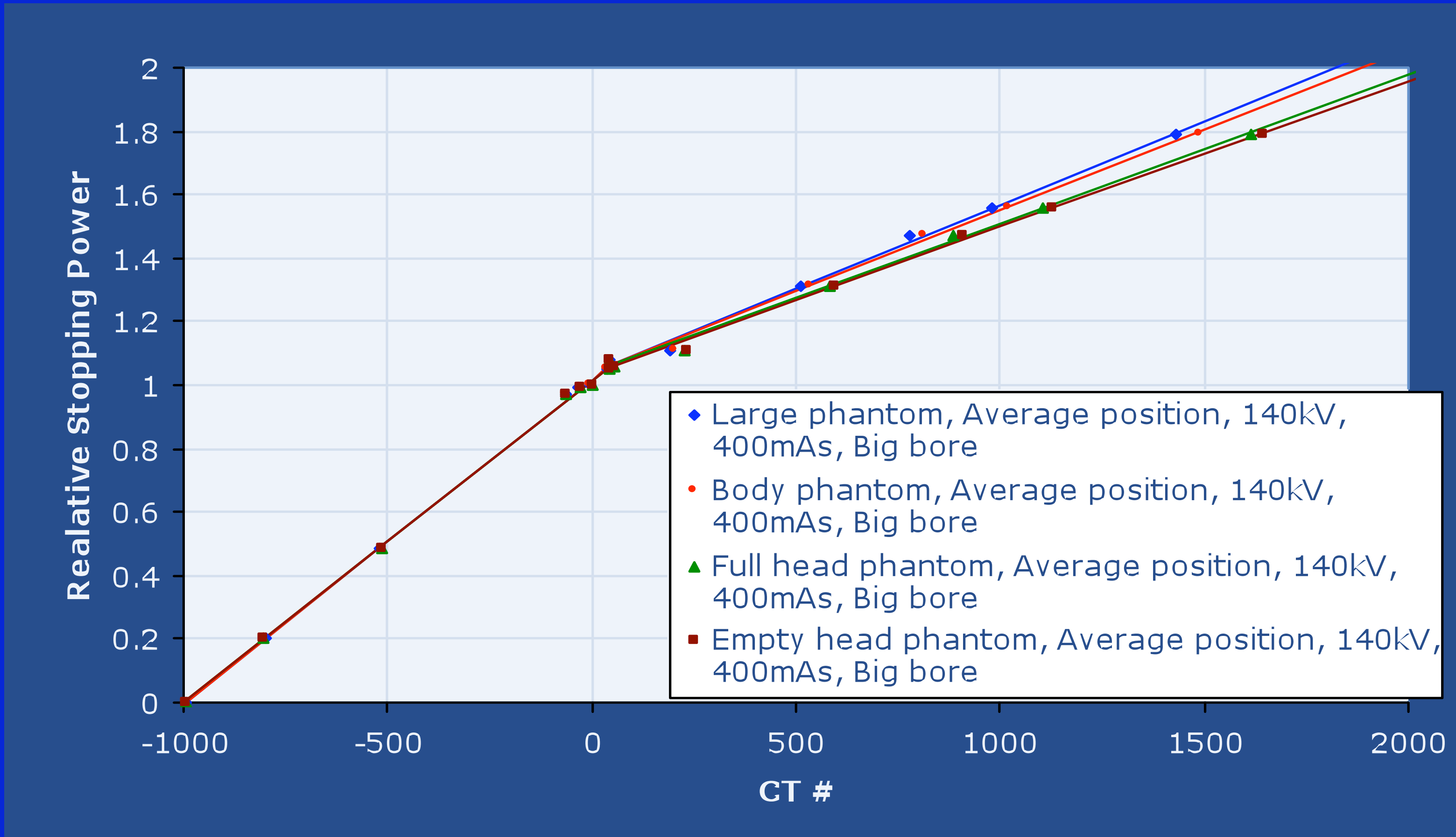
* Modular phantom made of solid water:
  - » Head (~18 cm WE diameter)
  - » Body (~30.5 cm WE diameter)
  - » Large Body (~39 cm WE diameter)
* 20 Tissue equivalent plugs

What is tissue equivalent?



S. Flampouri, 2007

Effect of Phantom Size



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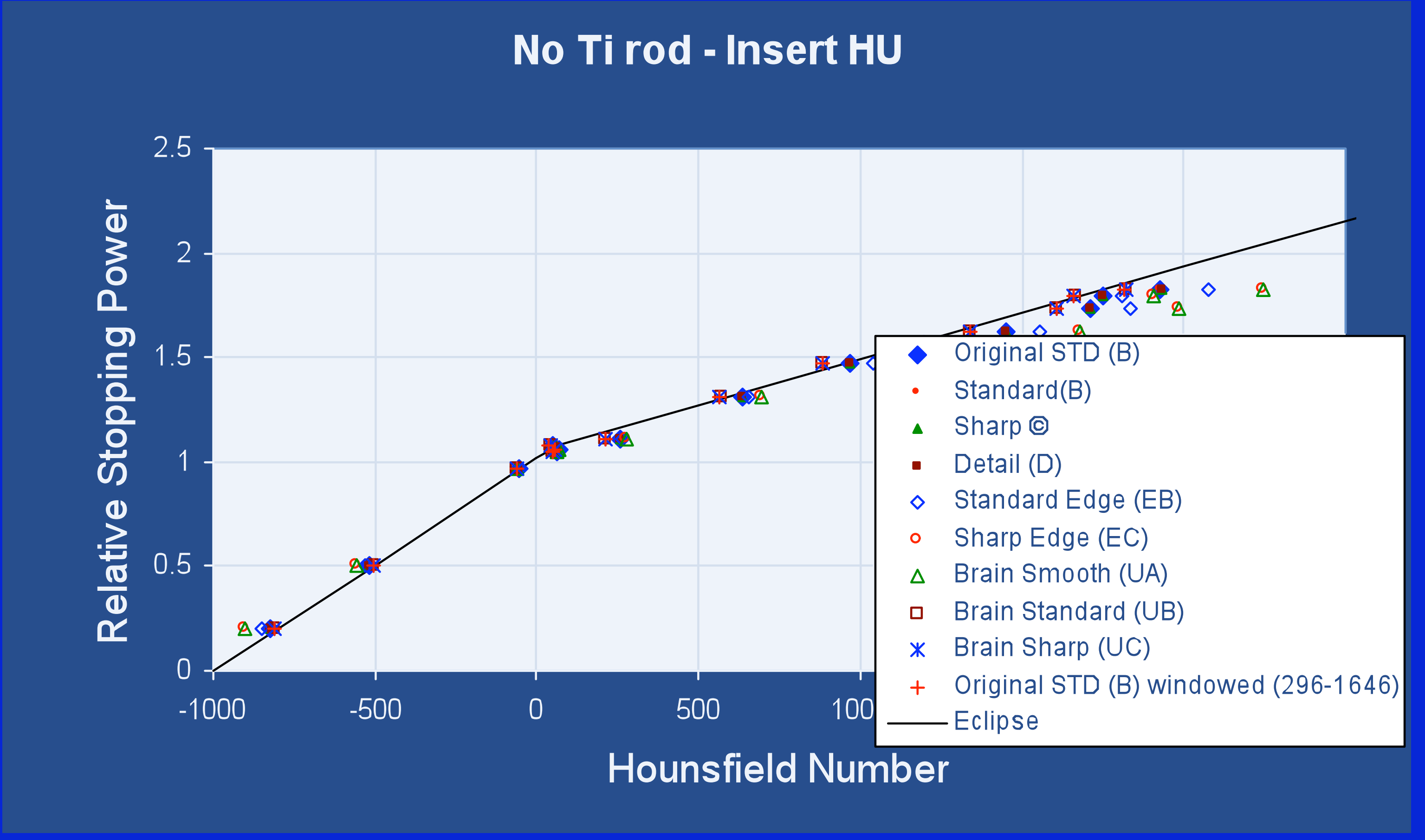
Effect of Reconstruction Algorithm



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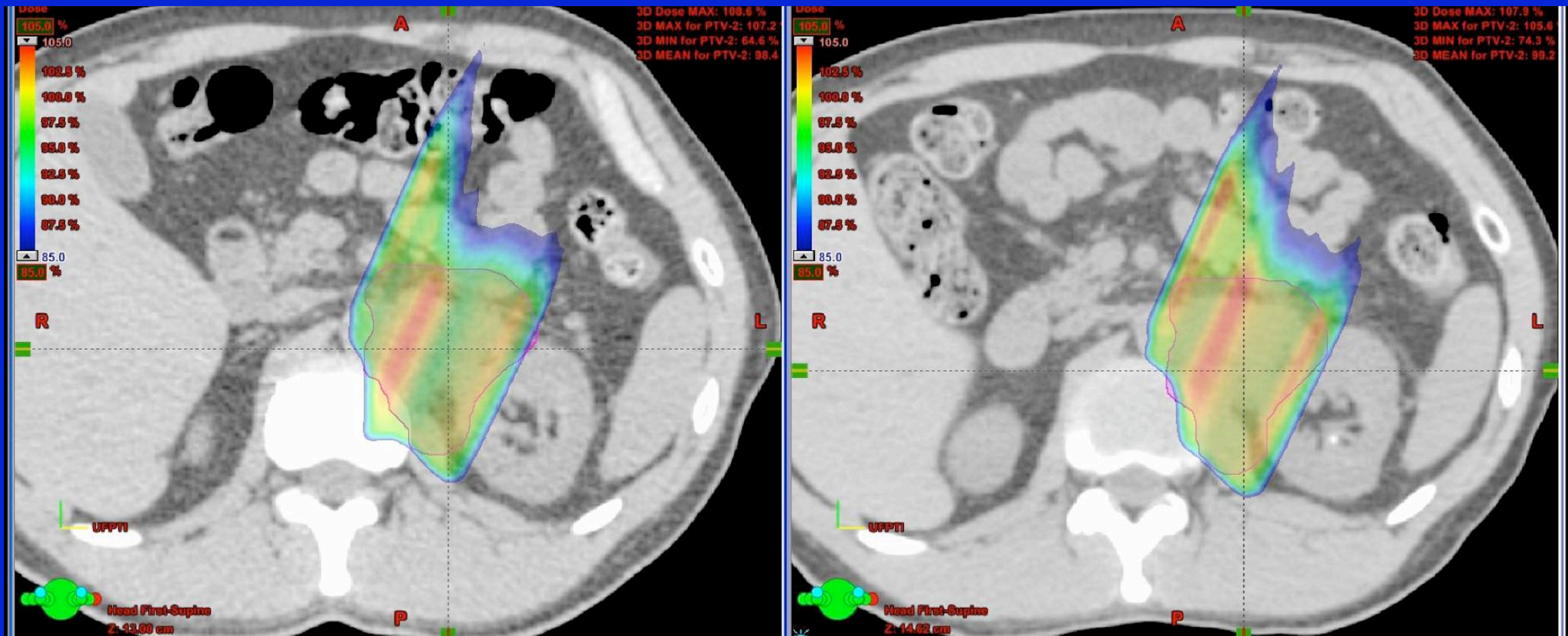
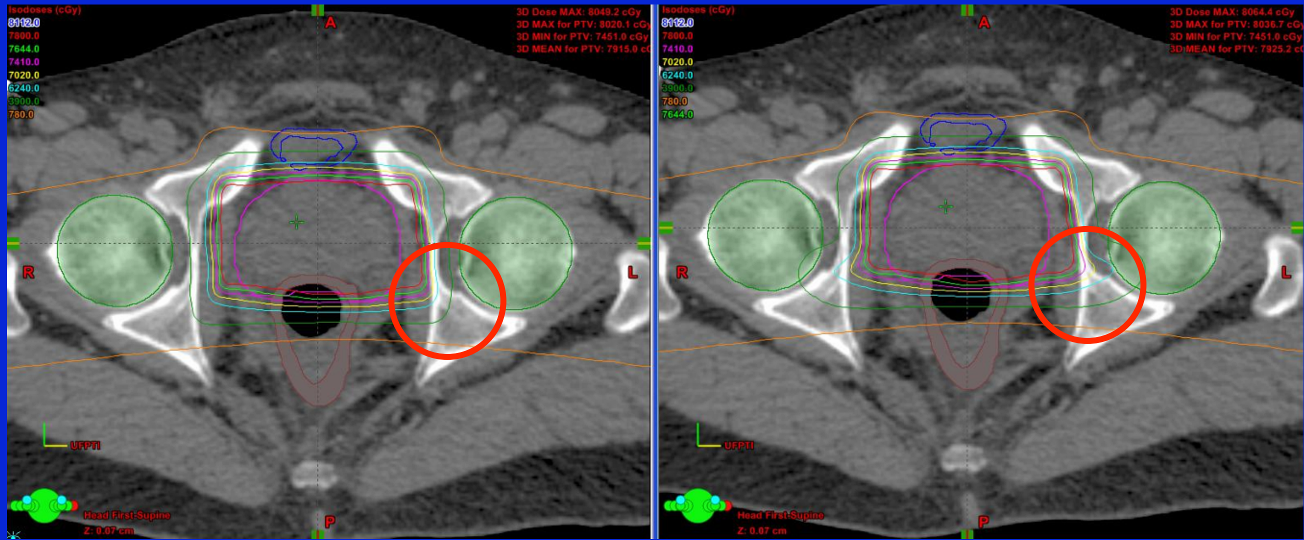
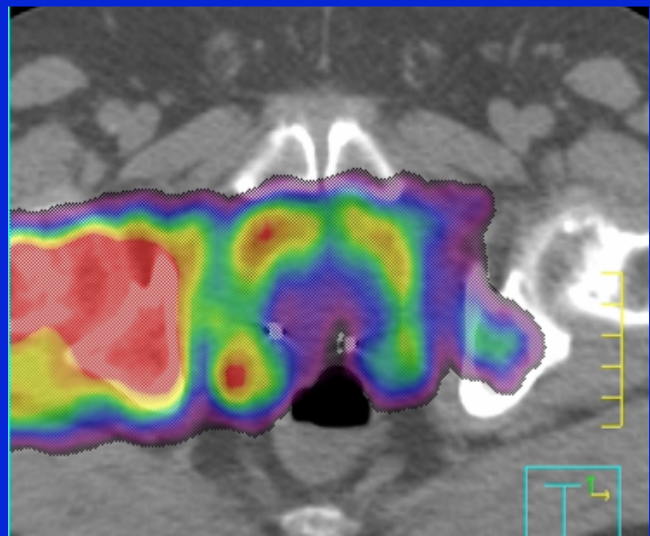
Uncertainties in Proton Therapy

- Range uncertainties due to physiological changes
  - Small bowel filling
  - Lung density change due to breathing
  - Rectal gas presence and amount of bladder filling



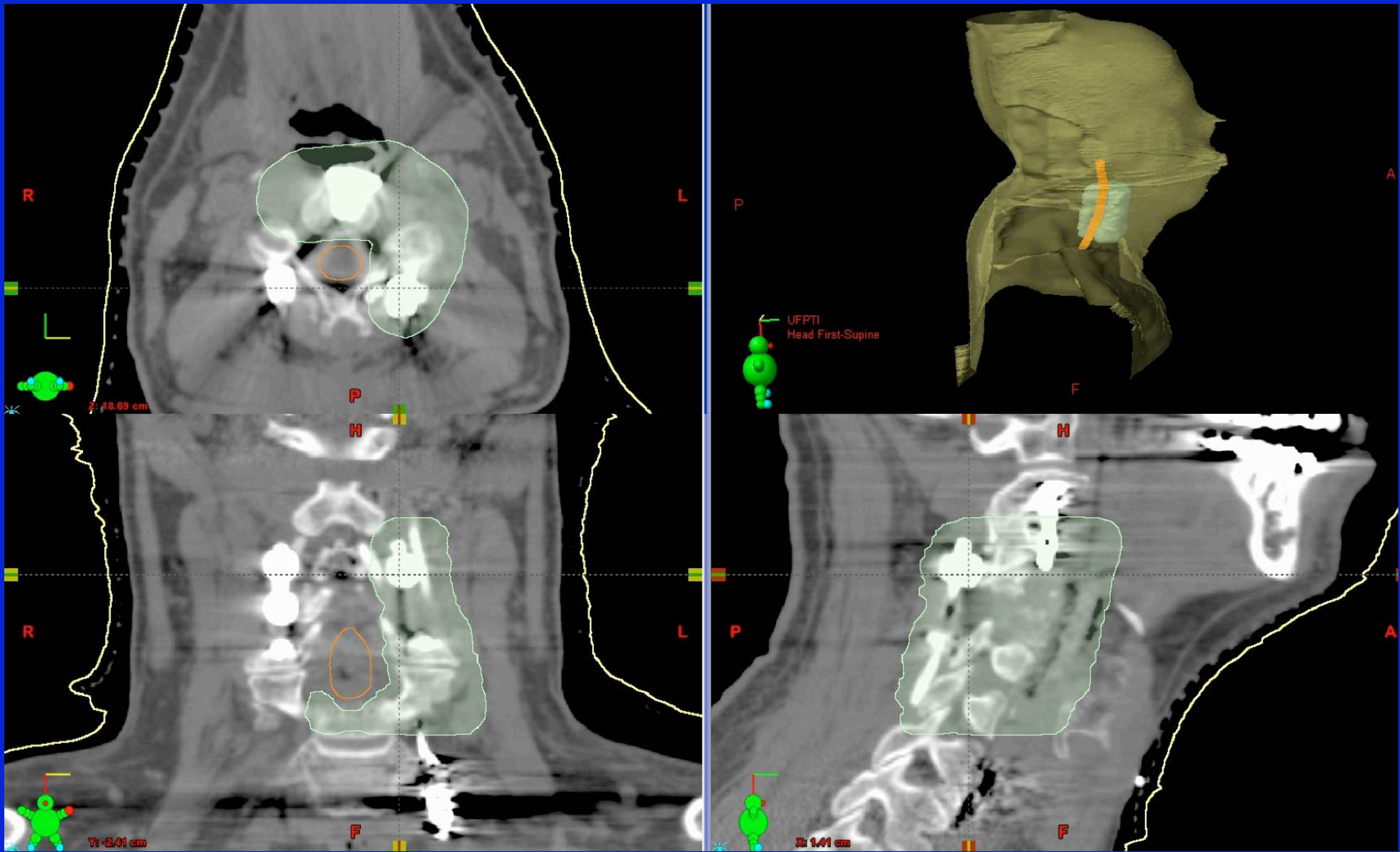
Uncertainties in Proton Therapy





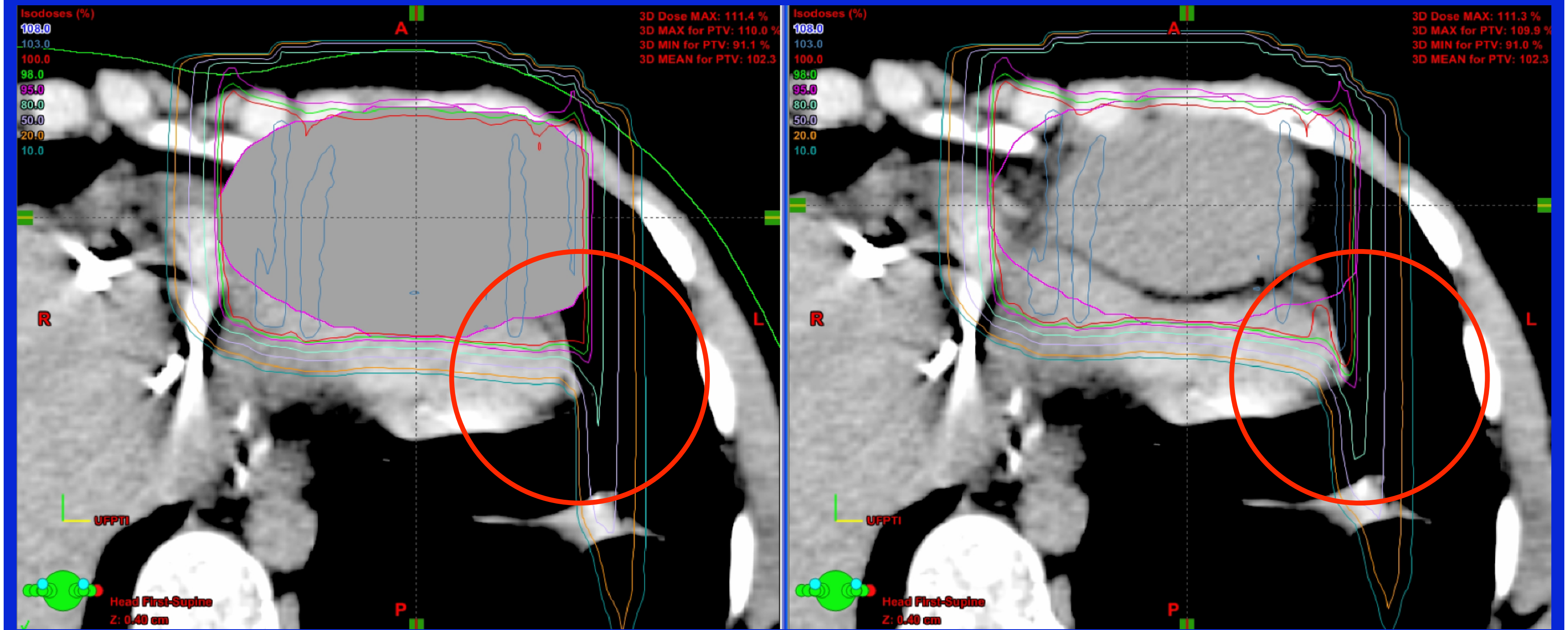
Uncertainties in Proton Therapy

- Range and lateral penumbra uncertainties due to implanted metal



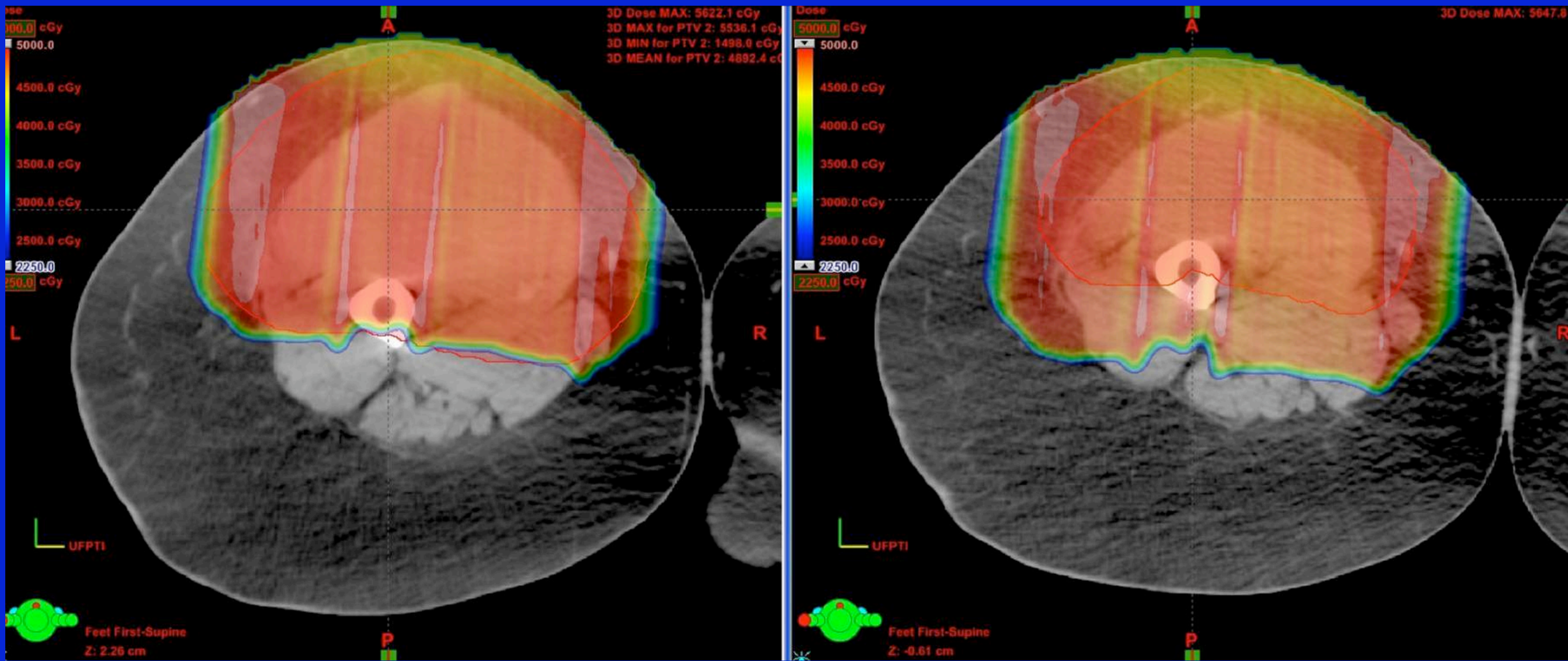
Uncertainties in Proton Therapy

- Range uncertainties due to organ motion and setup error (thoracic treatments)



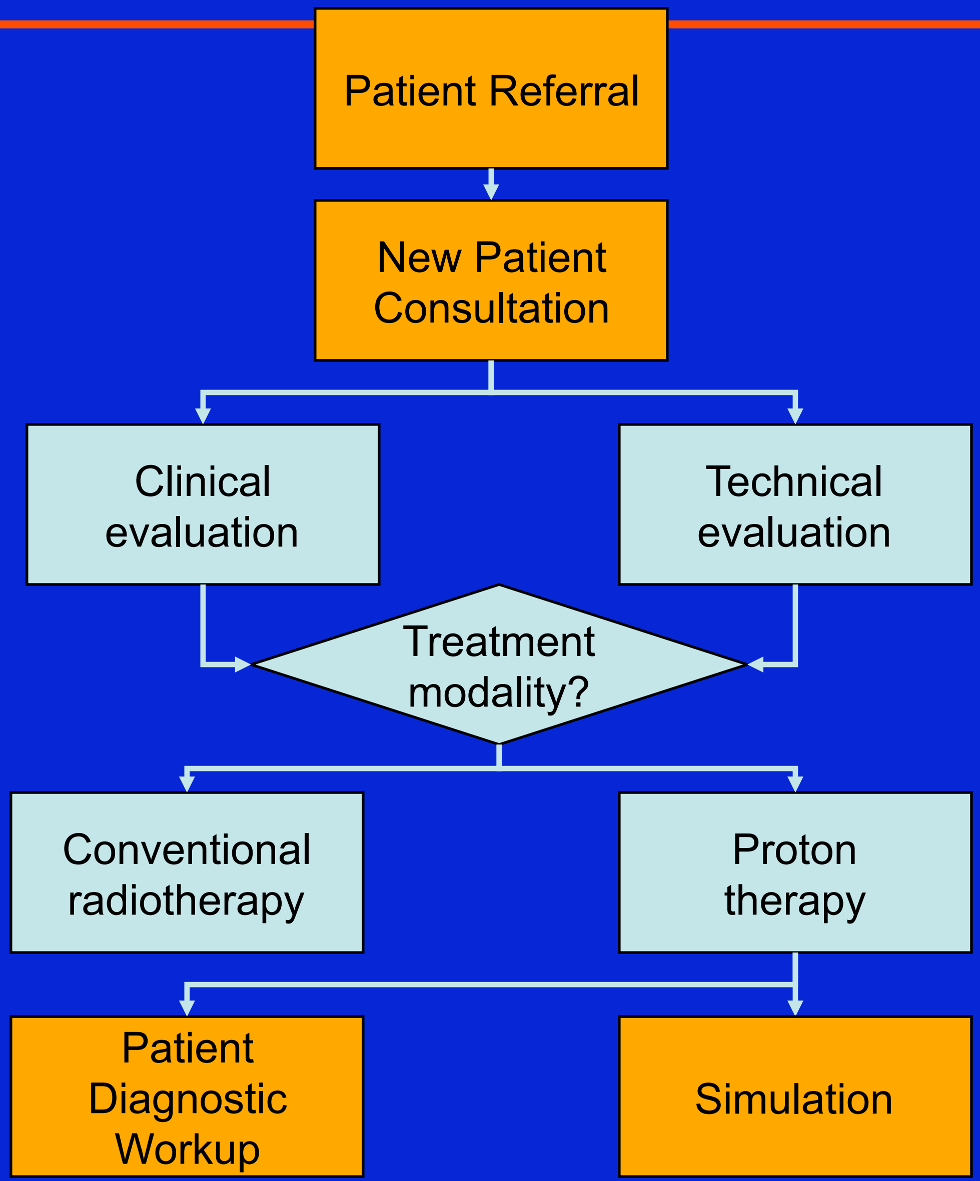
Uncertainties in Proton Therapy

- Range uncertainties due to tumor regression or progression



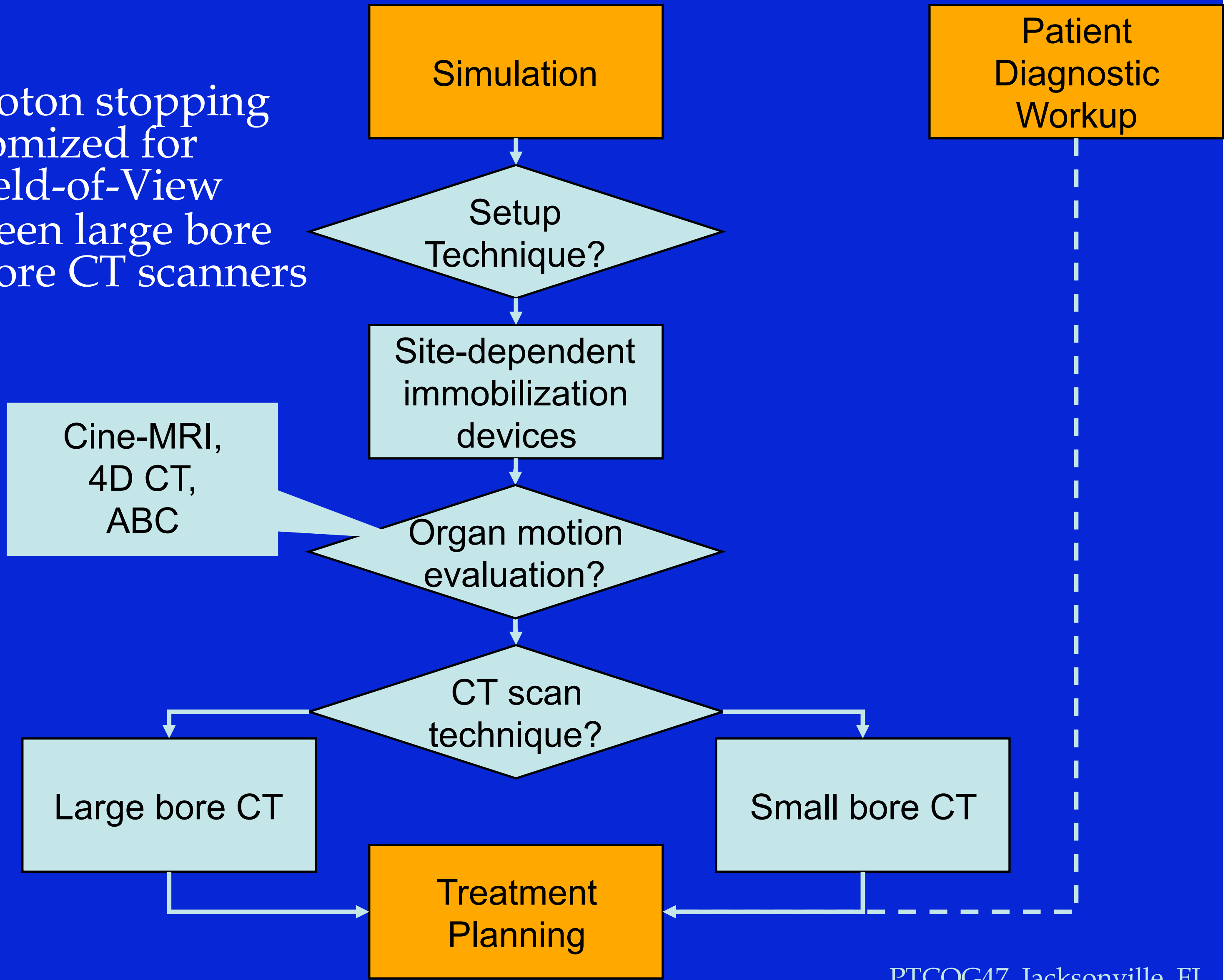
Proton Therapy Workflow

- Patient selection for proton therapy performed in *Proton Therapy Patient Disposition Conference* for new disease sites or patients that may require special considerations in simulation, planning, and delivery techniques



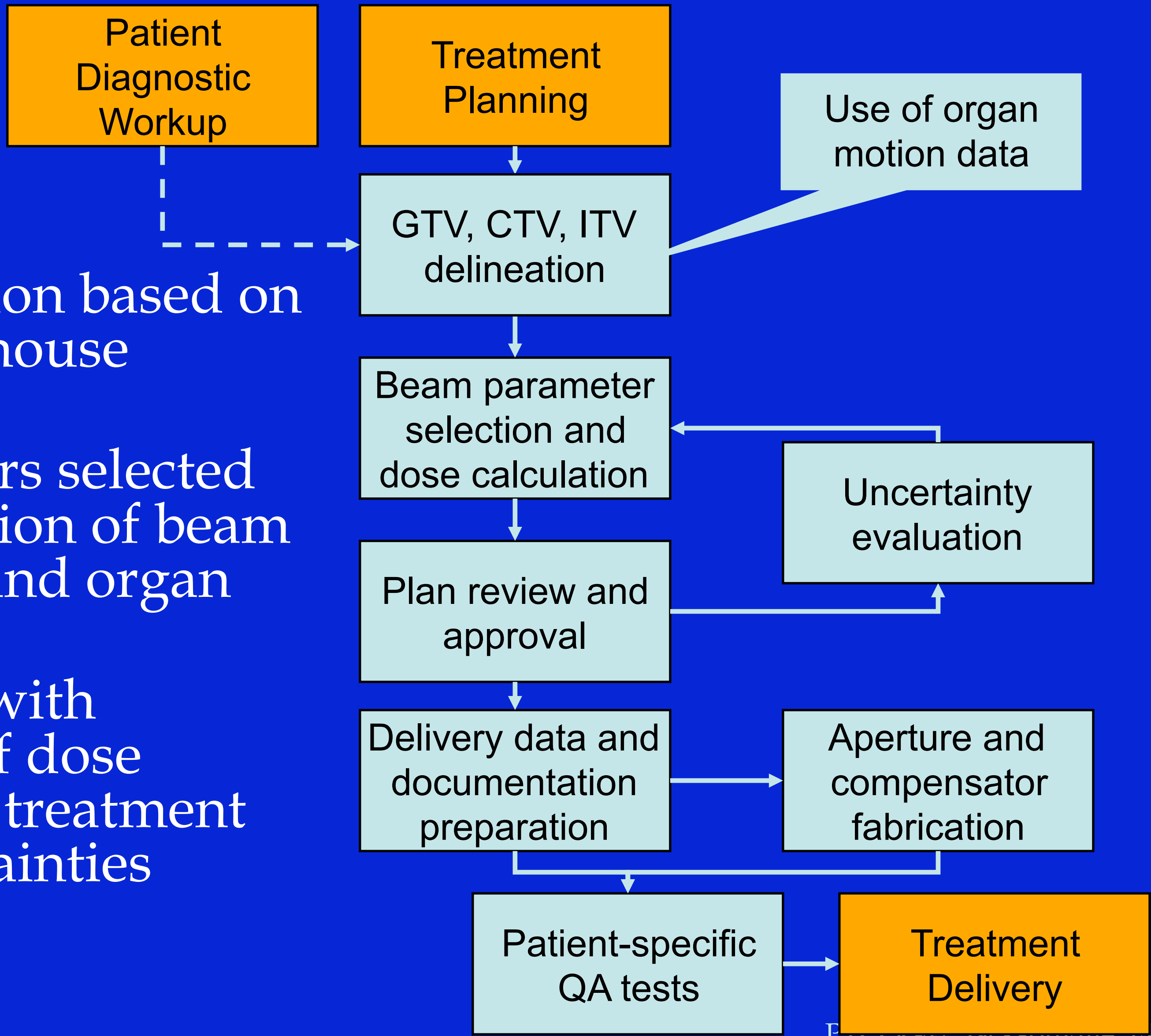
Proton Therapy Workflow

- CT HU – proton stopping power customized for scanning Field-of-View (FOV) between large bore and small bore CT scanners



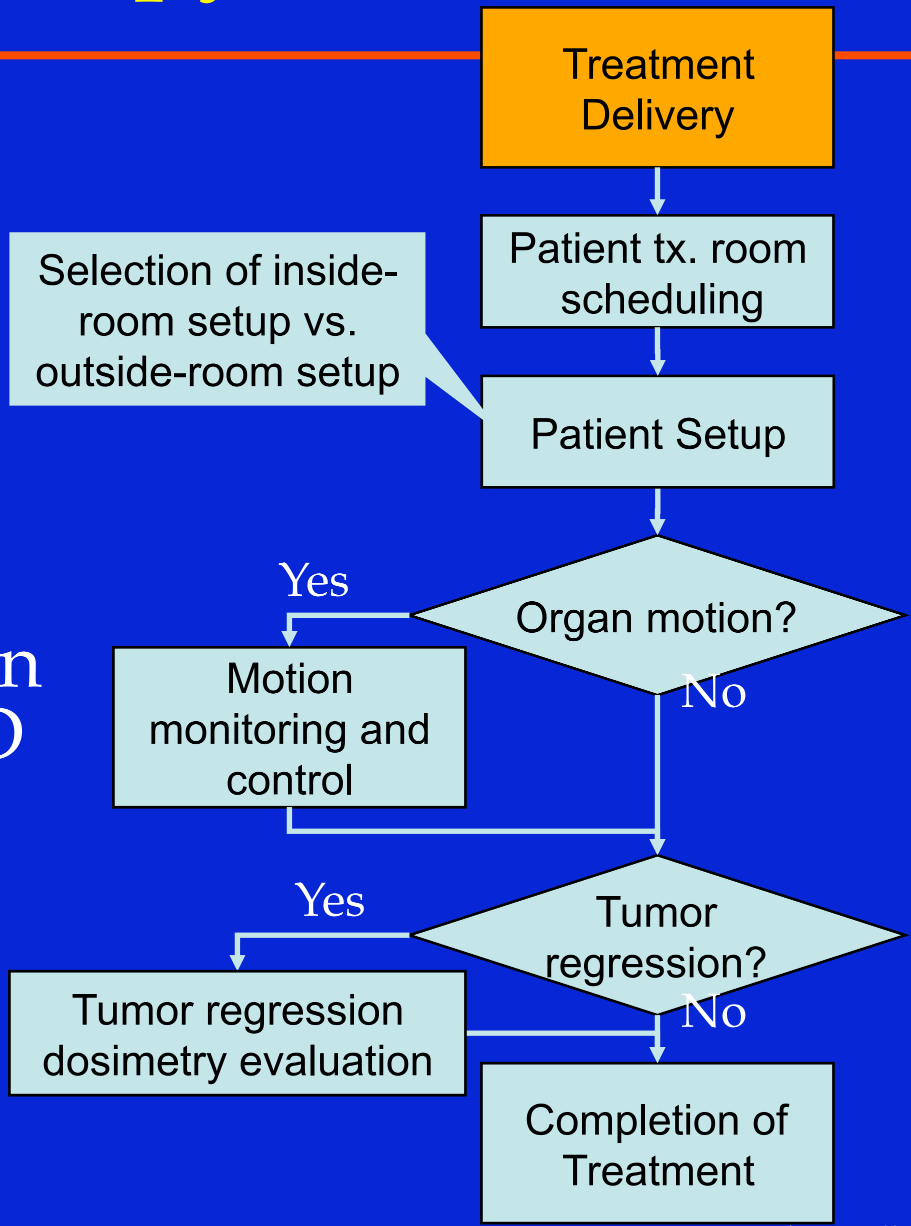
Proton Therapy Workflow

- Target delineation based on standard or in-house protocols
- Beam parameters selected with consideration of beam characteristics and organ motion data
- Plan reviewed with consideration of dose calculation and treatment delivery uncertainties



Proton Therapy Workflow

- Patient scheduling is constrained by
  - Need for anesthesia
  - Need for snout changes
  - Expected in-room time
  - Between-fraction time for BID treatments
- Motion monitoring action levels calculated from 4D CT or ABC scan data
- Tumor regression monitored by repeat imaging studies
- *Adaptive Proton Therapy*



Patient Treatment Room Scheduling

- At UFPTI:
  - Schedule anesthesia patients to same room (Gantry 1)
  - Schedule all BID patients to same room (Gantry 2)
  - Dedicate one of three gantry rooms (Gantry 3) to prostate treatments
  - All prostate patients in the dedicated prostate treatment room will use same size snout
  - Group patients with same size snout together in daily treatment delivery schedule
  - *Automatic optimized patient scheduling system under development with Industrial Engineering Dept. of Univ. of Florida*

Optimization of Workflow for Prostate Proton Therapy

- Prostate treatment:
  - Intra-fraction motion monitoring

Image courtesy of Marcel V Herk

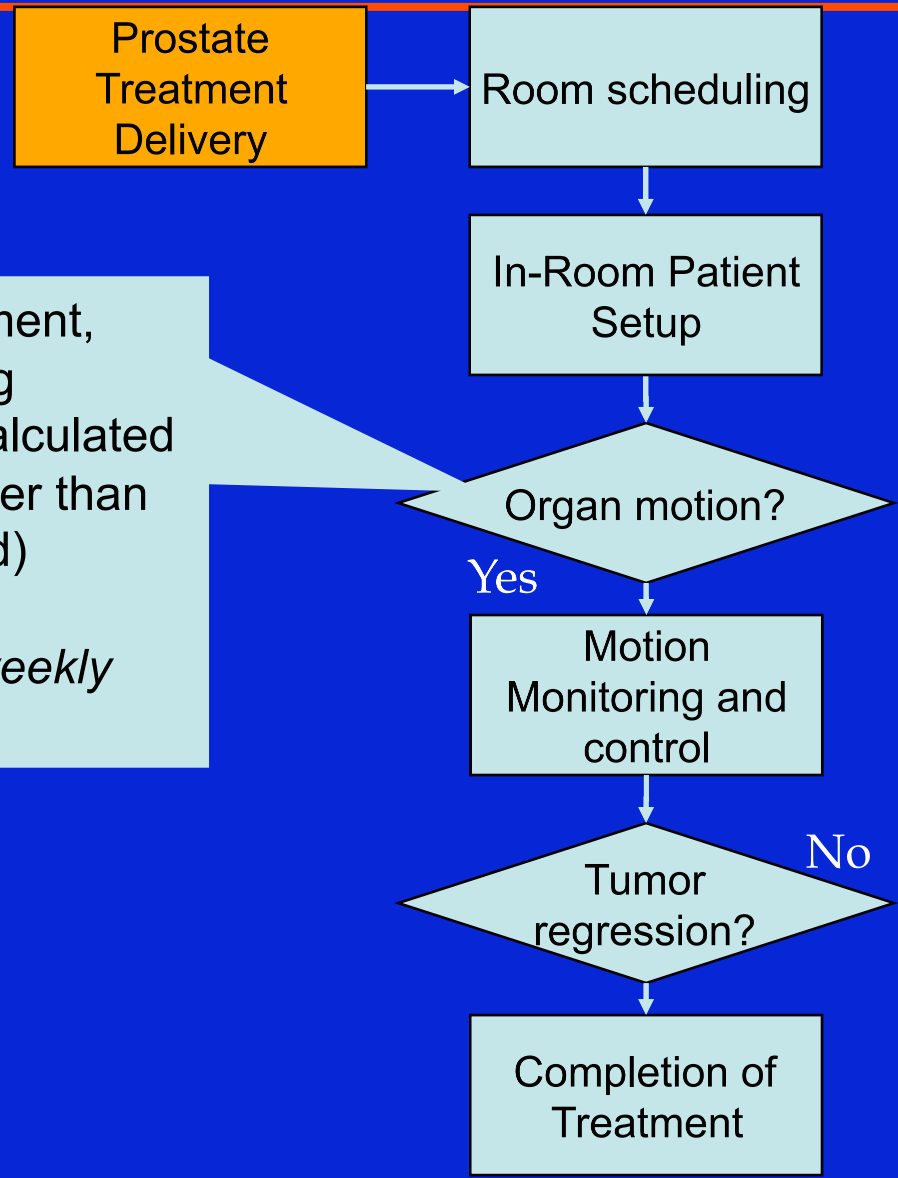
Prostate Motion Monitoring

- A PTV margin was calculated to allow CTV coverage in 95% of treatments for 90% of patients (van Herk, IJROBP, 2000)
  - Assuming setup error bounded within +/- 2 mm with daily orthogonal imaging and VisiCoil fiducial markers
  - Assuming prostate intra-fraction motion of 2 mm in 5 min
  - PTV margin = 4 mm axial and 6 mm cranial-caudal
  - *How to identify the 10% patients with larger intra-fraction prostate motion magnitude?*

Prostate Motion Monitoring

- Treatment Delivery Workflow Tasks:
  - Confirmation of appropriateness of PTV margin for *a specific patient* during treatment delivery
  - Selection of actions to take for *a specific patient* when intra-fraction motion magnitude is larger than assumption

Prostate Motion Monitoring



1. During first 10 days of treatment, perform post-tx DIPS imaging
2. Inform treating physician if calculated post-tx correction values larger than 4 mm (< 1 out of 10 expected)
3. Record correction values
4. After first 10 days, perform *weekly* post-tx imaging

Results of Prostate Motion Monitoring

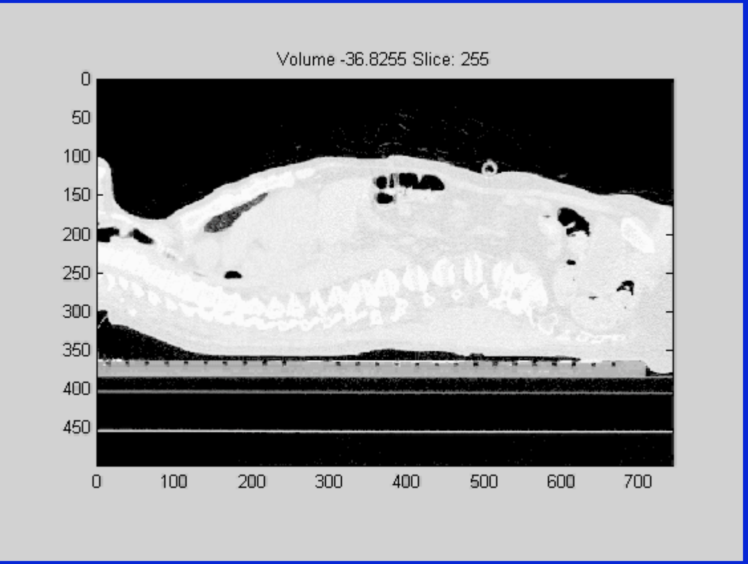
- For week of May 12, 2008 – May 16, 2008:
  - 181 Post-treatment DIPS image pairs taken
  - 10 of 181 with DIPS-calculated correction vectors larger than 4 mm axial or 6 mm cranial-caudal
  - 5.5 % of image pairs out of tolerance
    - 9 % expected
  - *Prostate motion monitoring working as expected*

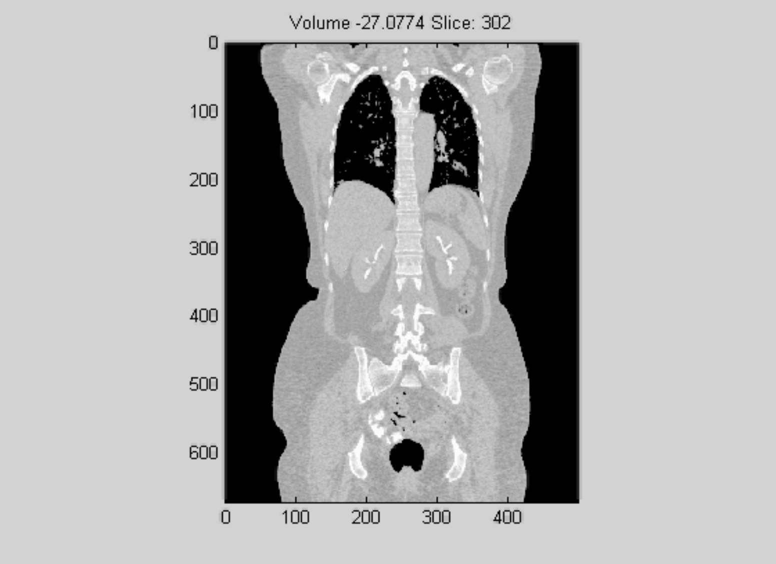
Prostate Motion Monitoring and Control

- Actions to improve control and reduce dosimetric effect of prostate intra-fraction motion
  - Patient diet control
  - Additional saline in rectum
  - Use of rectal balloon
  - Increase aperture margin

Optimization of Workflow for Thoracic/Abdomen Proton Therapy

- Thoracic and abdomen tumors
  - Proton range uncertainties due to lung perfusion or bowel content changes
  - Proton range uncertainties due to organ motion
  - Tumor regression during treatment





Images courtesy of D. Low

Thoracic/Abdomen
Organ Motion Evaluation

1. Perform 4D CT scan
2. If patient is candidate for use of ABC device, perform 3 ABC scans
3. Compare maximum target excursion between 4D CT scans and ABC scans to select technique to use
4. Calculate PTV margin and patient setup imaging tolerances

Simulation

Setup Technique?

Medical Intelligence BodyFIX system

Organ motion evaluation

Large bore CT

Treatment Planning

Treatment Planning for Thoracic and Abdomen Tumors

1. Use **average** 4D CT or ABC scans for ITV delineation
2. Override IGTV with tissue HU for thoracic tumor

   (Kang et al, IJROBP 2007)

Treatment Planning

GTV, CTV, ITV delineation

Beam parameter selection and dose calculation

Plan review and approval

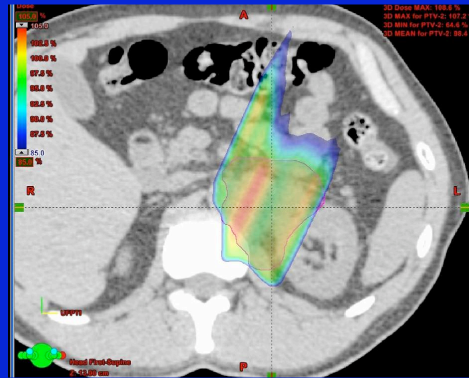
Delivery data and documentation preparation

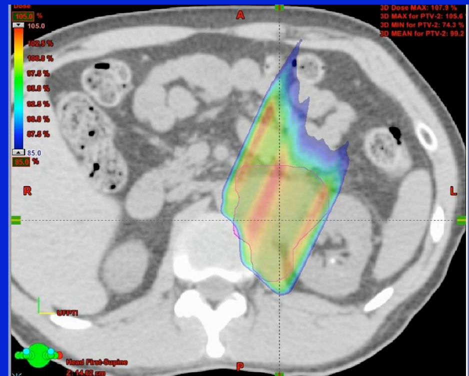
Aperture and compensator fabrication

Patient-specific QA tests

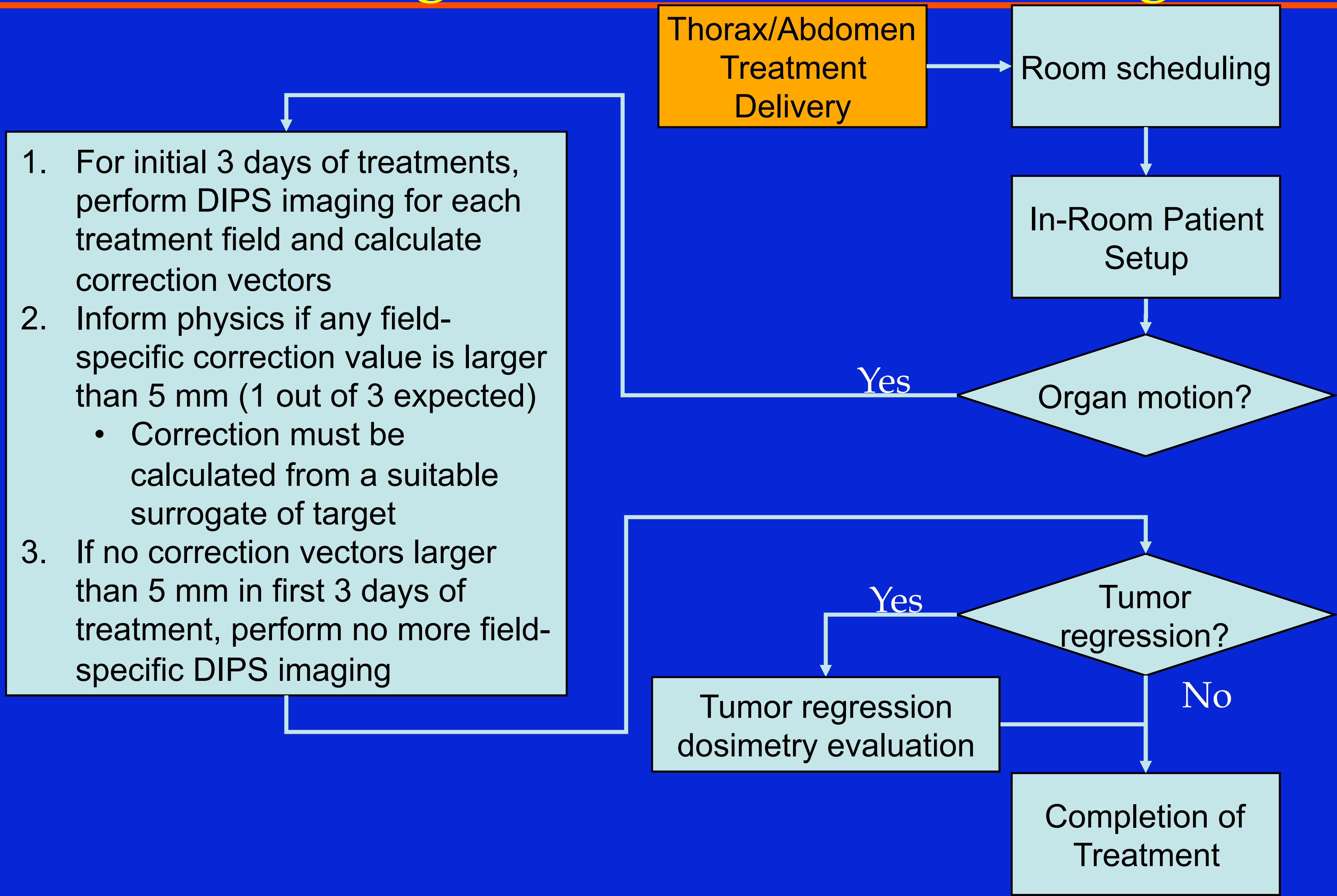
Treatment Delivery

1. Minimize weightings of beams with larger range uncertainties due to physiological changes
2. Use distal blocking for beams stopping near critical organs to reduce impact of range uncertainties and increased RBE
3. For patients receiving proton therapy as boost treatment following photon irradiation, constrain proton beam paths to within previous photon beam paths when possible





Thoracic and Abdomen Organ Motion Monitoring

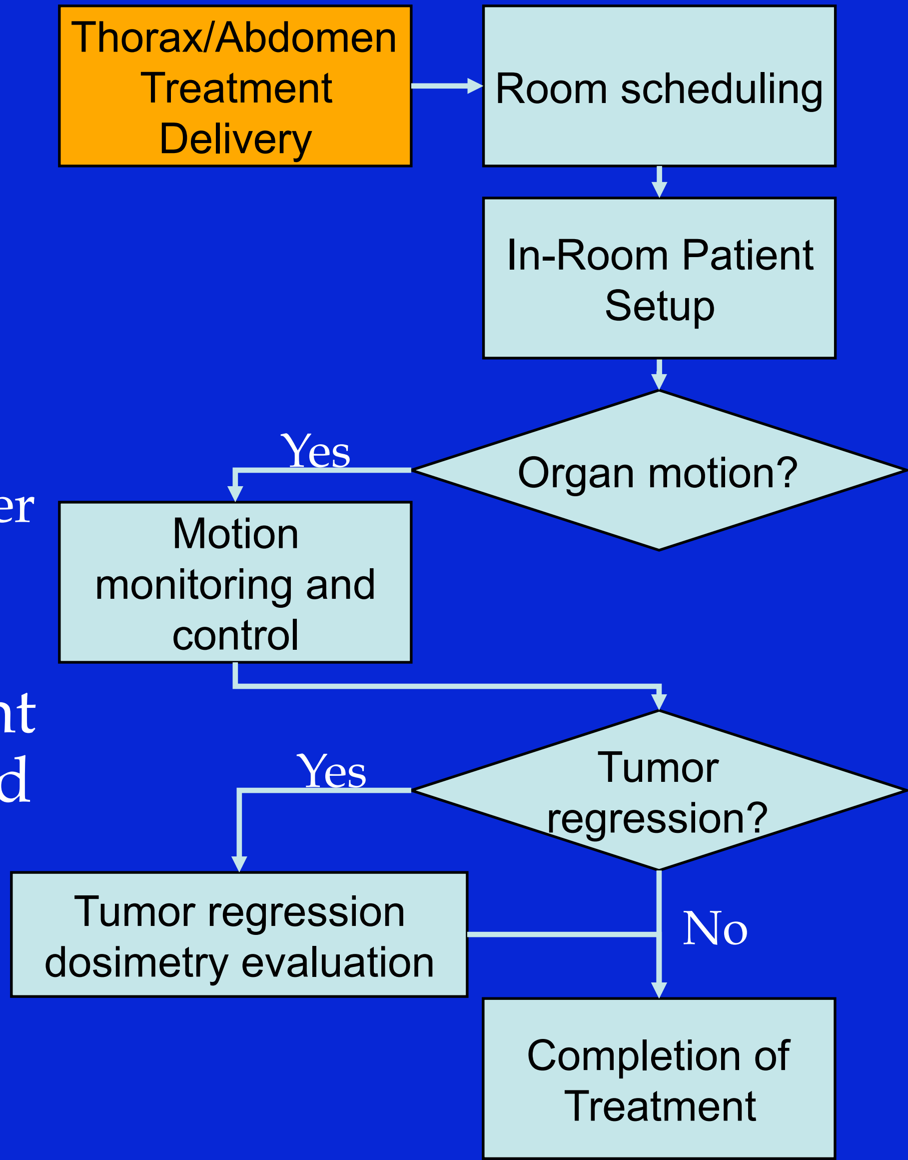


Results of Thoracic and Abdomen Organ Motion Monitoring

- Between April 30, 2008 and May 15, 2008:
  - 36 field-specific DIPS images obtained
  - 1 image showed larger than 5 mm correction
  - 2.8 % of images out of tolerance
  - *More data needed for validation of hypothesis*
  - *Potential to reduce target margin*

Thoracic and Abdomen Tumor Regression Monitoring

- Patient receives, in alternate weeks, PET-CT activation study scans, or 4D CT/ABC scans as patient is treated
- 4D CT/ABC scans reviewed for tumor regression
  - Tumor regression models under development at UF
- Verification plan performed on new CT scans if significant dosimetric changes suspected



Summary

- Proton therapy differs significantly from conventional radiotherapy in its higher sensitivity to various sources of uncertainties
- Disease-site-specific clinical workflow must be designed to address the dosimetric effects of these uncertainties
- These workflow modifications may require increased efforts compared to their conventional therapy counterparts, but are necessary to optimize proton therapy treatments