Modeling Expert Clinical Knowledge In Treatment Planning

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Motivation

- **Extract human expert's knowledge in treatment planning**
- **Model past planning experience**
- **Improve, or even automate the planning process**
- **Hypothesis**
  - Past knowledge and experience has always be applied to new patient case
  - Mathematical extraction and modeling such application of knowledge and experience enables systematic knowledge modeling
- **Ultimately, to improve treatment planning efficiency, consistency and quality.**

Treatment Planning Knowledge Modeling

- RT Knowledge System
- Target and OAR delineation
- Dose prescription
- Treatment plan/parameter generation
- Treatment plan evaluation/selection
- Treatment plan DVH and toxicity

Modeling Treatment Planning Knowledge

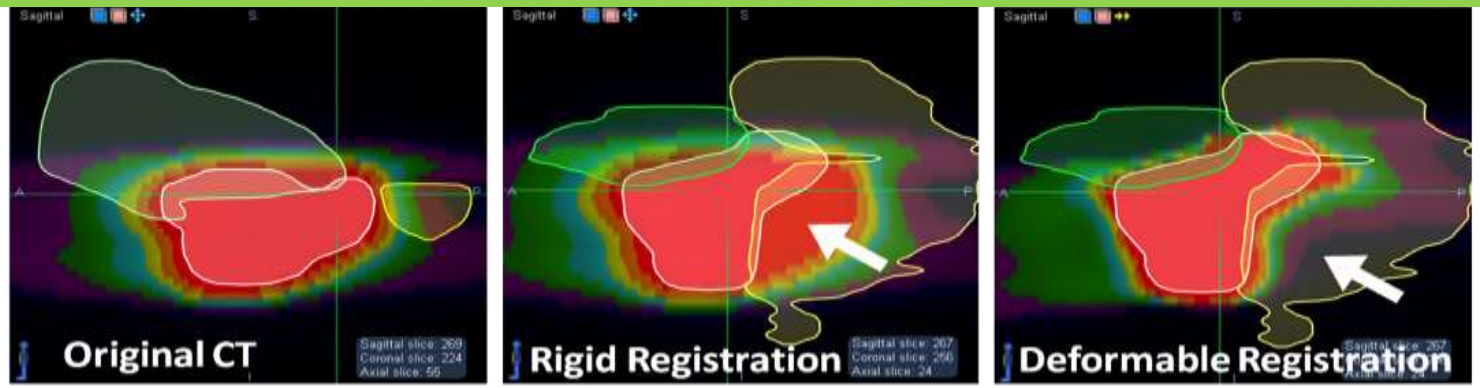
- Dose Based

Dose based knowledge planning:

1. Deformable registration -> CTref and CTnew anatomy registration

2. Wrap CTref dose to CTnew anatomy -> "goal" dose distribution

3. Solve fluence map -> known optimization parameter settings



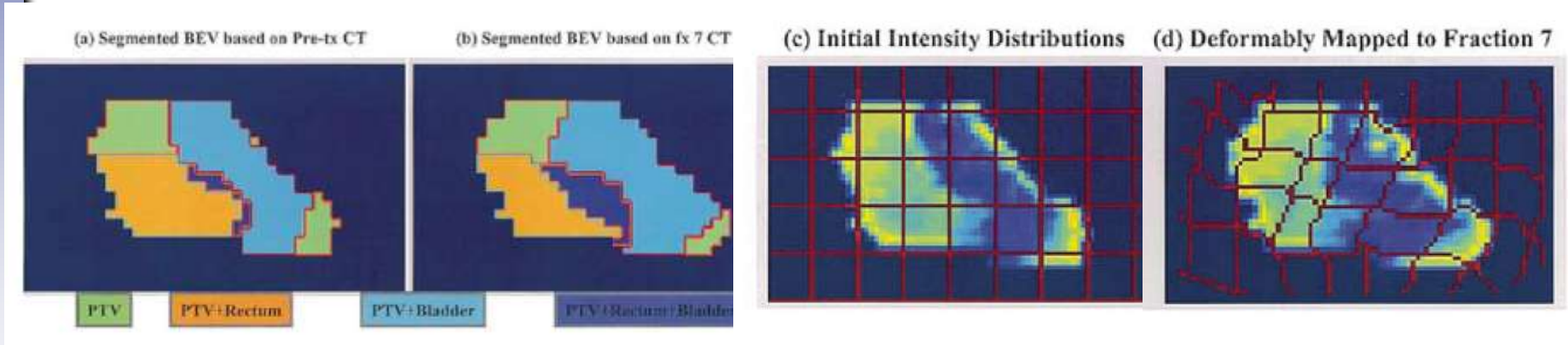
Wu et al, PMB 2008.

Modeling Treatment Planning Knowledge

- Fluence Map Based

Fluence map based knowledge planning:

1. **Deform anatomy in BEV**
2. **Warp fluence map**
3. **Refine the fluence map (planning)**

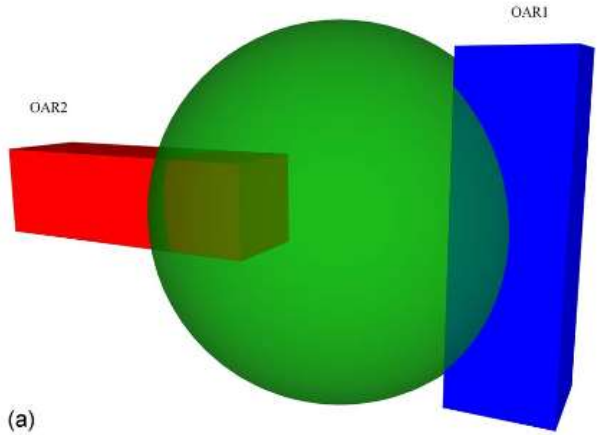


Mohan et al, Int J Radiat. Oncol. Biol. Phys., 2005

Modeling Treatment Planning Knowledge

DVH based knowledge planning:

1. **Learning OAR DVH from past plans**
2. **Associate DVH property with patient-specific anatomy feature**
3. **Estimate OAR DVH of new patient**
4. **Solve treatment plan with OAR DVH goals**



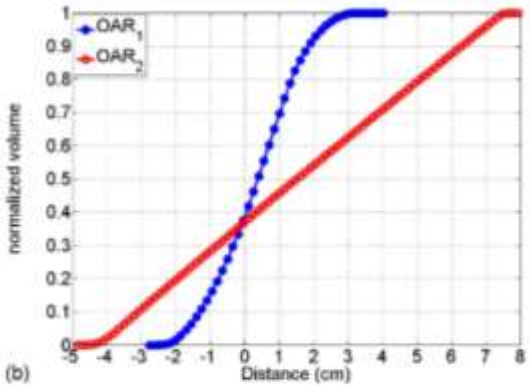
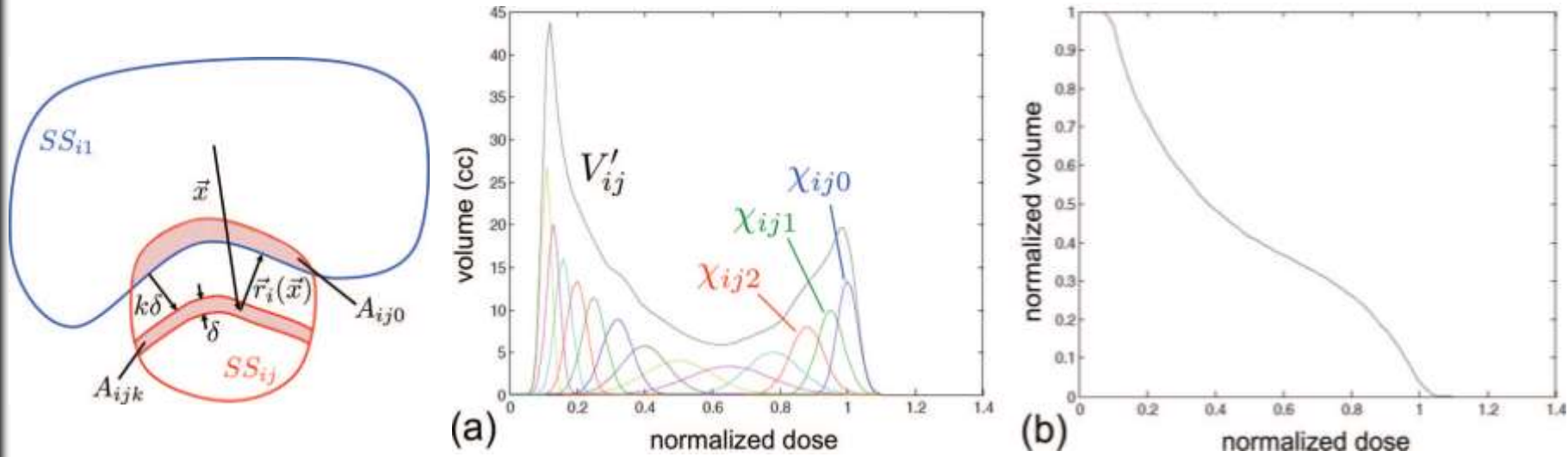


FIG. 1. An OVH example. (a) 3D shapes of the target and OARs. (b) OVHs.

Wu et al. Med Phys 2009

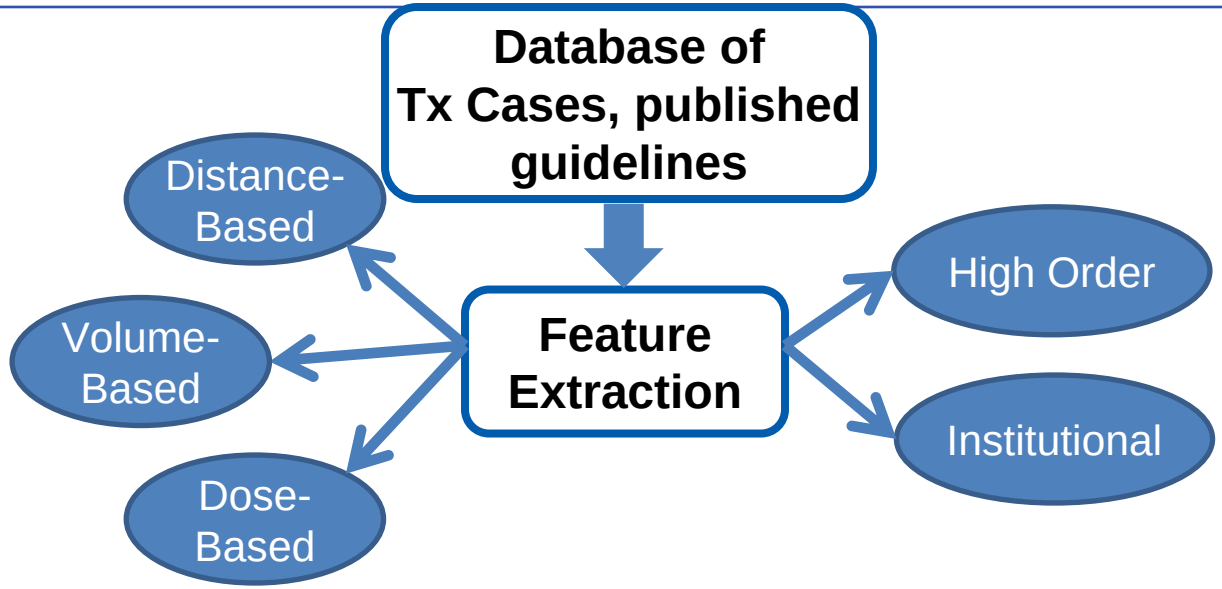
Modeling Treatment Planning Knowledge

- DVH Based



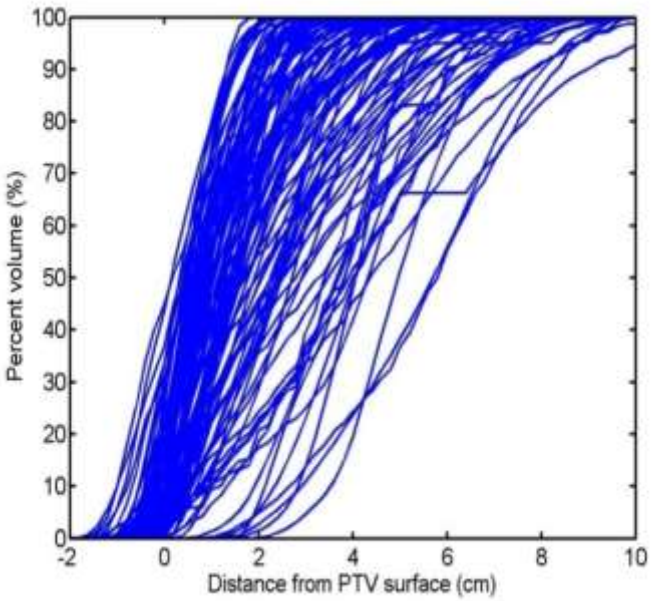
Appenzoller et al, Med Phys 2012

Treatment Planning Modeling – Our Strategy



Treatment Planning Modeling – Our Strategy

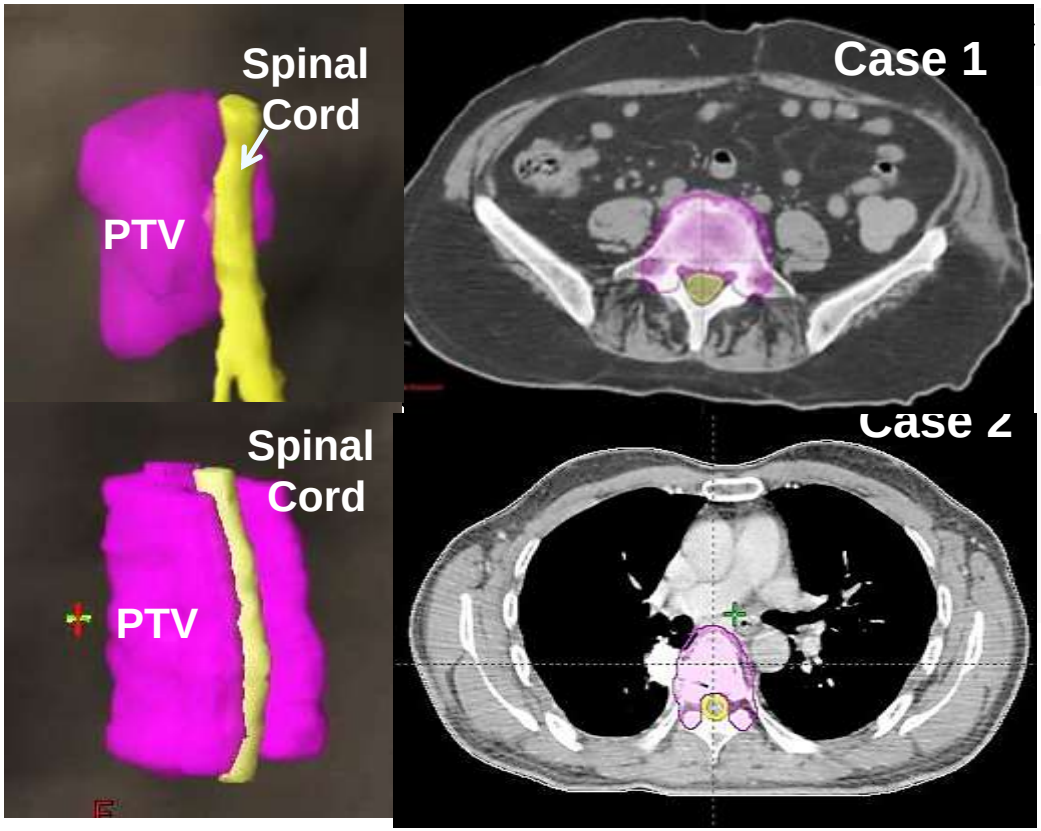
- DVH Based
- Distance-to-target Histogram (DTH)
  - Signed Distance-to-target histogram (D
  - (overlap: negative distance)
  - Relative geometrical relationships betw

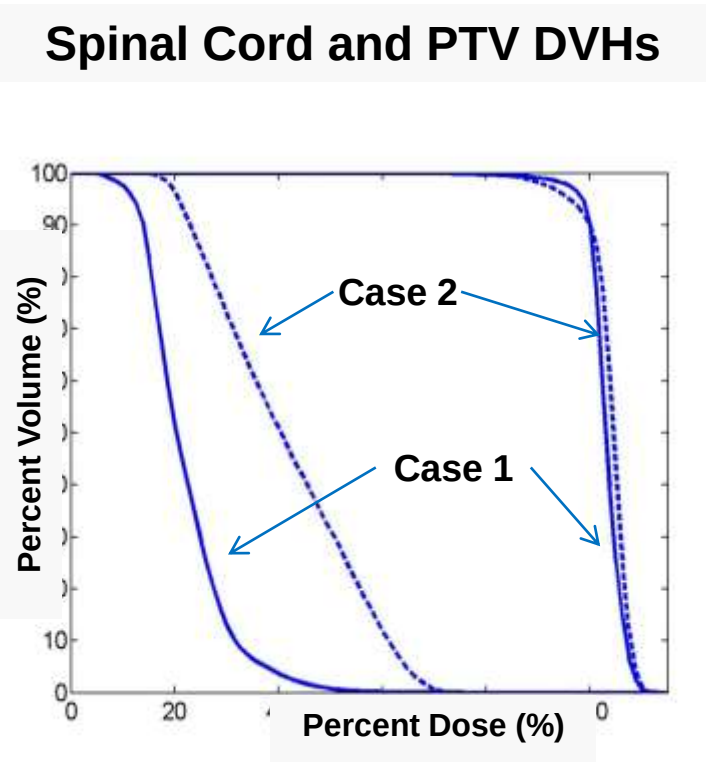


$$V(d) = \frac{\cup\{v_i|\ v_i \in V_{OAR} \text{ and } r(v_i, PTV) \leq d}{\cup\{v_i|\ v_i \in V_{OAR}\}}$$

Zhu et al. Med Phys 2011

Treatment Planning Modeling – Our Strategy



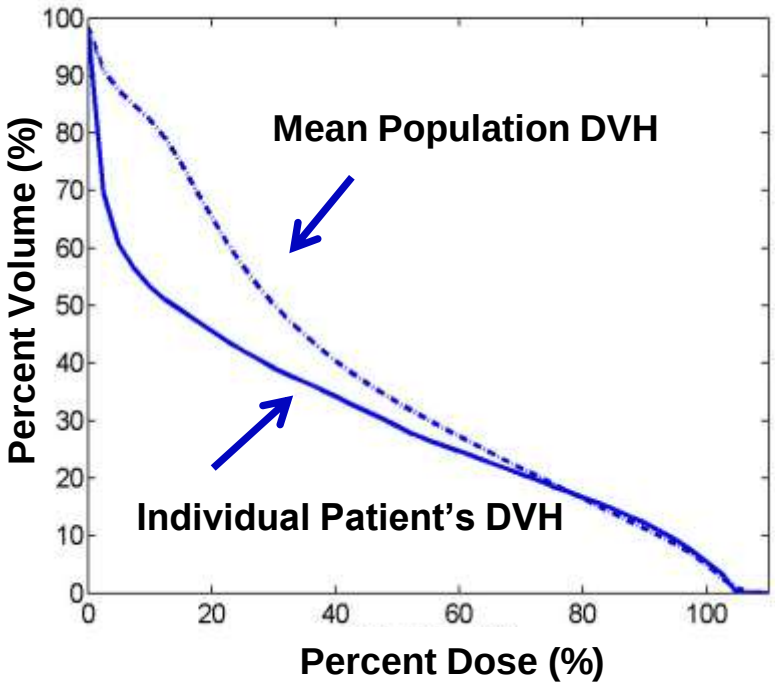


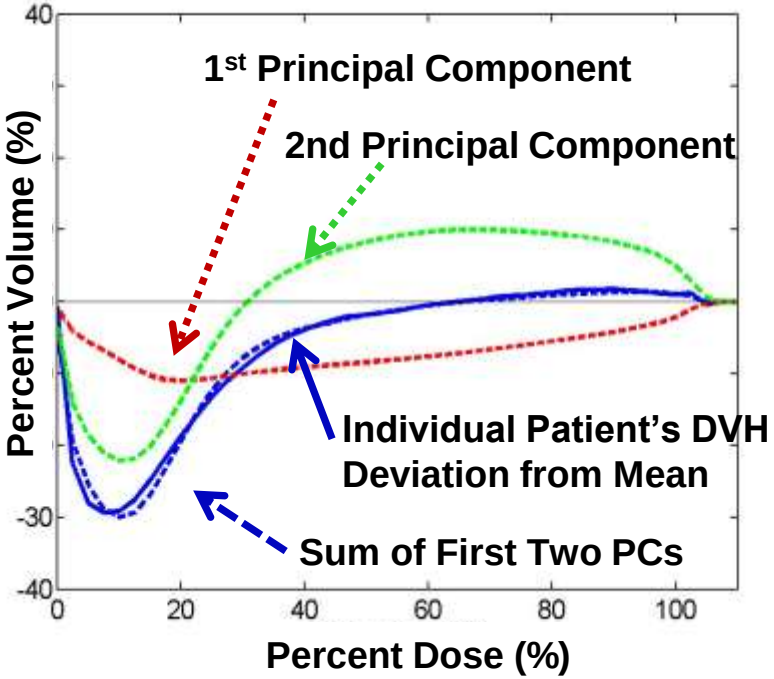
Yuan et al, Med Phys 2012

Treatment Planning Modeling – Our Strategy

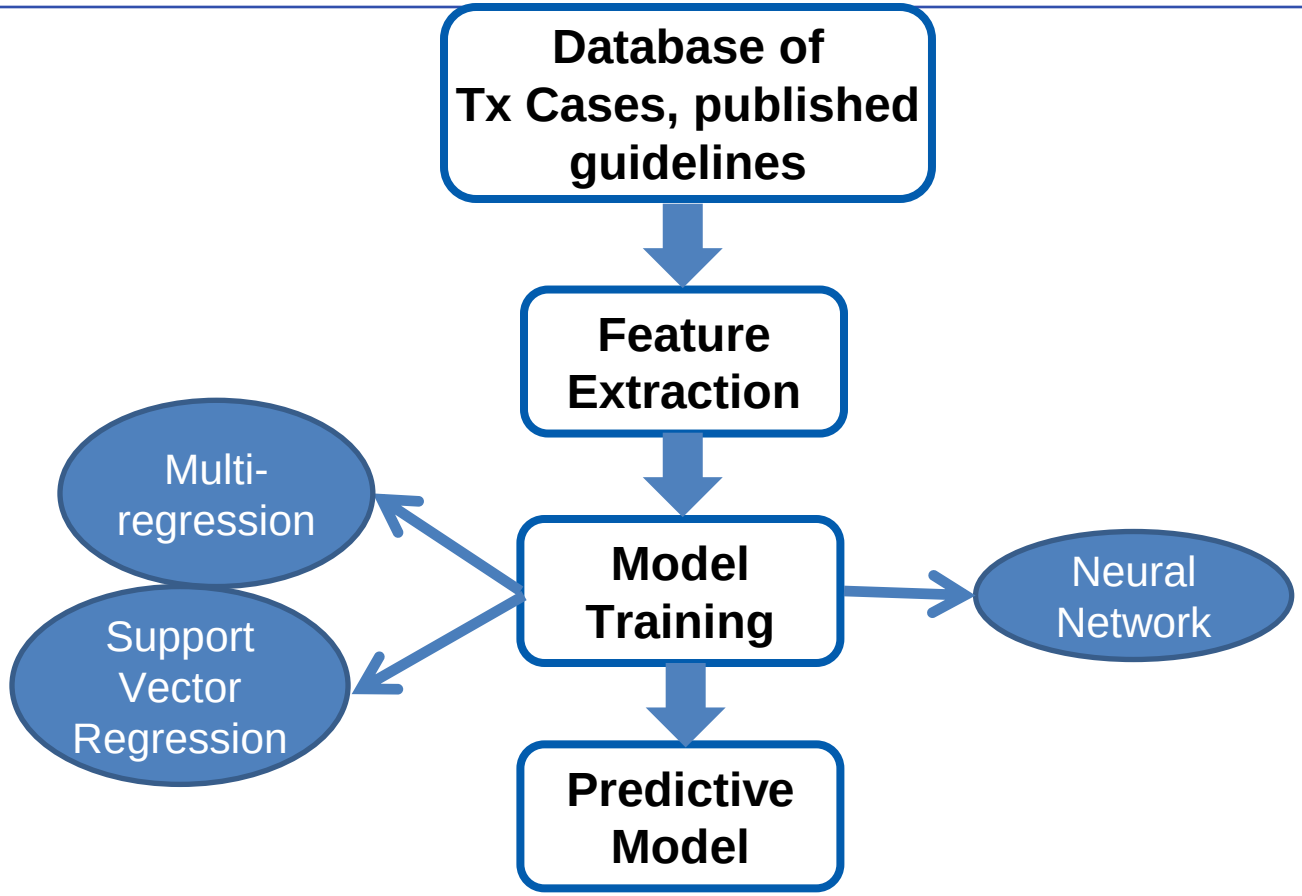
- Principal Component Analysis (PCA): Data Dimension Reduction
  - Distance to target histogram (DTH): PCS
  - Distance to OAR (DOH): PCS

Example: Parotid DVH PCA

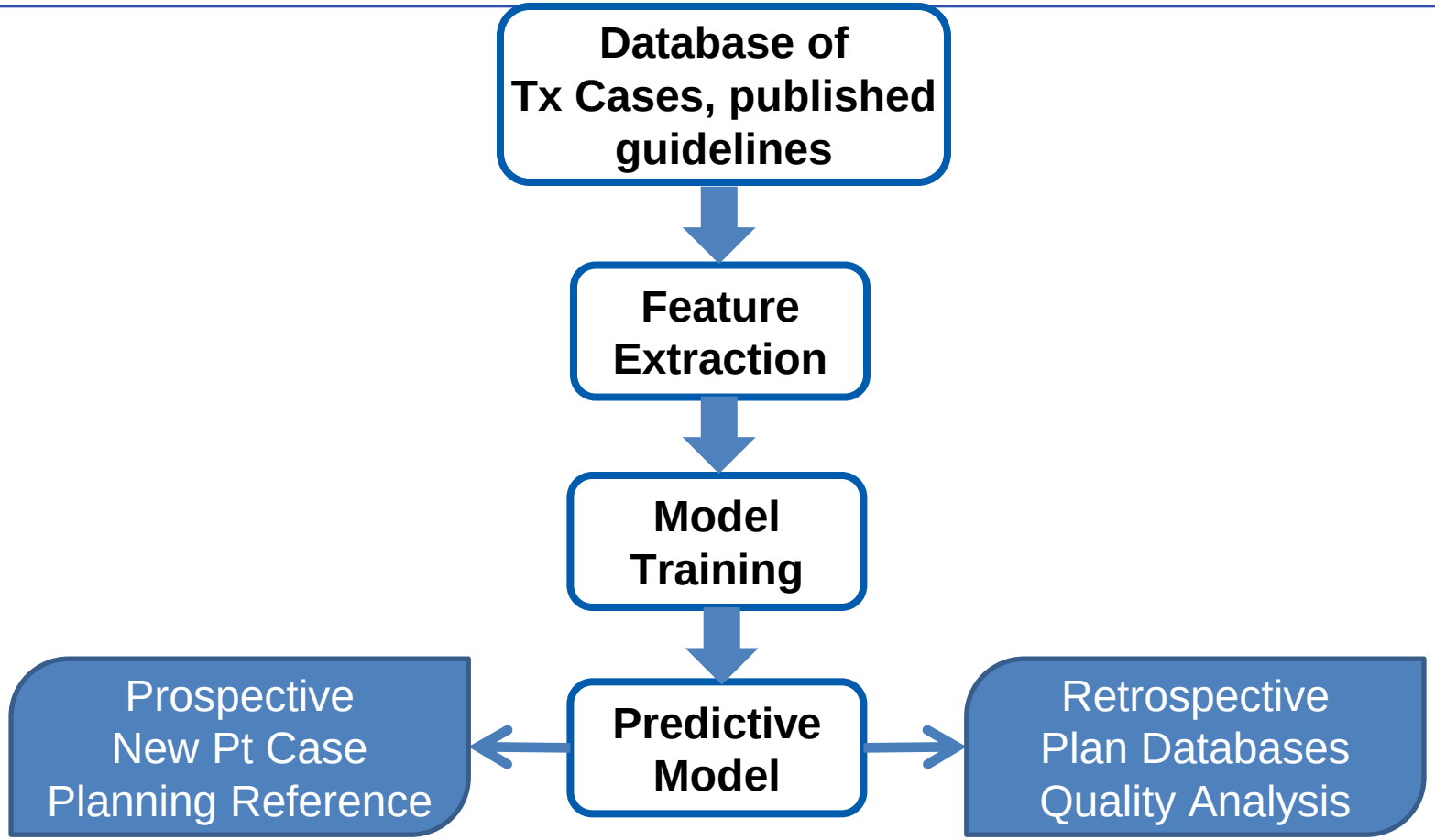




Treatment Planning Modeling – Our Strategy



Treatment Planning Modeling – Our Strategy



Quantitative analysis of the factors which affect the interpatient organ-at-risk dose sparing variation in IMRT plans.
Medical Physics 39, 6868,2012

A planning quality evaluation tool for prostate adaptive IMRT based on machine learning
Medical Physics 38, 719,2011

Model Prediction Validation

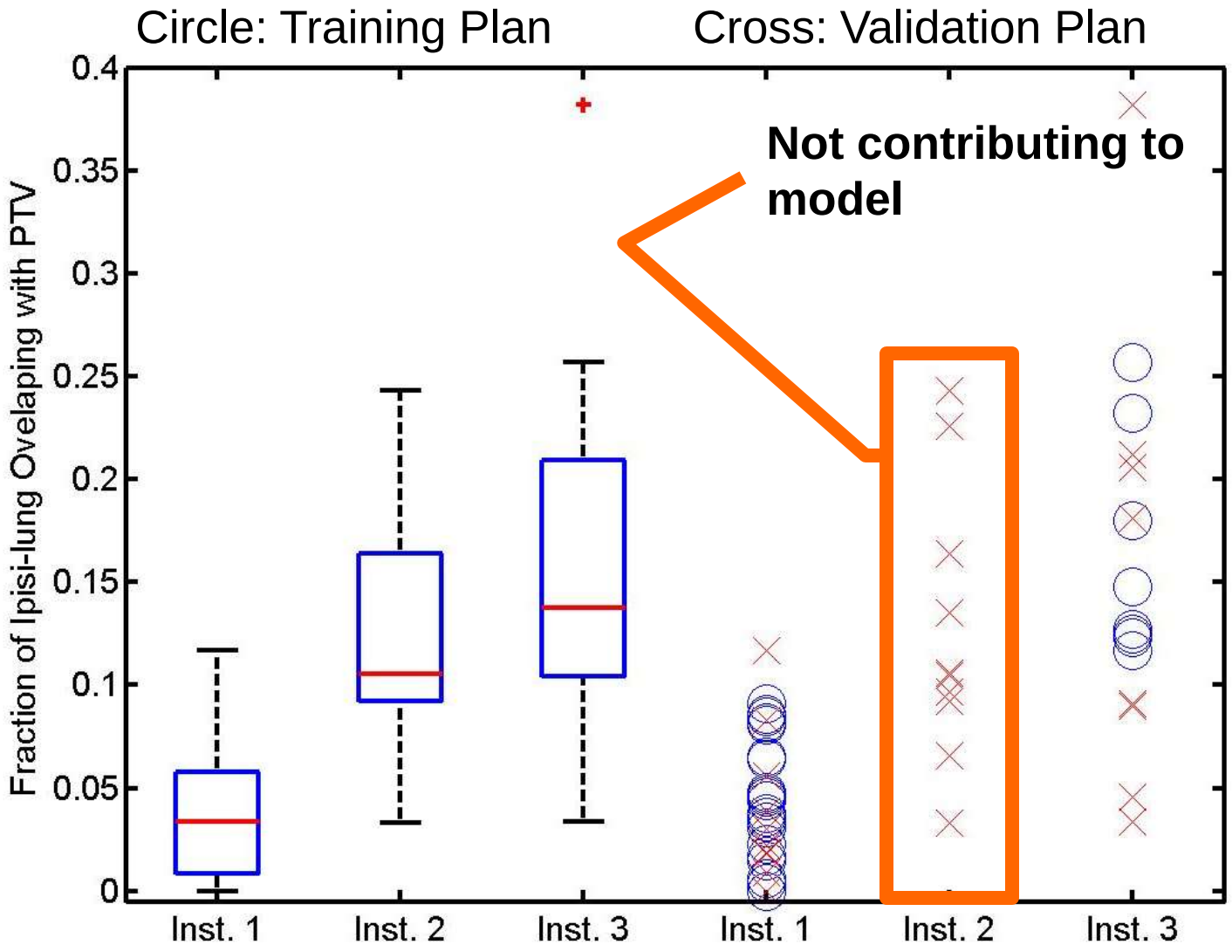
Bladder DVH PCS1 (Median Dose)		Rectum DVH PCS1 (Median Dose)	
Significant Factors	**R^2**	**Significant Factors**	**R^2**
Bladder DTH PCS1 (Median Distance)	0.81	Rectum DTH PCS1 (Median Distance)	0.59
2nd Order of Bladder DTH PCS1	0.22	Volume of Rectum	0.12
		Overlap Volume	0.08
Combined	**0.88**	**Combined**	**0.68**
Bladder DVH PCS2 (DVH Slope)		**Rectum DVH PCS2 (DVH Slope)**	
Significant Factors	**R^2**	**Significant Factors**	**R^2**
Out-of-field Volume	0.50	Rectum DTH PCS2 (gradient)	0.32
Overlap Volume	0.33	Out-of-field Volume	0.32
Bladder DTH PCS2 (gradient)	0.30	Overlap Volume	0.12
Combined	**0.85**	Rectum DTH PCS3	0.12
		Combined	**0.69**

Cross-Institution Validation

- LUNG IMRT Pilot Study By RTOG
- 71 Cases
- 3 Institutions

		Mean	Median	Min	Max
Prescriptions (Gy)		67	64	40	74
			Institution 1	Institution 2	Institution 3
Volume (cm^3)	mean		421	595	512
	median		343	519	379
	min, max		62, 1132	76, 1132	175, 1161
Location (side)	Total		45	10	16
	Left/Left-Medial		18	4	5
	Right/Right-Medial		21	6	10
	Medial		6	0	1

Cross-Institution Validation



Cross-Institution Validation

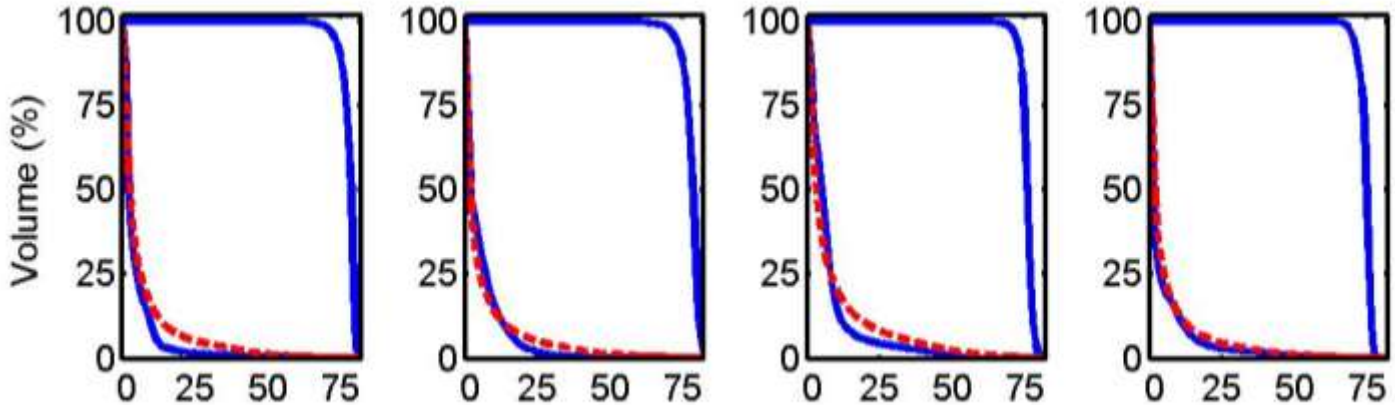
Photon

Contralateral Lung

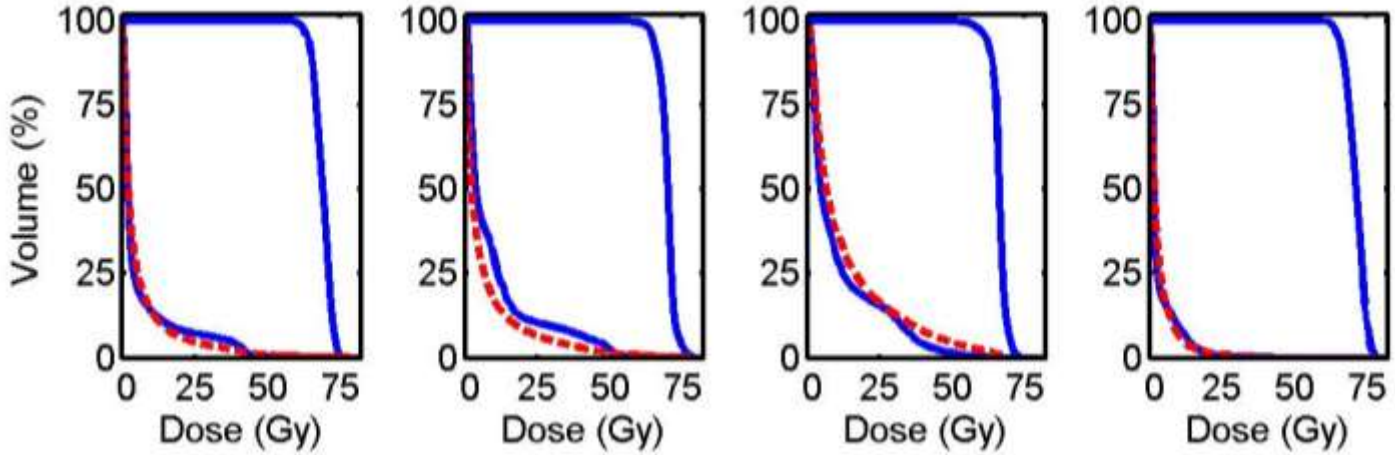
— **Prediction**

— **Plan**

Institution 2 **Not contributing to model**



Institution 3 **Contributing to model**

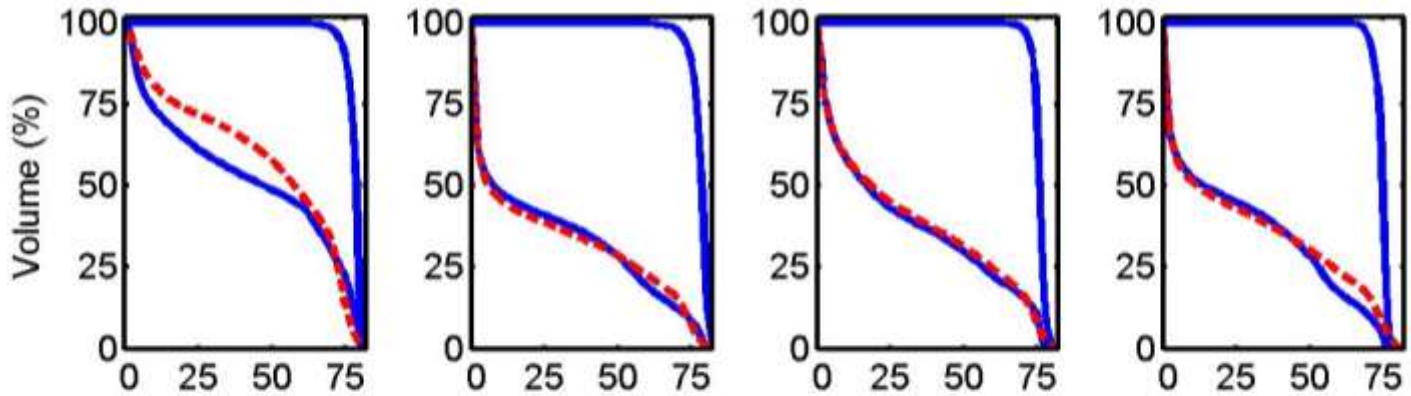


Cross-Institution Validation

Institution 2 **Not contributing to model**

Photon

Ipsilateral Lung



The high agreement between model and plan:

1. **Modeling accuracy of representing anatomical influence on dose sparing**

2. **High consistency of planning quality among institutions**

Cross-modality, Cross-Institution Validation

Institution A

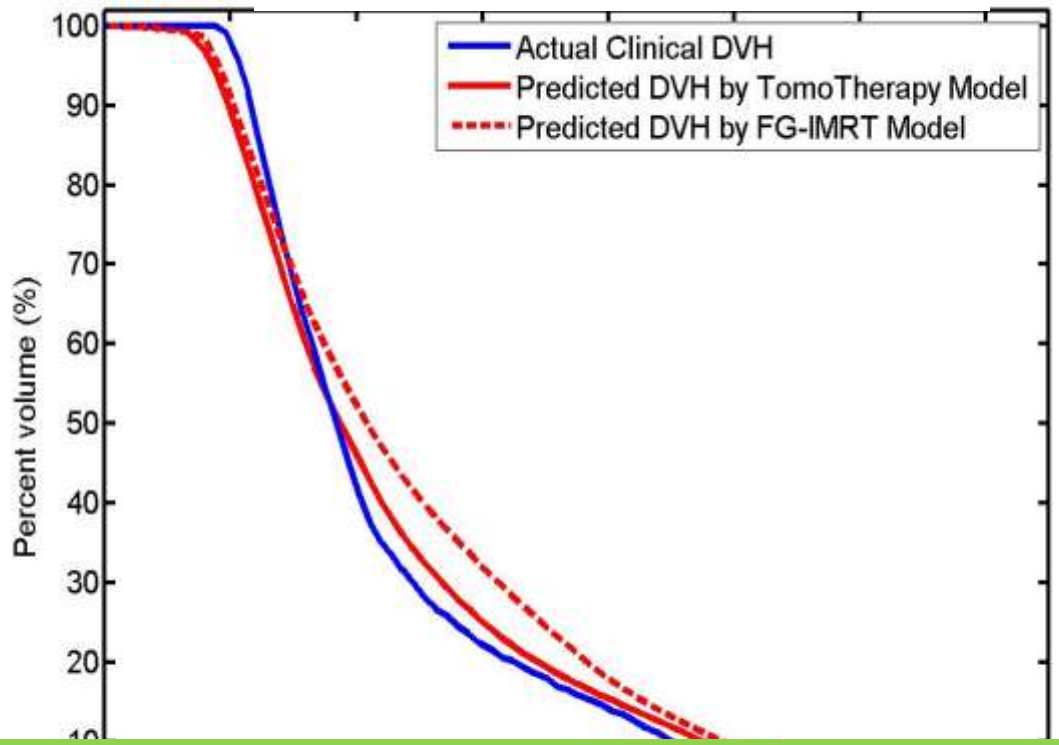
- 7-8 min delivery time
- Delivery system: Varian IMRT
- Planning system: Eclipse
- Multiple PTVs
- Sequential Boost
  - Multiple plans (one plan for 1 PTV)
  - 40-50 Gy and 60-70 Gy
- ~60 head-and-neck cases

Institution B

- 7-8 min delivery time
- Delivery system: Tomotherapy
- Planning system: Tomotherapy
- Multiple PTVs
- SIB
  - 1 plan (one plan cover all PTVs with diff. daily doses)
  - 54.25 Gy and 70 Gy
- ~60 head-and-neck cases

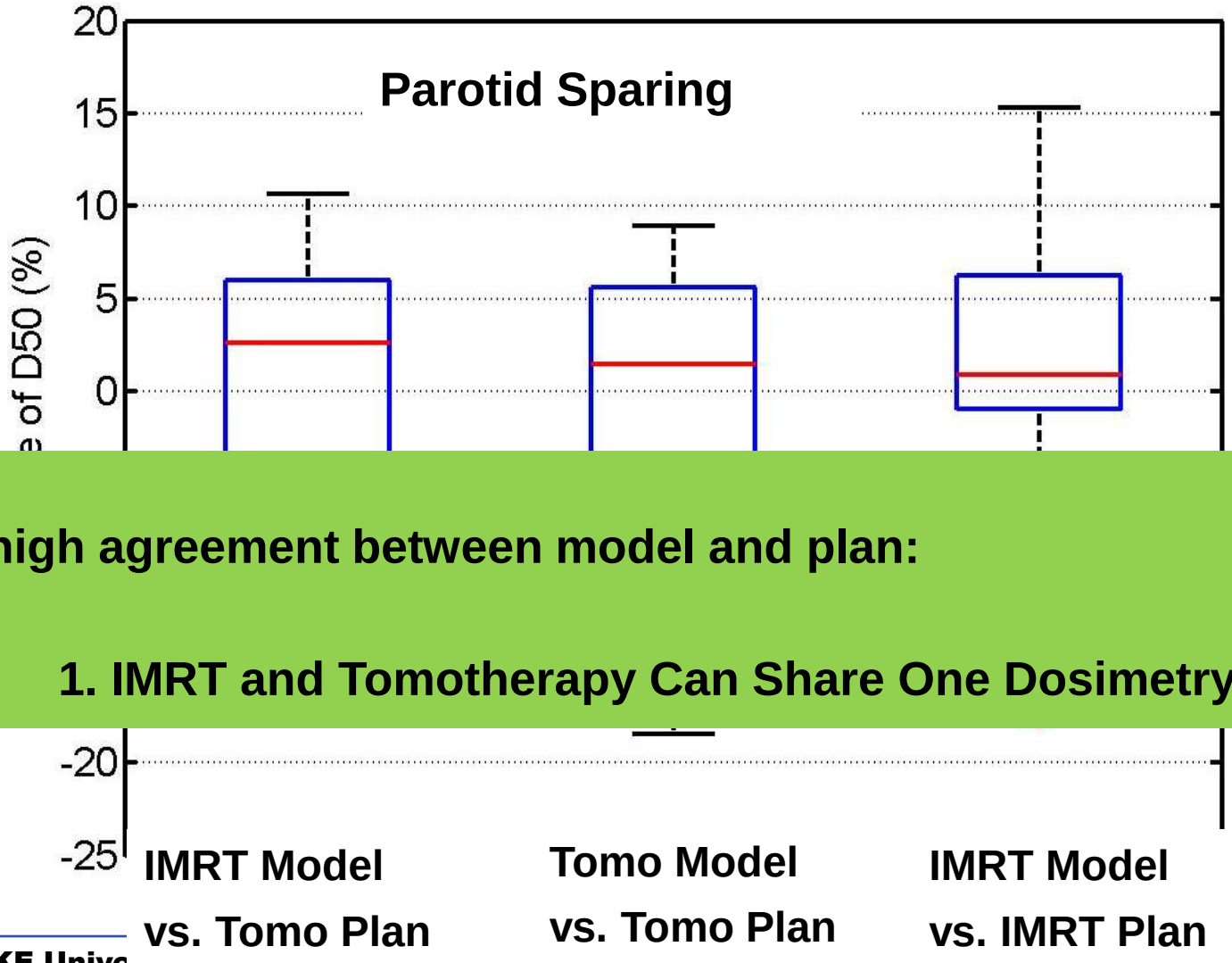
Cross-modality, Cross-Institution Validation

Parotid



Tomotherapy Model vs. IMRT Model vs. Actual Plan DVH

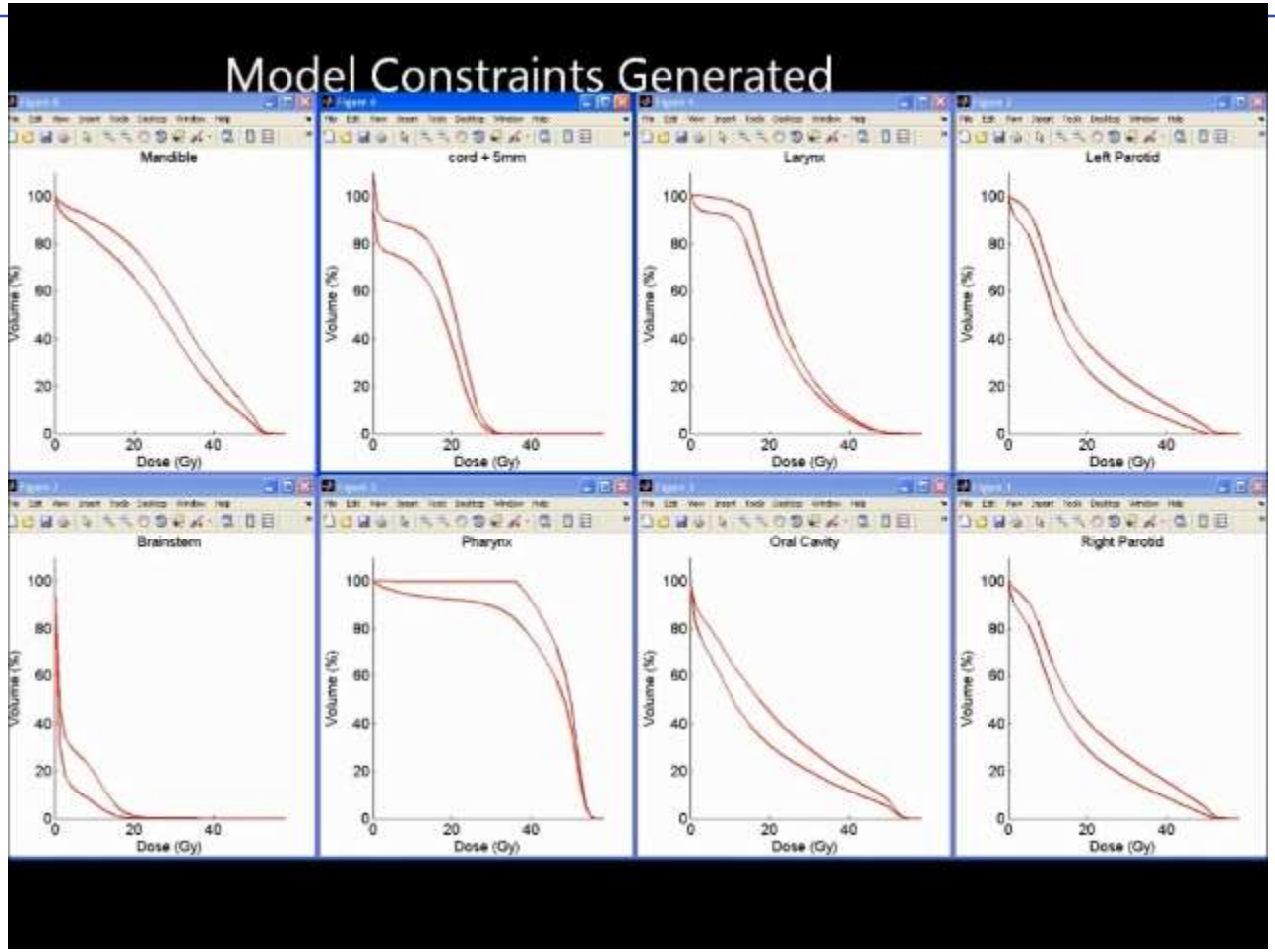
Cross-modality, Cross-Institution Validation



The high agreement between model and plan:

1. IMRT and Tomotherapy Can Share One Dosimetry Model

Model-based Plan Validation (IMRT)



Model-based Plan Validation (VMAT)

Model-based Plan Validation

- Time Savings
  - Prostate:

    30-60 min vs. 3-5 min (IMRT)
  - HN:

    60min-hrs vs. 5-8 min (IMRT) vs. 20-30 min (VMAT)

- From no trial-and-error adjustments – fast planning time

Model-based Plan Validation (VMAT)

OAR/PTV	Dosimetric Parameters	IMRT Mean (S.D.) (Gy)	VMAT Mean (S.D.) (Gy)	p-value
Parotids	Median	25.7 (12.8)	25.8 (8.6)	0.23
Oral Cavity	Median	31.6 (9.5)	33.2 (8.5)	0.61
Larynx	Median	26.3 (14.5)	27.6 (13.3)	0.64
Pharynx	Median	58.4 (9.4)	54.8 (10.3)	0.24
Spinal Cord	D2%	36.2 (4.5)	34.9 (2.2)	0.48
Brainstem	D2%	20.7(5.9)	18.9 (5.9)	0.40
Mandible	D2%	68.0 (7.7)	64.3 (10.4)	0.32
PTV54	D95%	54.8 (1.5)	54.3 (0.8)	0.26
PTV70	HI†	7.1 (1.8)	5.2 (0.9)	0.0006

† homogeneity index (D2%-D99%)

- OAR Dosimetric parameters in the VMAT and IMRT plans not significant different by Wilcoxon ranksum test
- Dose homogeneity index of the boost PTV better in the VMAT plans, but may not carry clinical significance

Summary: What Knowledge Modeling May Help

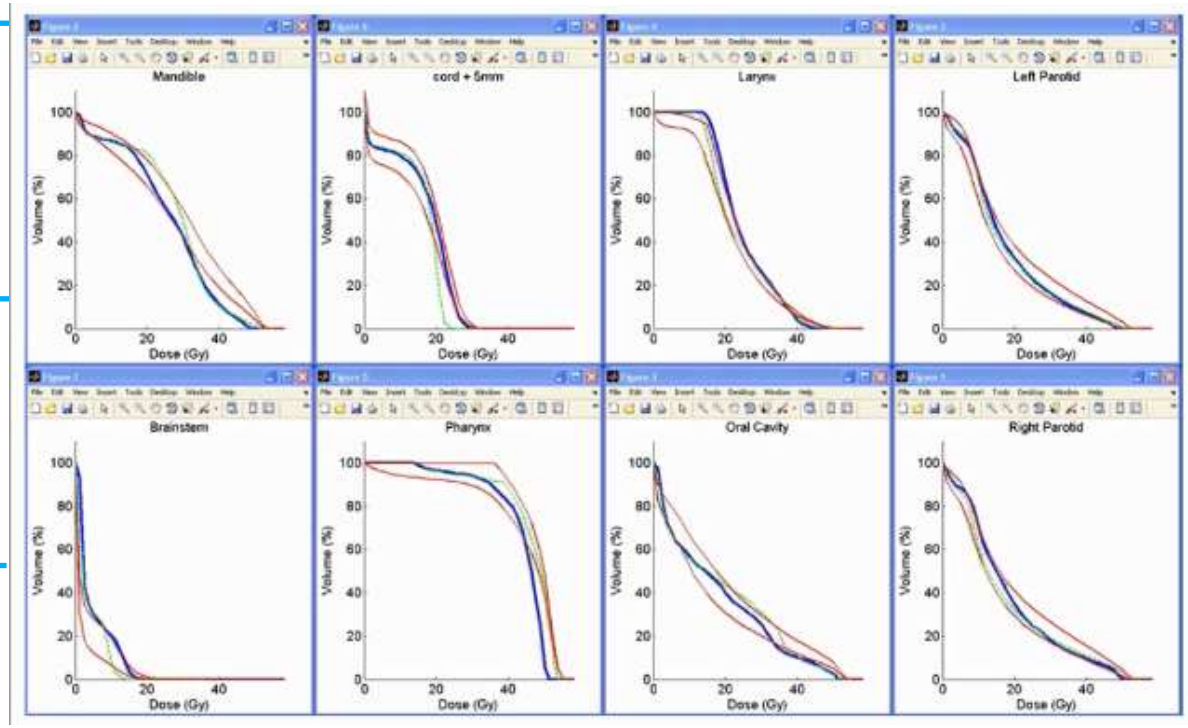
Physician Contouring, Prescription

IMRT/VMAT Planning

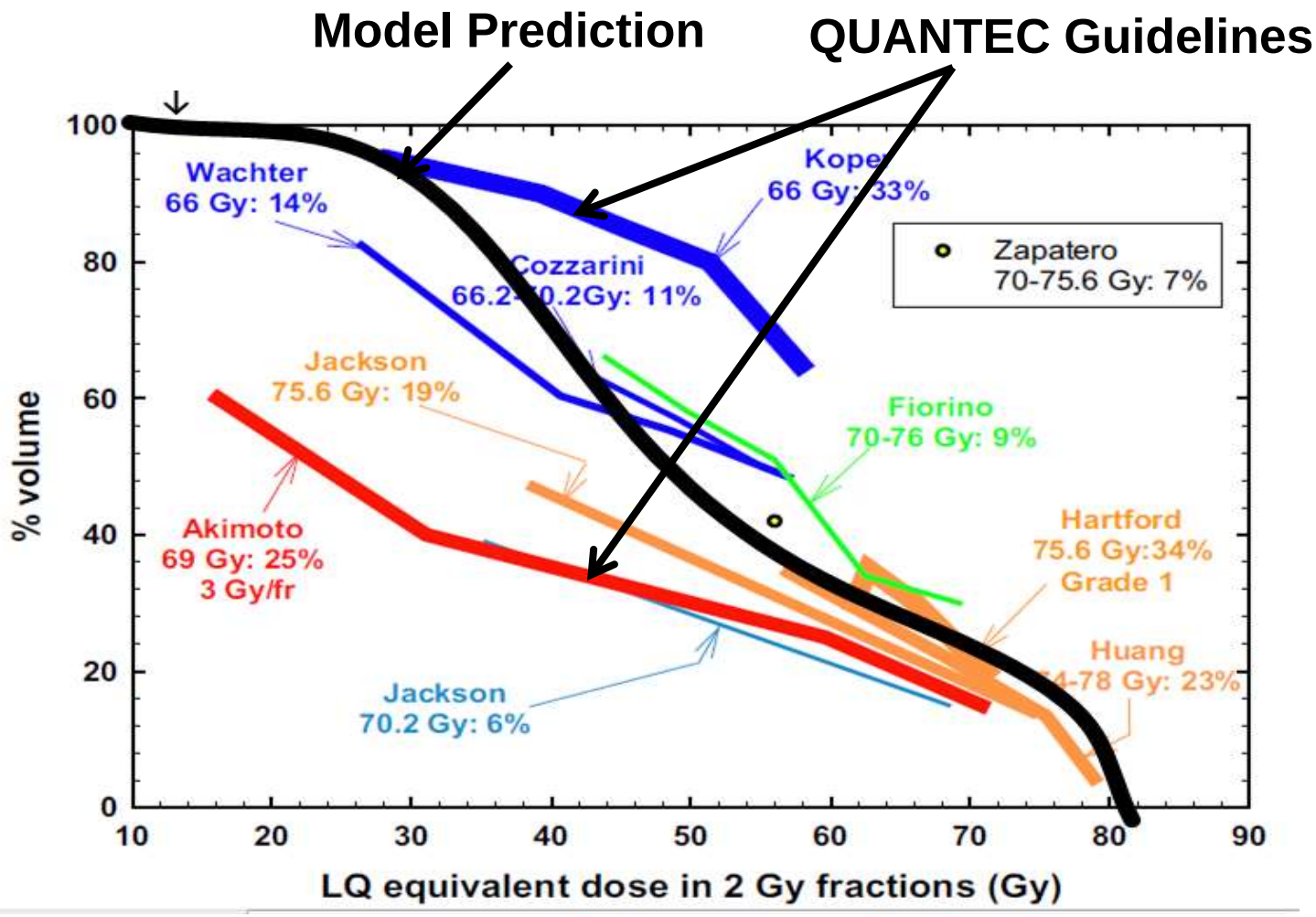
Physician Plan Evaluation

Plan Approved For Treatment

Planned vs. Modeled



Summary Treatment Planning Knowledge Modelin



Summary

- **Thank You!**

Model-based Plan Validation

- Head-and-Neck
- Modeling Base
  - 61 prior clinical plans
  - IMRT with sequential boost(40-50Gy and 60-70Gy)
- Validation
  - 18 HN cases
  - IMRT with sequential boost(40-50Gy and 60-70Gy)
  - VMAT with SIB (54.25 Gy and 70Gy)
- Quality of the model-based plans evaluated by compare the dosimetric parameters with those in the clinical plans

Summary: Current Treatment Planning