# Clinical Implementation of a Proton Therapy System

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## Acknowledgements

#### Clinical

Nancy Price Mendenhall, MD

Robert Malyapa, MD, Ph.D. Sameer Keole, MD

Carlos Vargas, MD

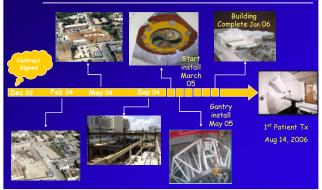
## Technical

Zuofeng Li, DSc Daniel Yeung, PhD Rolf Slopsema, MS Stella Flampouri, PhD Darren Kahler, PhD Wen Hsi, PhD George Zhao, PhD Liyong Lin, PhD

### Outline

- Overview of the University of Florida Proton Therapy Institute (UFPTI)
- Overview of clinical operations and work flow at UFPTI
- Review of a strategic and operational optimization model of Patient Scheduling
- Personal Observations

## The University of Florida Proton Therapy Institute (UFPTI)



# **UFPTI Proton Area** fixed beam 🕼 IBA 3 gantry rooms 230 MeV Cyclotron **Integrated Facility Management** • Treatment Planning Patient Scheduling Treatment Control & Delivery

#### **UFPTI Conventional and Simulation Area**

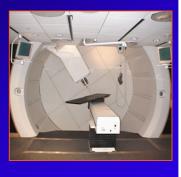


### **UFPTI Equipment**

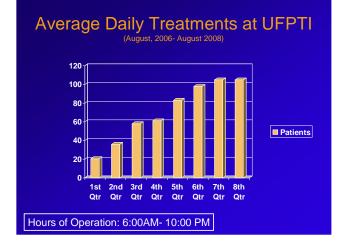
- IBA Proteus 235 Proton Therapy System 3 Gantry Treatment Rooms, 1 Eye Treatment Room
- Conventional Therapy Equipment
- 2 Elekta Synergy LINACs with Camera Systems
- Simulation
  - Philips Big Bore CT, PET-CT, and 0.23 T open MR Scanners
- Treatment Planning
- Varian Eclipse and Philips Pinnacle system for proton and conventional treatment planning respectivelyFacility Management System
- IMPAC MOSAIQ

Nozzle installed on gantry Snout installed in nozzle

- PPS: 6 degree-offreedom isocentric motion
  - 50X50X50 cm<sup>3</sup> treatable volume
  - +/- 3° ranges of pitch and roll
  - corrections

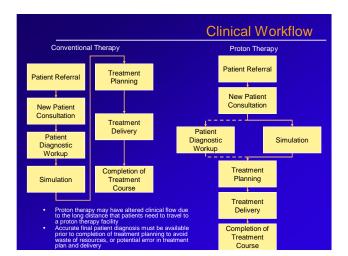


**Proton Gantry and PPS** 



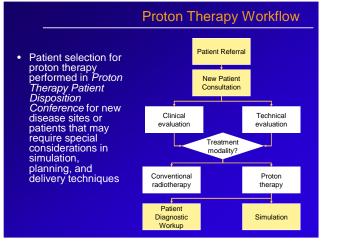
## **Clinical Operations and Workflow**

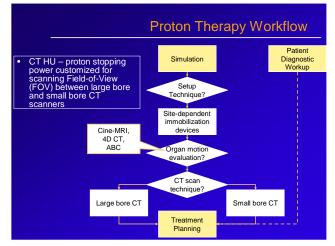
Carlos Vargas, Robert Malyapa, and Nancy Mendenhall: Physicians Zuofeng Li, Wen Hsi, and Daniel Yeung: Physicists Gary Barlow, Trevor Fleming Ernie St John; Therapists Debbie Louis and Craig McKenzie; Dosimetrists Stuart Klein; Administrator

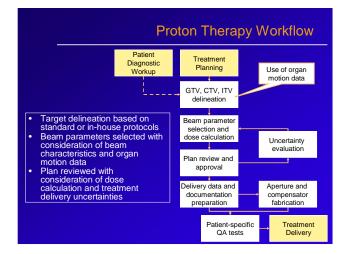


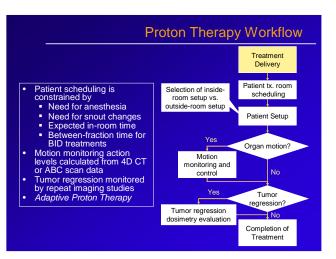
### Need for Optimized Workflow in Proton Therapy

- 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









#### 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 cranialcaudal
  - 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 Prostate Room scheduling Treatment Delivery In-Room Patient 1. During first 10 days of treatment. Setup perform post-tx DIPS imaging 2. Inform treating physician if calculated post-tx correction values larger than Organ motion? 4 mm (< 1 out of 10 expected) es 🕴 3. Record correction values Motion After first 10 days, perform weekly Monitoring and post-tx imaging contro Tumor regression?

Completion of Treatment

#### **Results of Prostate Motion Monitoring**

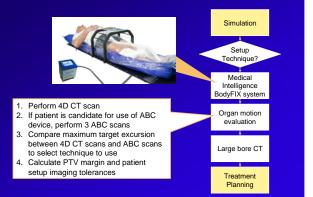
- For week of May 12, 2008 May 16, 2008:
  181 Post-treatment DIPS image pairs taken
  - 10 of 181 with DIPS-calculated correction vectors larger than 4 mm axial or 6 mm cranial-caudal
  - 5.5 % of image pairs out of tolerance
     >9 % expected
  - Prostate motion monitoring working as expected

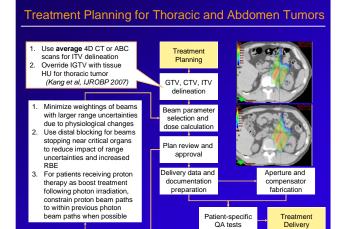
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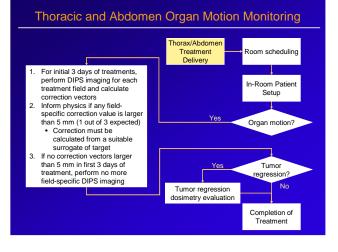
#### Prostate Motion Monitoring and Control

- 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

#### Thoracic/Abdomen Organ Motion Evaluation







#### 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

Curtsey Zuofeng Li DSc

#### Thoracic and Abdomen Tumor Regression Monitoring

Yes

Yes

control

Tumor regression

dosimetry evaluation

Room scheduling

In-Room Patient Setup

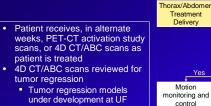
Organ motion?

Tumor

regression?

Completion of Treatment

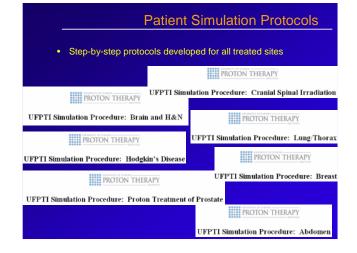
No



- Verification plan performed on new CT scans if significant
- dosimetric changes suspected

Hypofraction

Prostate



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**Dosimetry Check List** 

# **Dosimetry Check List**

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Outcome tracking protocol for Prostate

# **Dosimetry Check List**

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#### **Dosimetry Check List**

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#### Patient-Specific QA

- Verification of aperture and compensator geometries
   Dosimetric properties verified as part of commissioning with regularly-shaped apertures and compensators
   1 mm tolerance
- Output model (*Kooy*, 2003 & 2005) commissioned for limited proton beam range and modulation combinations
  - Output measured for range and modulations outside commissioned model
  - Range verifier readings obtained for commissioned range and modulation combinations
  - Output measured for small field sizes
- Depth dose and profiles measured per physicist recommendations
  - Depth doses measured for first 5 uses of a sub-option
  - Dose profiles measured for each new disease site for first 5 patients

Strategic and Operational Optimization Model of Patient Scheduling for a Multi-Room Proton Therapy Facility

Edwin Romeijn and Ehsan Salari: Industrial Engineers Nancy Mendenhall; Physician Jatinder Palta and Zuofeng Li; Physicists Gary Barlow; Therapists Stuart Klein; Administrator

#### **Project goals**

- Analyzing the capacity of the center in treatment delivery
- Studying the effect of different scenarios on the capacity
- Investigating the potential capacity improvements
- Developing an operational algorithm to schedule individual patients for treatment

#### **UFPTI** specifications

- Number of gantry rooms: 3 gantries
- Capacity of each gantry: 15 hours/day
- New patients' treatment starting day: Monday-Wednesday
- New patient's treatment starting time: 7 am 4 pm
- Minimum time between fractions for B.I.D patients: 6 hours
- Snout changing time: 15 minutes
- Anesthesia team availability: 4 hours/day on a single gantry
- Gantry switches are not allowed during the treatment.
- Gantry 3 is specialized to 1-field prostate patients.

#### Patient Categories and Patient Mix

Categor y	Anesthesia (Y/N)	Time/fraction (min)	# fractions	# fractions /day	Add. 1 <sup>st</sup> Fraction (min)	Snout size	Curren t mix (%)	Comment
1	Ν	18	40	1	15	18	65	1-Field Prostate
2	Ν	30	40	1	15	18	15	2-Field Prostate
3	Ν	35	62	2	20	18	7	H&N/BOS
4	N	45	62	2	25	25	3	Thorax/Abdomen chordomas
5	Ν	35	30	1	20	10	3	Simple Brain
6	Y	55	30	1	20	18	2	Peds Brain with Anesthesia
7	N	60	30	1	45	25	1	CSI no Anesthesia
8	Y	90	30	1	45	25	1	CSI with Anesthesia
9	N	50	42	1	30	18	2	Lung/Abdomen with ABC/Body FIX
10	Ν	35	12	1	20	18	1	Concomitant Boost Patients

#### Strategic-level model

#### Objective function:

- Maximizing number of fractions delivered per day Minimizing deviation from the desired patient mix Maximizing number of pediatrics patients treated

#### Constraints:

- Patients' treatment continuity
   Gantry capacity

- Gantry capacity
   Constraints on
   Starting day for new patients
   Starting time for new patients during a day
   Anesthesia team availability
   Minimum time between fractions for B.I.D patients
   Gantry specialization
   Gantry switching (allowed/not allowed)

#### Strategic-level model

#### **Other Considerations**

- $\geq$ treatment time/fraction reduction
- Category1: 3min; Category2: 2min; Category6: 15 min; Category7: 15 min; Category8: 30 min
- Saturday start for prostate cases (categories1and 2)
- > No gantry specification/ no gantry switching
- > Gantry capacity variability: reducing gantry availability on Thu-Fri while extending the availability on Mon-Wed
- > Vary patient mix

#### Modeling and Solution Approach

#### Sensitivity analysis

#### • Modeling approach:

- A Mixed-Integer-Programming model has been developed based on these objective functions and constraints.

- This model is a cyclic one assuming the system is in steady state.

• Solution approach:

- The model is implemented in Cplex and solved close to optimality using Branch & Bound techniques.

#### Studying the effect of:

- Allowing gantry switches during treatment
  Reducing snout changing time
  Specializing a gantry for a certain category
  Reducing the treatment time/fraction for some categories
- Changing the desired patient mix
  Extending the anesthesia team's availability

- Extending gantries' working hours
  Saturday start for prostate patients
  Increasing the average number of fractions delivered per day

on:

- Average daily number of fractions delivered
- Performance measures (resource utilization and set-up time) •
- Treated patient mix

#### **Results** Patient mix scenarios C4 C4 C5 C6 Scenario C8 C9 C10 Idea 49 65 15 Rasir

Daily capacity and utilization								
enario	Average frac./day	Gantry 1 utilization	Gantry 2 utilization	Gantry 3 utilization				
Ideal	82	96	87	84				
Basic	100	96	93	97				

### Studying the effect of extending the anesthesia team availability (an example)

	TBD	15	7	3	3	TBD	1	TBD	2	1
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	65.3	15.9	5.1	2.8	1.2	2.8	1.2	2.8	1.7	1.2
	64.1	11.6	6.1	0	2.2	6.6	1.1	6.6	1.1	0.6
Desired patient mix vs. the solution patient mix										
Performan measures										
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Performance measures for different scenarios

#### Strategic Model Conclusions

- With the treatment time/fraction reduction of :
  - Category 1: 3min; Category 2: 2min; Category 6: 15 min; Category 7: 15 min; Category 8: 30 min
  - Can treat up to 15 pediatric patients per day
  - Treat up to a maximum of 135 fractions per day (30,000 fractions per year)
- Concerns:
  - The optimal patient mix with respect to pediatric patients consists largely of Category 6 cases
  - The optimal patient mix with respect to other patients consists largely of single-field prostate cases

#### Summary and Personal Observations

- Proton therapy differs significantly from conventional radiotherapy in its higher sensitivity to various sources of uncertainties
  - What you see is not what you get
- Disease-site-specific clinical workflow must be designed to address the dosimetric effects of these uncertainties
  - Even then some patients may have to be treated with modalities other than protons
- These workflow modifications may require increased efforts compared to their conventional therapy counterparts, but are necessary to optimize proton therapy treatments
  - It is highly unlikely that we will realize greater efficiency in clinical operation of PTS compared to conventional radiation therapy