Clinical Implementation of a Proton Therapy System

Jatinder R. Palta PhD
University of Florida

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

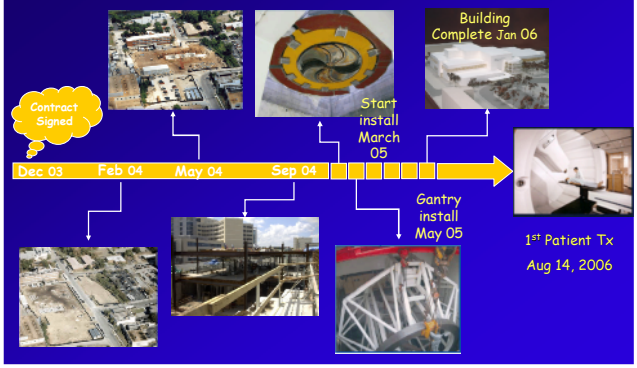
George Zhao, PhD

Liyong Lin, PhD

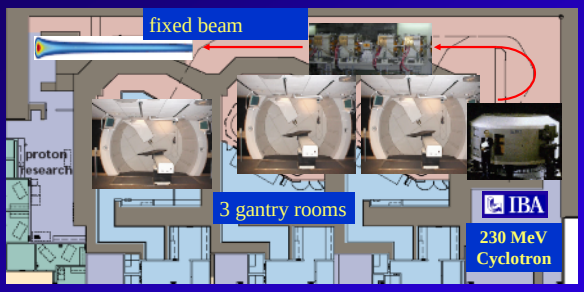
Outline

- 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)

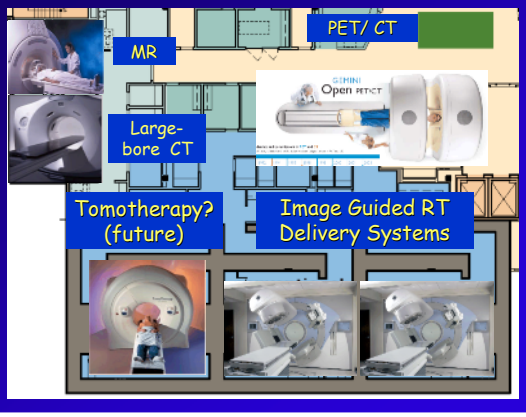


UFPTI Proton Area



- 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 respectively
- Facility Management System
  - IMPAC *MOSAIQ*

Proton Gantry and PPS

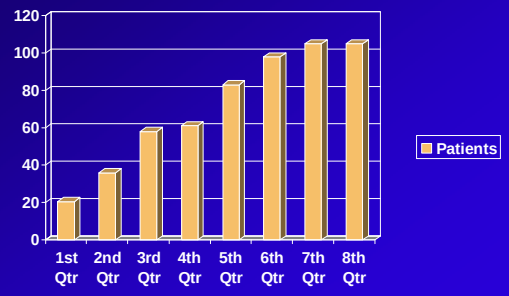
- Nozzle installed on gantry
- Snout installed in nozzle
- PPS: 6 degree-of-freedom isocentric motion
  - 50X50X50 cm^3 treatable volume
  - +/- 3^o ranges of pitch and roll corrections

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

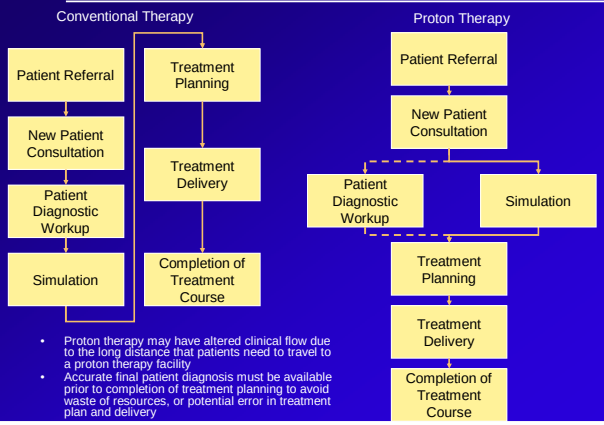
Average Daily Treatments at UFPTI

(August, 2006- August 2008)



Hours of Operation: 6:00AM- 10:00 PM

Clinical Workflow



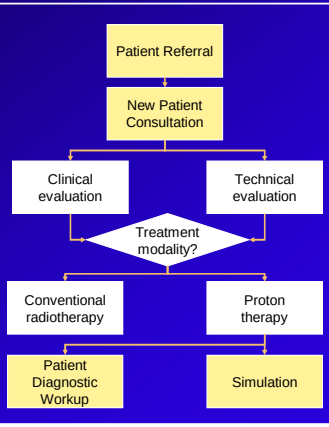
- Proton therapy may have altered clinical flow due to the long distance that patients need to travel to a proton therapy facility
- Accurate final patient diagnosis must be available prior to completion of treatment planning to avoid waste of resources, or potential error in treatment plan and delivery

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

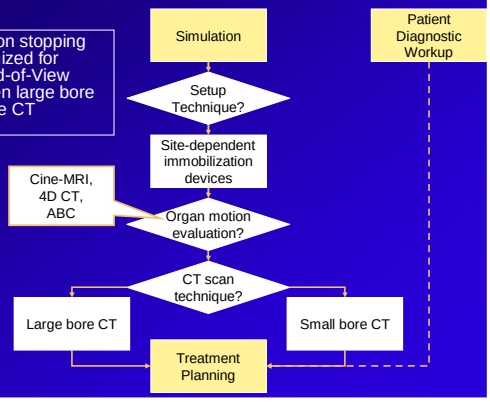
Proton Therapy Workflow

- 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



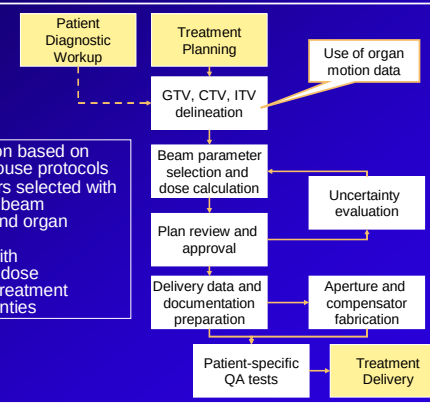
Proton Therapy Workflow

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



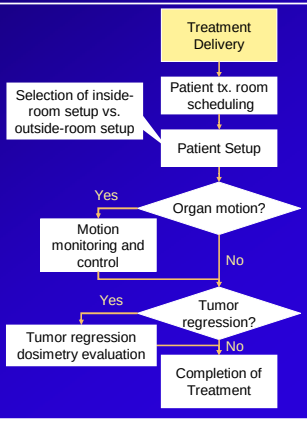
Proton Therapy Workflow

- 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*



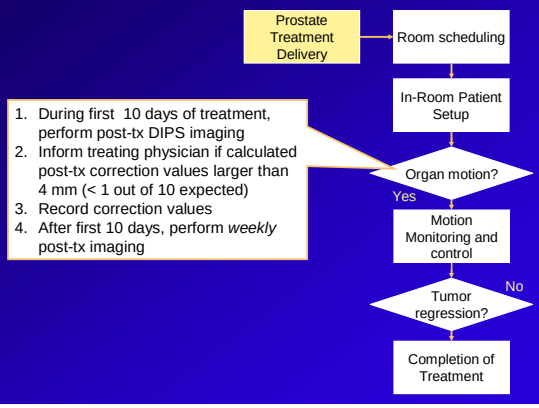
Prostate Motion Monitoring

- 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



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*

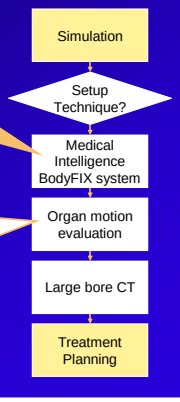
Curtsey Zuofeng Li DSc

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

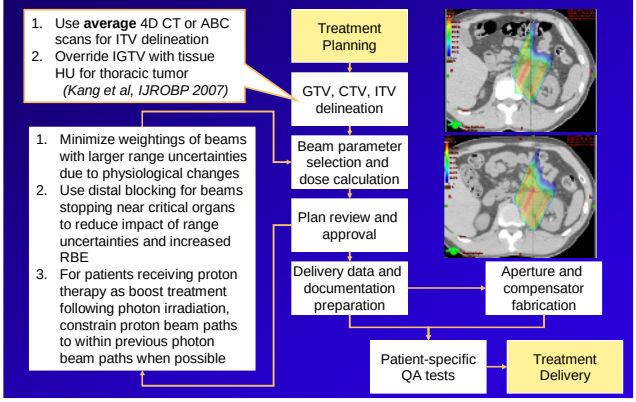
1. Perform 4D CT scan
2. If patient is candidate for use of ABC device, perform 3 ABC scans
3. Compare maximum target excursion between 4D CT scans and ABC scans to select technique to use
4. Calculate PTV margin and patient setup imaging tolerances



Treatment Planning for Thoracic and Abdomen Tumors

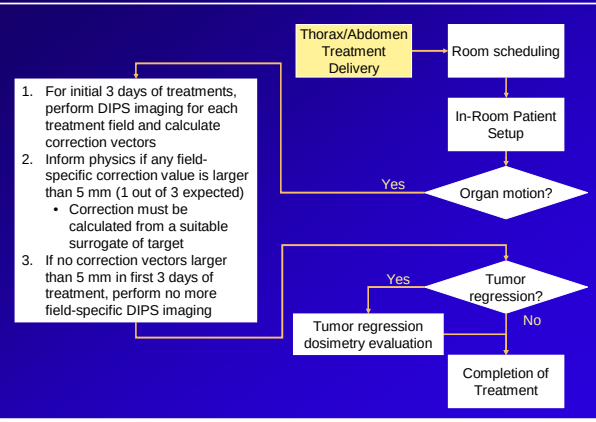
1. Use **average** 4D CT or ABC scans for ITV delineation
2. Override IGTV with tissue HU for thoracic tumor *(Kang et al, IJROBP 2007)*

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

1. For initial 3 days of treatments, perform DIPS imaging for each treatment field and calculate correction vectors
2. Inform physics if any field-specific correction value is larger than 5 mm (1 out of 3 expected)
   - Correction must be calculated from a suitable surrogate of target
3. If no correction vectors larger than 5 mm in first 3 days of treatment, perform no more field-specific DIPS imaging



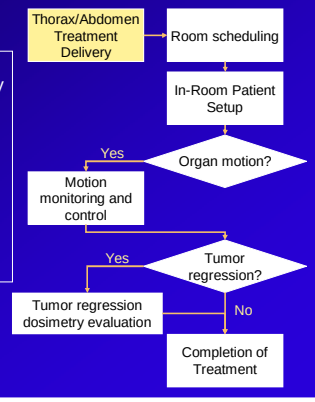
Results of Thoracic and Abdomen Organ Motion Monitoring

- 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

- 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



Patient Simulation Protocols

- Step-by-step protocols developed for all treated sites

UFPTI Simulation Procedure: Cranial Spinal Irradiation

UFPTI Simulation Procedure: Brain and H&N

UFPTI Simulation Procedure: Lung/Thorax

UFPTI Simulation Procedure: Hodgkin's Disease

UFPTI Simulation Procedure: Breast

UFPTI Simulation Procedure: Proton Treatment of Prostate

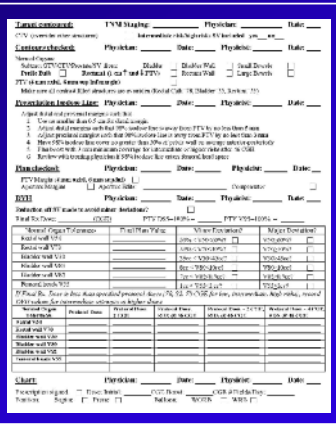
UFPTI Simulation Procedure: Abdomen

Dosimetry Check List

Hypofractionationated Prostate

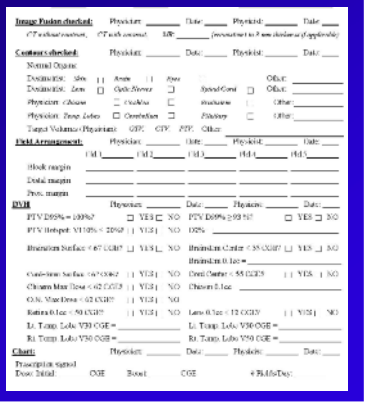
Dosimetry Check List

Outcome tracking protocol for Prostate



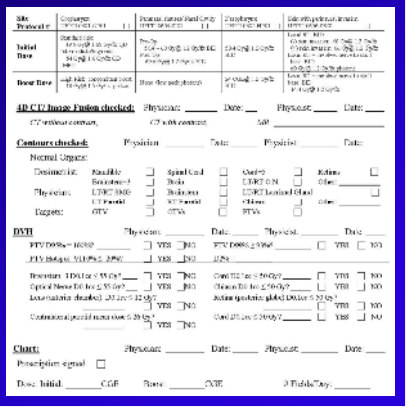
Dosimetry Check List

Base of Skull Chordoma, Chondrasarcoma, and Cervical Spine



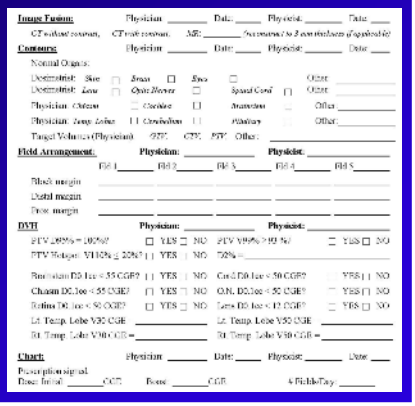
Dosimetry Check List

Head and Neck



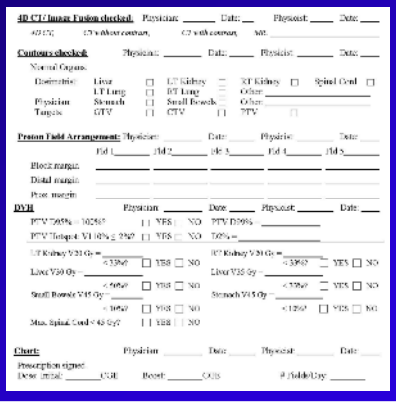
Dosimetry Check List

Intracranial Tumor



Dosimetry Check List

Unresectable Pancreatic Cancer



4D CT/ Image Fusion checked: Physician: _____ Date: ___ Physicist: ____ Date: ____

4D CT; CT w/wo contrast, CT with contrast, MR: _____

Contours checked: Physician: _____ Date: ____ Physicist: _____ Date: ____

Normal Organs:

Dosimetrist:	Liver	☐	LT Kidney	☐	RT Kidney ☐ Spinal Cord ☐
	LT Lung	☐	RT Lung	☐	Other: _____
Physician	Stomach	☐	Small Bowels	☐	Other: _____
Targets:	GTV	☐	CTV	☐	PTV ☐

Proton Field Arrangement: Physicist: _____ Date: ____ Physicist: _____ Date: ____

Fld 1_____ Fld 2_____ Fld 3_____ Fld 4_____ Fld 5_____

Proximal margin: _____

Distal margin: _____

Penumbra margin: _____

DVH Physician _____ Date: ____ Physicist: _____ Date: ____

PTV 295% = 102%? ☐ YES ☐ NO PTV D99% = _____

PTV Integral V110% ≤ 2%? ☐ YES ☐ NO D95% = _____

LT Kidney V20 Gy = _____ RT Kidney V20 Gy = _____

<33%? ☐ YES ☐ NO <33%? ☐ YES ☐ NO

Liver V30 Gy = _____ Liver V35 Gy = _____

<50%? ☐ YES ☐ NO <35%? ☐ YES ☐ NO

Small Bowels V45 Gy = _____ Stomach V45 Gy = _____

<10%? ☐ YES ☐ NO <120%? ☐ YES ☐ NO

Max. Spinal Cord < 45 Gy? ☐ YES ☐ NO

Chart: Physician _____ Date: ____ Physicist: _____ Date: ____

Prescription signed

Dose /total: _____CGE Bowel: _____CGE # fields/Day: _____

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

Category	Anesthesia (Y/N)	Time/fraction (min)	# fractions	# fractions /day	Add. 1st Fraction (min)	Snout size	Current mix (%)	Comment
1	N	18	40	1	15	18	65	1-Field Prostate
2	N	30	40	1	15	18	15	2-Field Prostate
3	N	35	62	2	20	18	7	H&N/BOS
4	N	45	62	2	25	25	3	Thorax/Abdomen chordomas
5	N	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	N	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
- 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

- 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

- 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.

Sensitivity analysis

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

Scenario	C1	C2	C4	C4	C5	C6	C7	C8	C9	C10
Ideal	49	11	14	6	6	4	2	2	4	2
Basic	65	15	7	3	3	2	1	1	2	1

Daily capacity and utilization

Scenario	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)

Categories	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Desired patient mix	TBD	15	7	3	3	TBD	1	TBD	2	1
1 x 4	66.5	16.4	5.7	1.7	1.7	2.3	0.6	2.3	1.7	1.1
1 x 5	65.3	15.9	5.1	2.8	1.2	2.8	1.2	2.8	1.7	1.2
2 x 6	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

Performance measures	G1 %	G2 %	G3 %	Average # ped/day	Average # fx/day
1 x 4	91	90	93	3.7	110.1
1 x 5	96	92	93	4.6	110.1
2 x 6	95	97	96	11	110.1

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