How to Oversee Automated Planning

Ping Xia, Ph.D.
Professor of Molecular Medicine
Cleveland Clinic, Cleveland, OH

Cleveland Clinic

Disclosures

- Philips: Research Grant

Cleveland Clinic

Cleveland Clinic Main Campus

Learning Objectives

- Understand the technique for iterative OAR objective optimization
- Understand the technique to use libraries of previous plans to generate a plan best suited to meet clinical objectives
- Understand the technique of multi-criteria optimization (MCO).
- How medical physicists oversee plans that are created using these advance techniques and understand the potential pitfalls.

What are "automated" plans?

- There is no "automated" plans, but plans created with some computer aided automation.
- Inverse planning is one of automation tools.
  - Auto-planning module (AP)
  - Knowledge based planning (KBP)
  - Multi-criteria optimization (MCO)

Three Key Components in Inverse Planning

- Planning dose objectives
  - Maximum dose, Minimum dose, Mean dose
  - Vxx (e.g, $V20_{Gy}$), Dxx (e.g., D95%)
- Cost functions – quantitatively measure the goodness (based on the dose objectives) of a plan
- Search engines – find solution (intensity fluence maps) with the lowest cost.

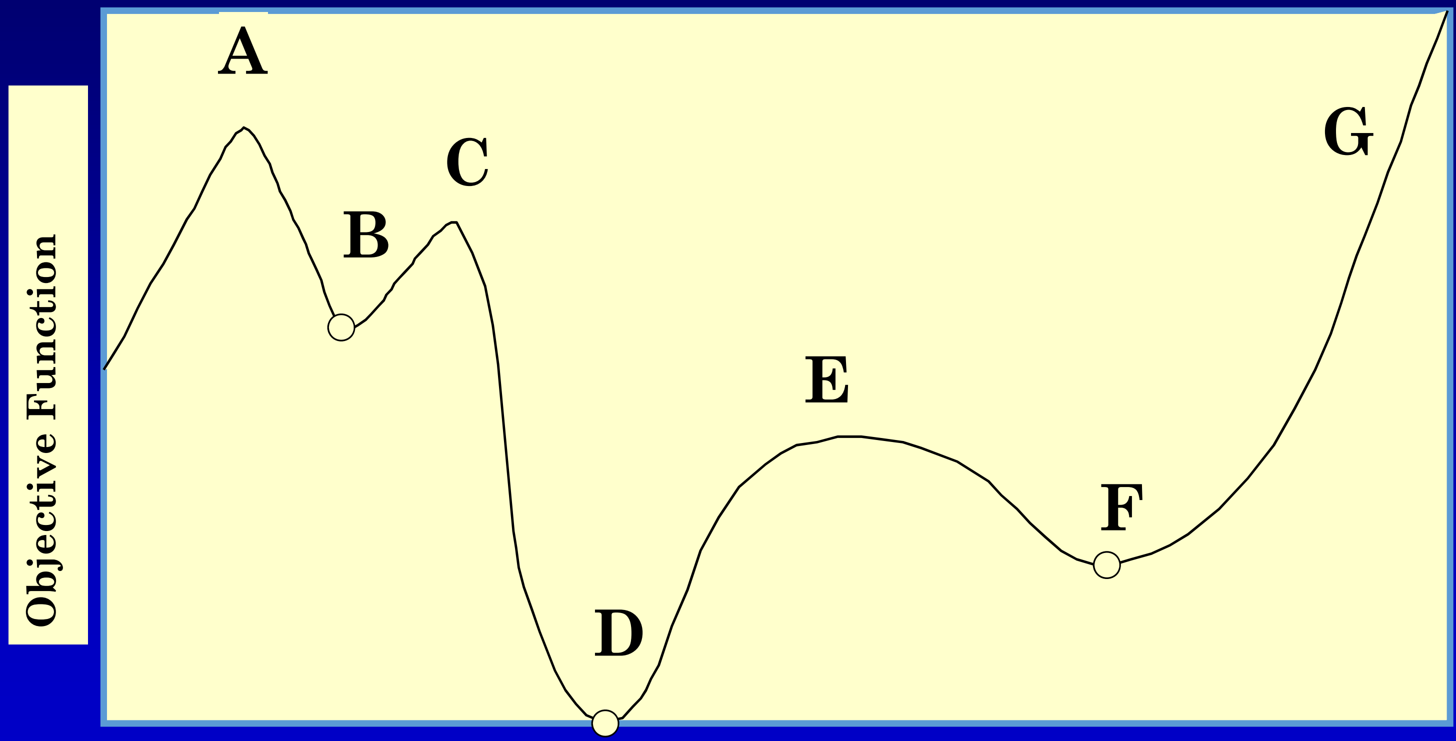
Cleveland Clinic

Problems with Current Inverse Planning

- The dose objectives are not well defined for each case – using KBP can mitigate this problem.
- The solution found from optimization is not unique (due to the use of gradient search engine) – using a progressive optimization
- Trade-off among many solutions – using MCO to show.

Cleveland Clinic

Local Minimum and Global Minimum

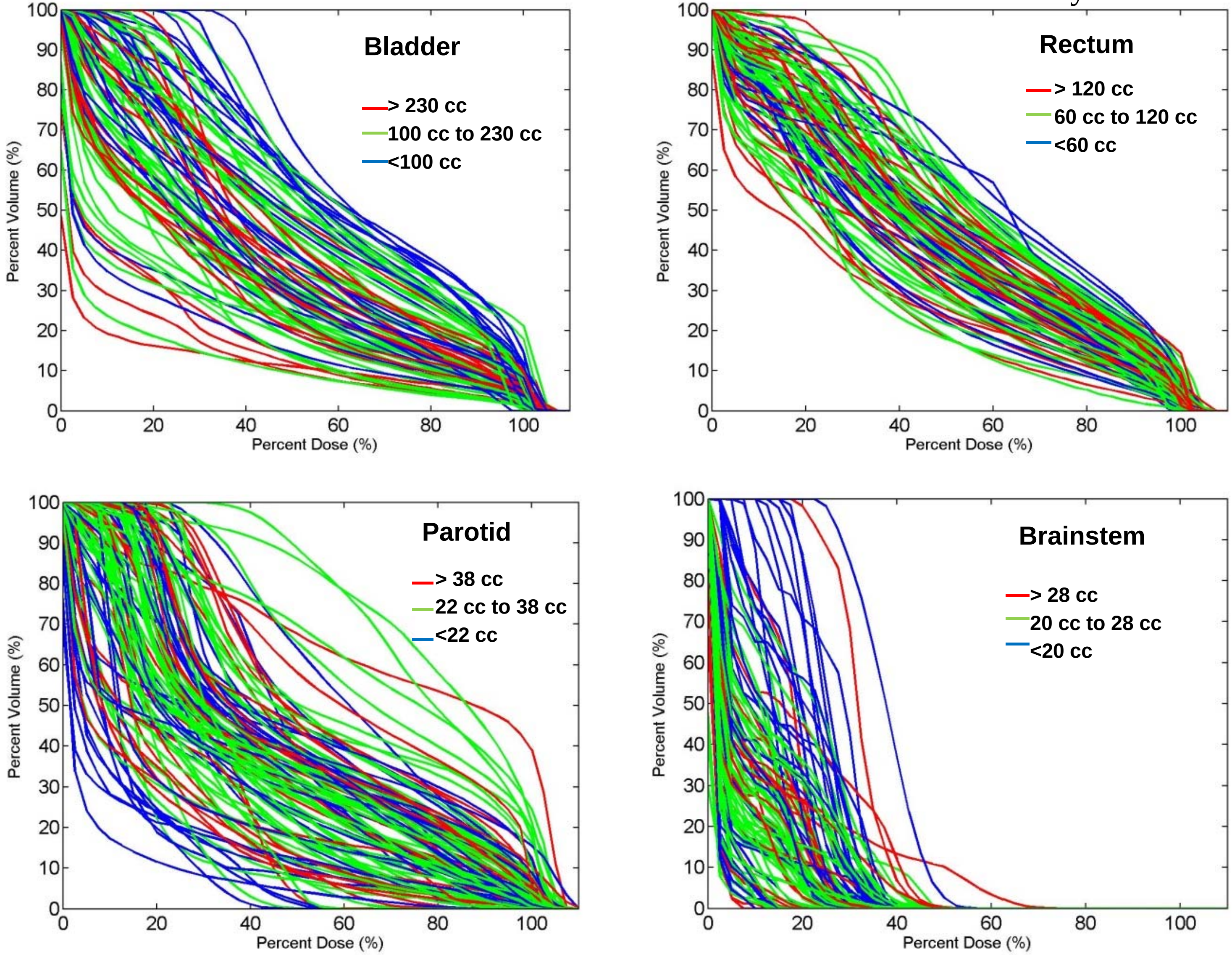


Cleveland Clinic

How Does Knowledge Based Planning Work?

Cleveland Clinic

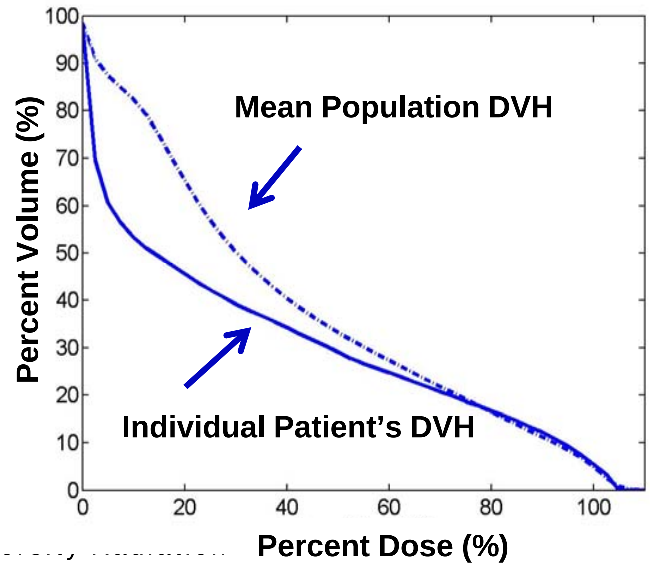
Courtesy of Jackie Wu

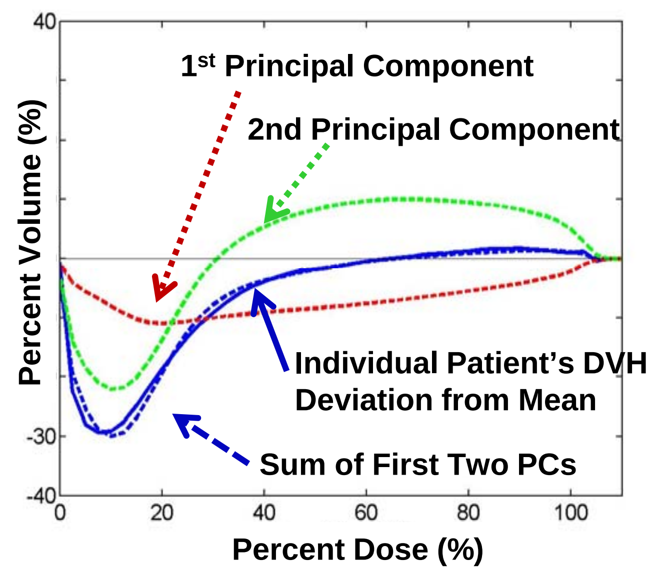


Courtesy of Jackie Wu

Modeling Planning Knowledge

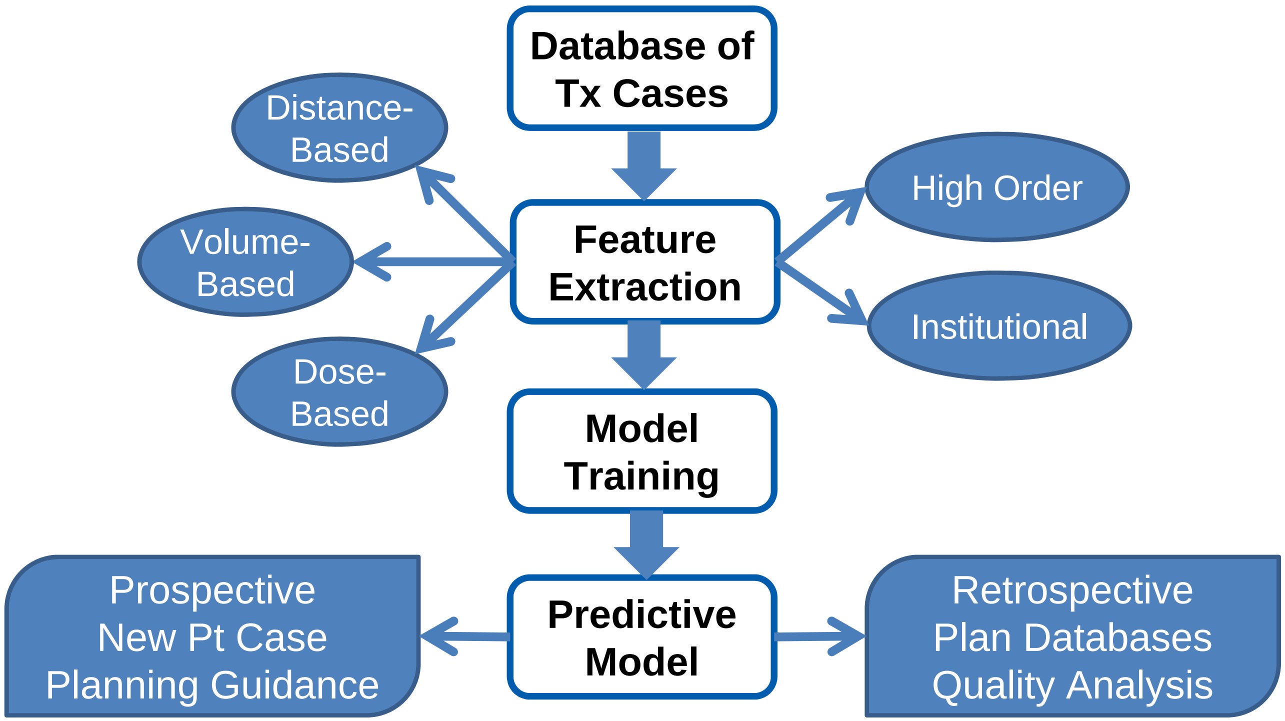
- **DVH/DTH Feature Extraction and Dimension Reduction**
  - Principal Component Analysis (PCA)





Courtesy of Jackie Wu

Modeling Planning Knowledge



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

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

How Does Auto Planning Work?

Auto-Planning in Pinnacle System

- Mimics the planners' thought process
- Utilizes the planners' tricks to create surrounding structures and tuning contours automatically
- Automatically runs multiple loops while adjusting planning objectives – similar to what planners manually do

Ouyang Z et. al. JACMP, 2019

Cleveland Clinic

Input Planning Goals

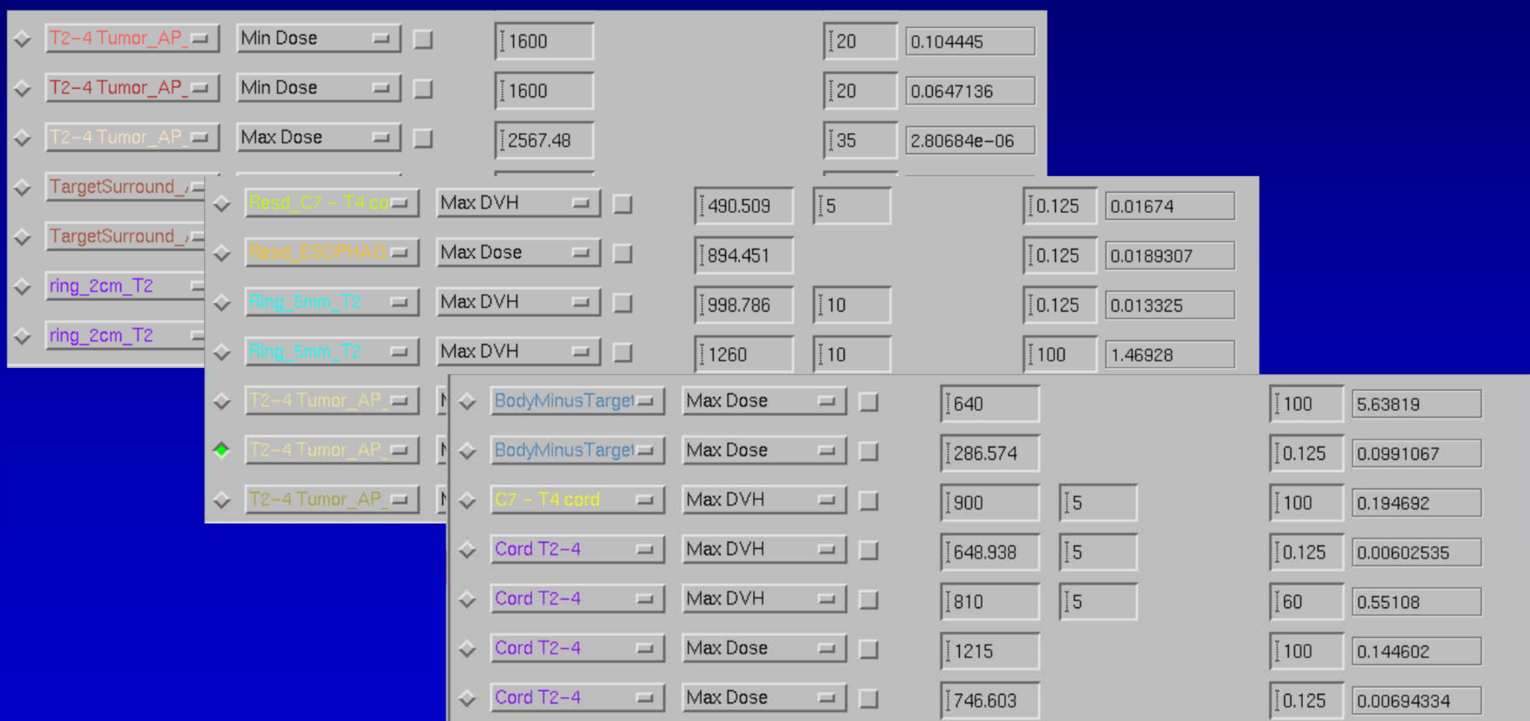
Target Optimization Goals

ROI	Dose cGy
T2-4 Tumor	1600

Organ At Risk (OAR) Optimization Goals

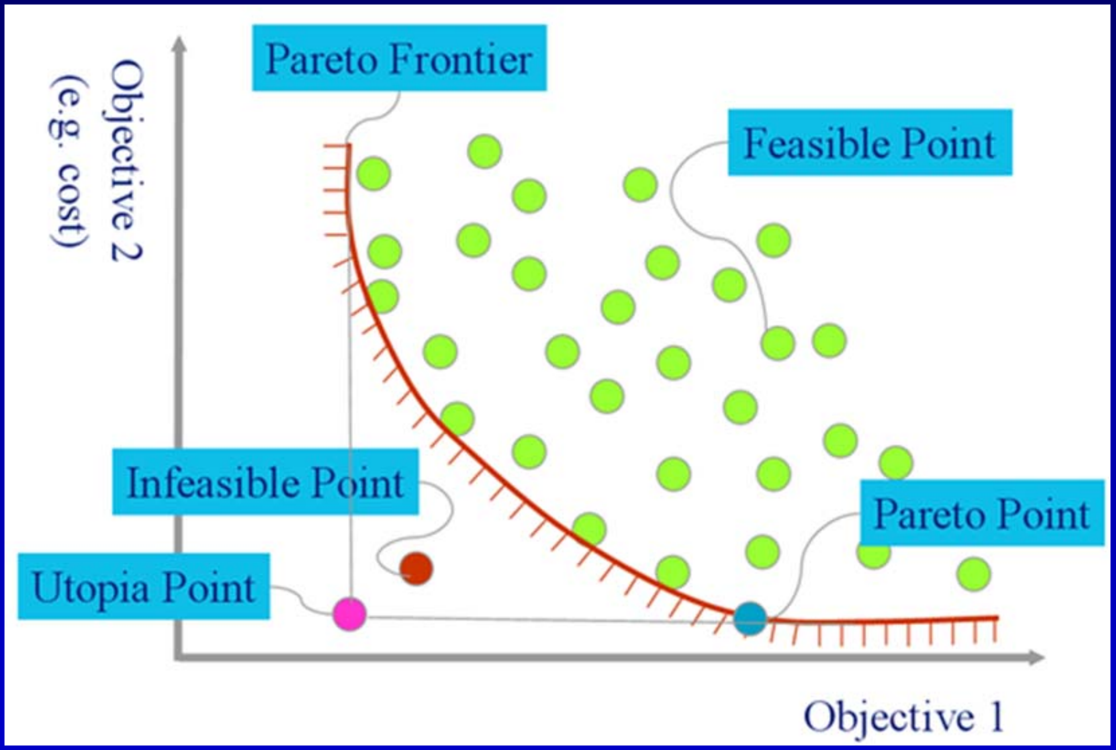
ROI	Type	Dose cGy	Volume (%)	Priority	Compromise
Cord T2-4	Max Dose	1350		High	☐
C7 - T4 cord	Max DVH	1000	5	High	☑
Cord T2-4	Max DVH	900	5	High	☐
Ring_5mm_T2	Max DVH	1400	10	High	☑
ring_2cm_T2	Max DVH	1000	10	High	☑
ESOPHAGUS	Max Dose	1600		High	☑

Automatic Created Planning Objectives



Multi-criteria Optimization (MCO)

Pareto Frontier

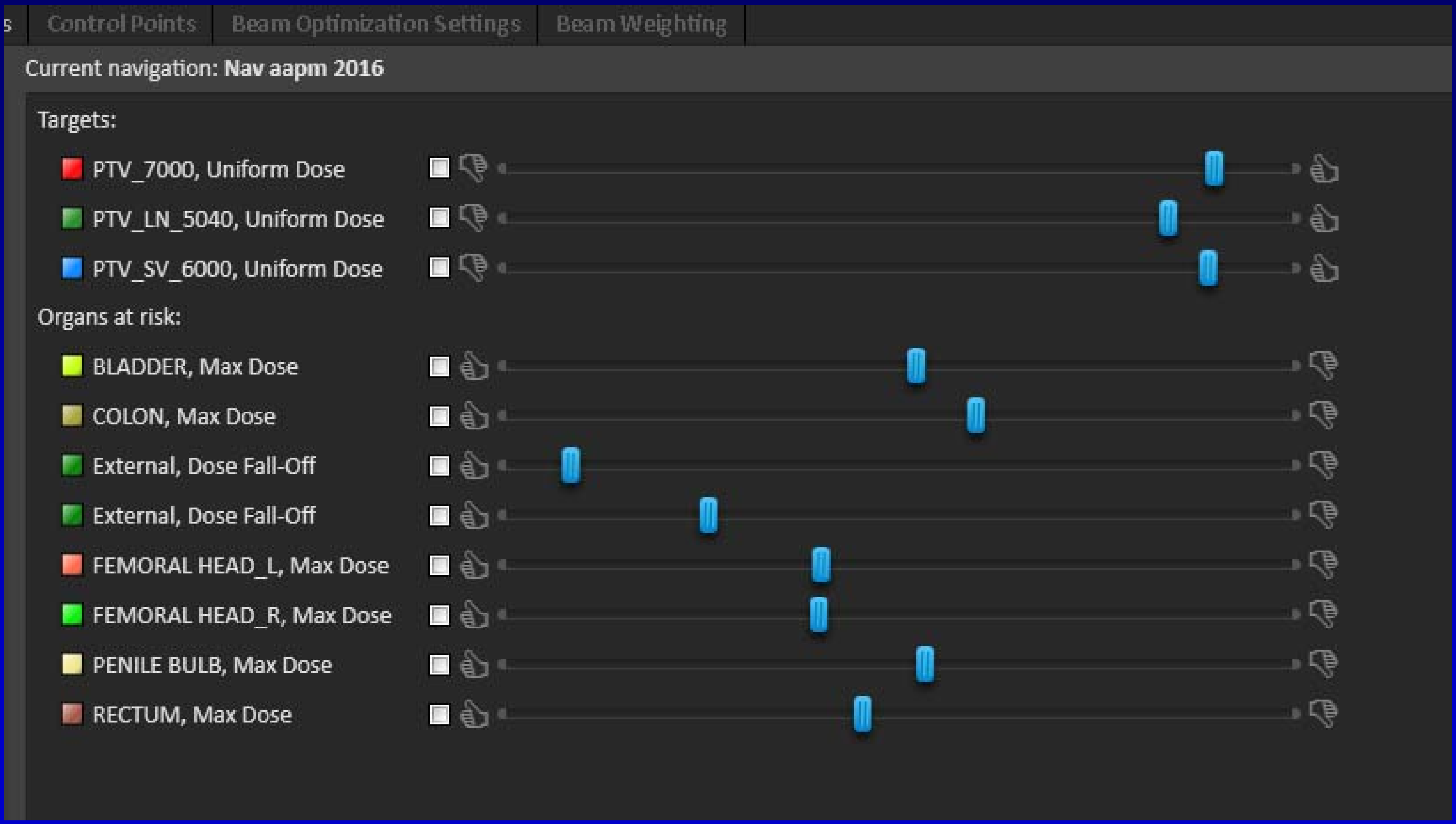


Courtesy of Jeremy Donaghue **www.noesissolutions.com/Noesis/sites/default/files/Pareto_Front.png**

MCO Implemented in RaySearch

- Requires a set of dose constraints (anchor points) – no violation allowed.
- Requires a set of dose objectives (tradeoffs) – negotiations allowed.
- Multiple (2n+1) plans are created automatically according number (n) of tradeoffs.
- Users can lock the satisfied tradeoffs to narrow the search space.

Navigation Panel



Courtesy of Jeremy Donaghue

The Ideal World

Knowledge Based Planning

Patient specific DVH predictions
No "one size fits all"
Dose constraints

Auto Planning

Automatically create a plan that meets the predicted DVHs

Multiple Criteria Optimization

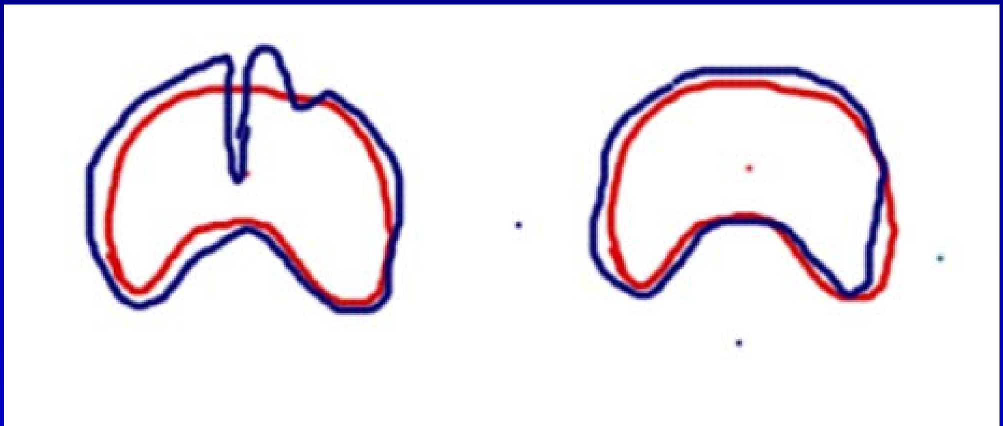
Provide trade-off solutions

Promises and Pitfalls

- Use of these advanced planning tools in IMRT planning improve plan quality, efficiency, and consistency.
- Using these advanced planning tools prevents “bad” plans.
- Plans created from these tools are not necessary clinical acceptable.

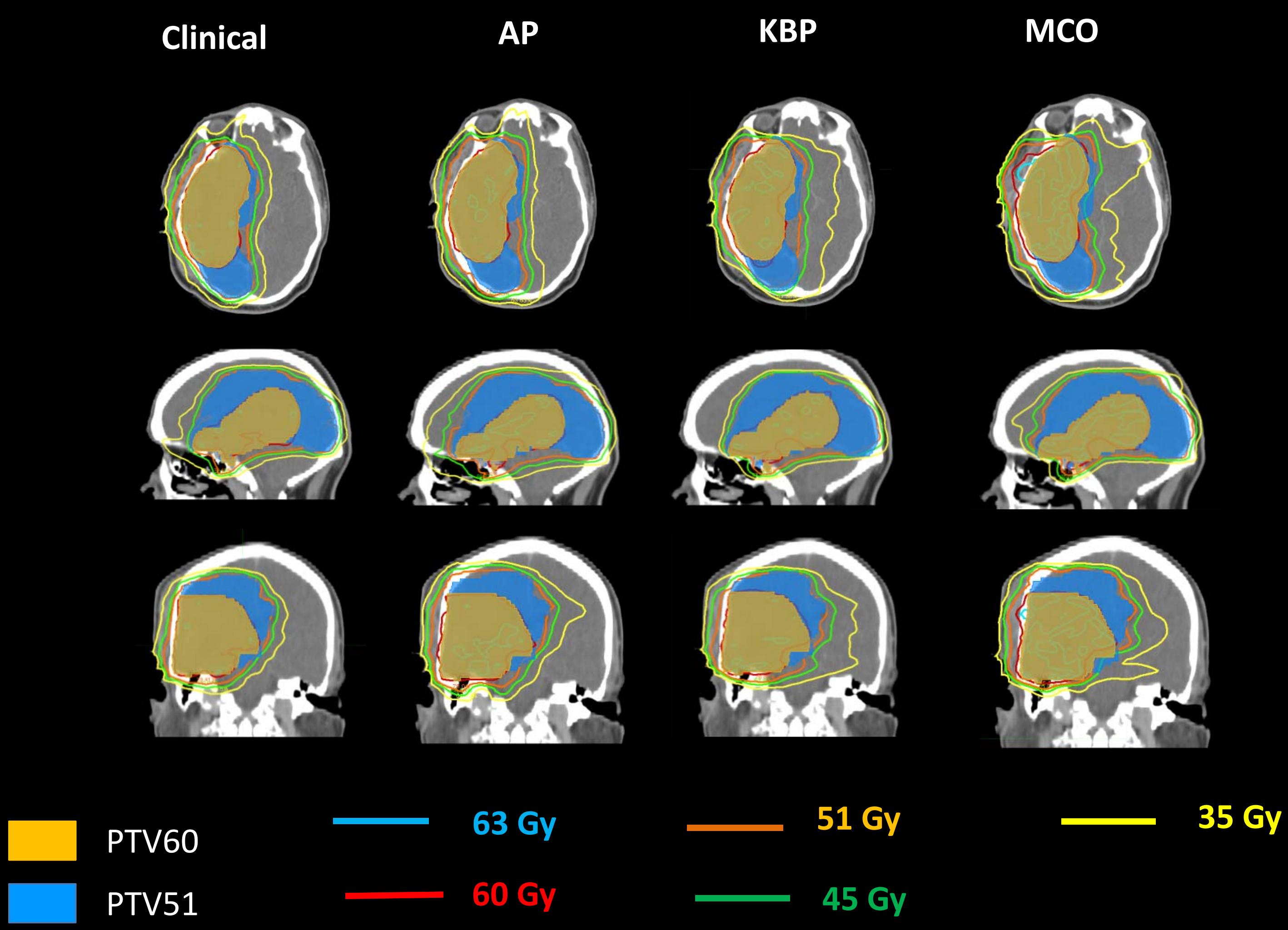
Cleveland Clinic

Lack of Spatial Information in the Cost Functions and Objectives



Bad Good

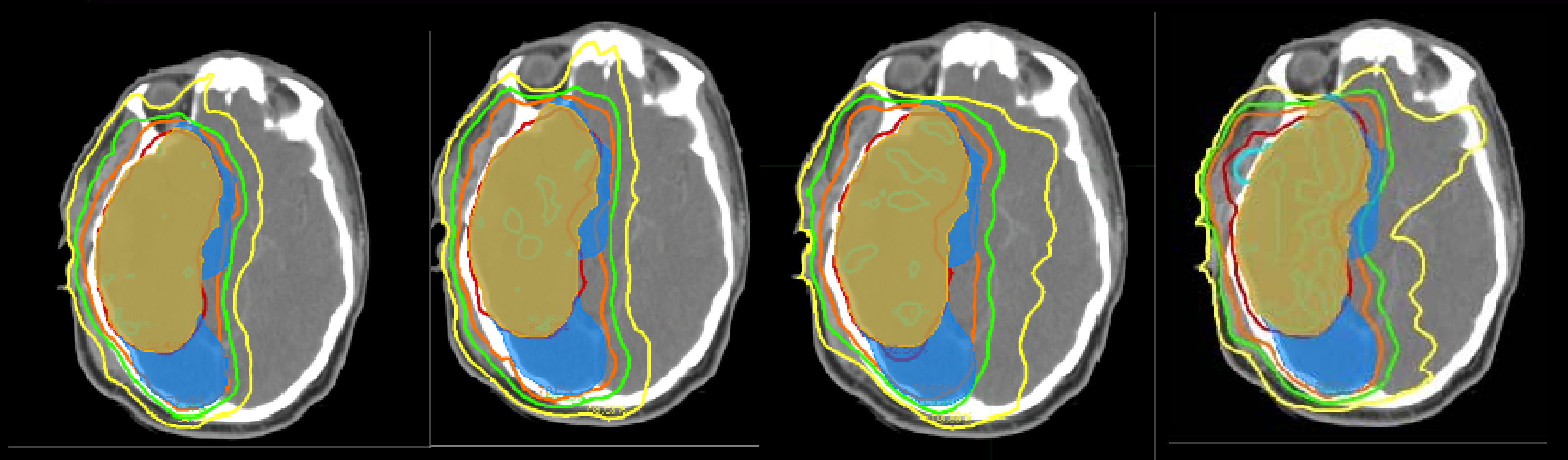
Partial Brain Cases


Clinical
AP
KBP
MCO
PTV60
PTV51
63 Gy
60 Gy
51 Gy
45 Gy
35 Gy

Rx: 60 Gy to HD-PTV, 51 Gy to LD-PTV

OARs	Goals	Clinical	AP	KBP	MCO
Brainstem	<60 Gy	61.1 Gy	60.99 Gy	59.95 Gy	59.47 Gy
Chiasm	<56 Gy	54.5 Gy	55.59 Gy	55.44 Gy	50.15 Gy

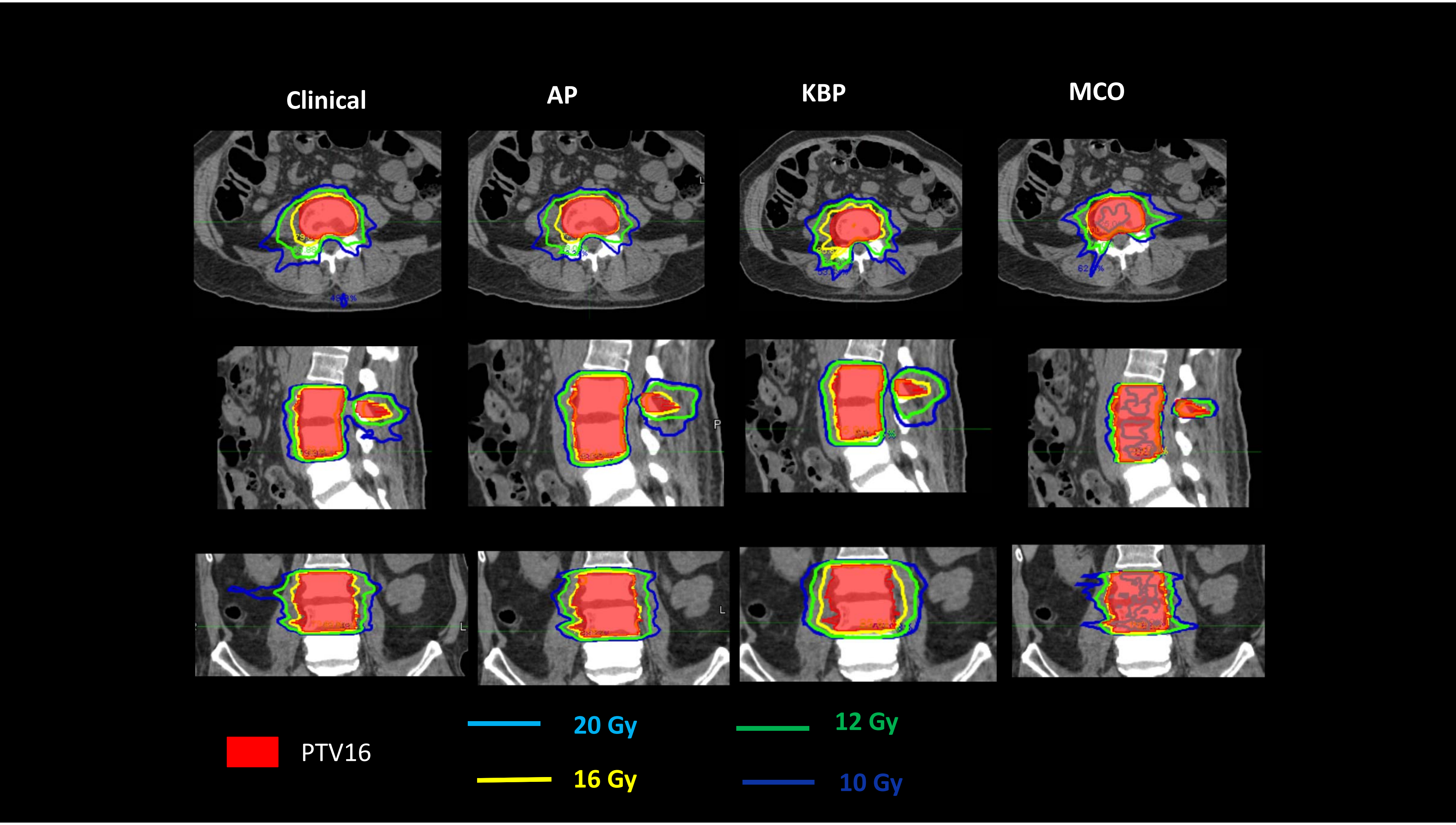
Clinical | AP | KBP | MCO



63 Gy, 60 Gy, 51 Gy, 45 Gy, 35 Gy

OARs	Goals	Clinical	AP	KBP	MCO
Brainstem	<60 Gy	61.1 Gy	60.99 Gy	59.95 Gy	59.47 Gy
Chiasm	<56 Gy	54.5 Gy	55.59 Gy	55.44 Gy	50.15 Gy

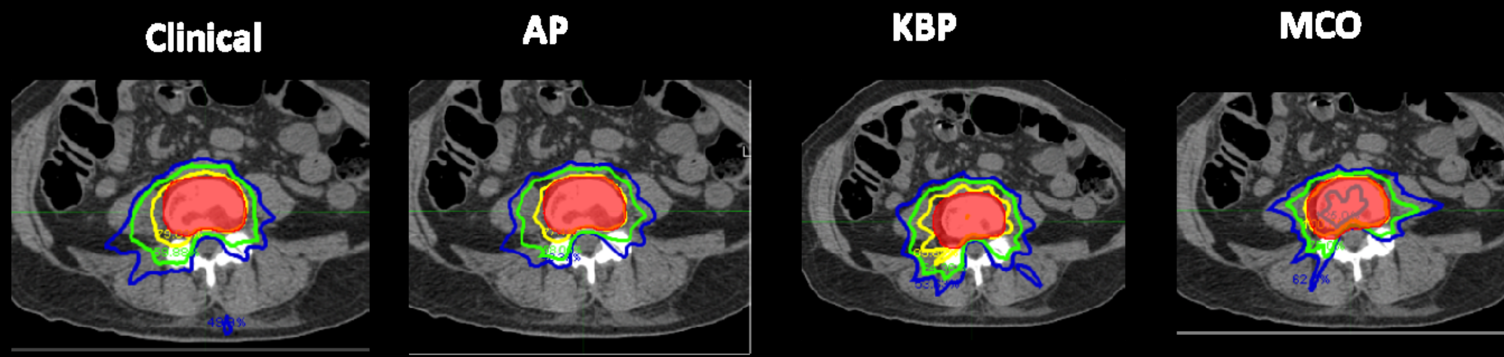
Spinal SBRT Cases


Clinical
AP
KBP
MCO
PTV16
20 Gy
12 Gy
16 Gy
10 Gy

Rx: D90% > 16 Gy

	Goal	Clinical	AP	KBP	MCO
Spinal Cord (Max. Dose)	<14 Gy	13.9 Gy	14.4 Gy	14.1Gy	12.8 Gy

Lu L, et. al. JACMP, 2019.



	Goal	Clinical	AP	KBP	MCO
Spinal Cord (Max. Dose)	<14 Gy	13.9 Gy	14.4 Gy	14.1Gy	12.8 Gy

PTV16

20 Gy

16 Gy

12 Gy

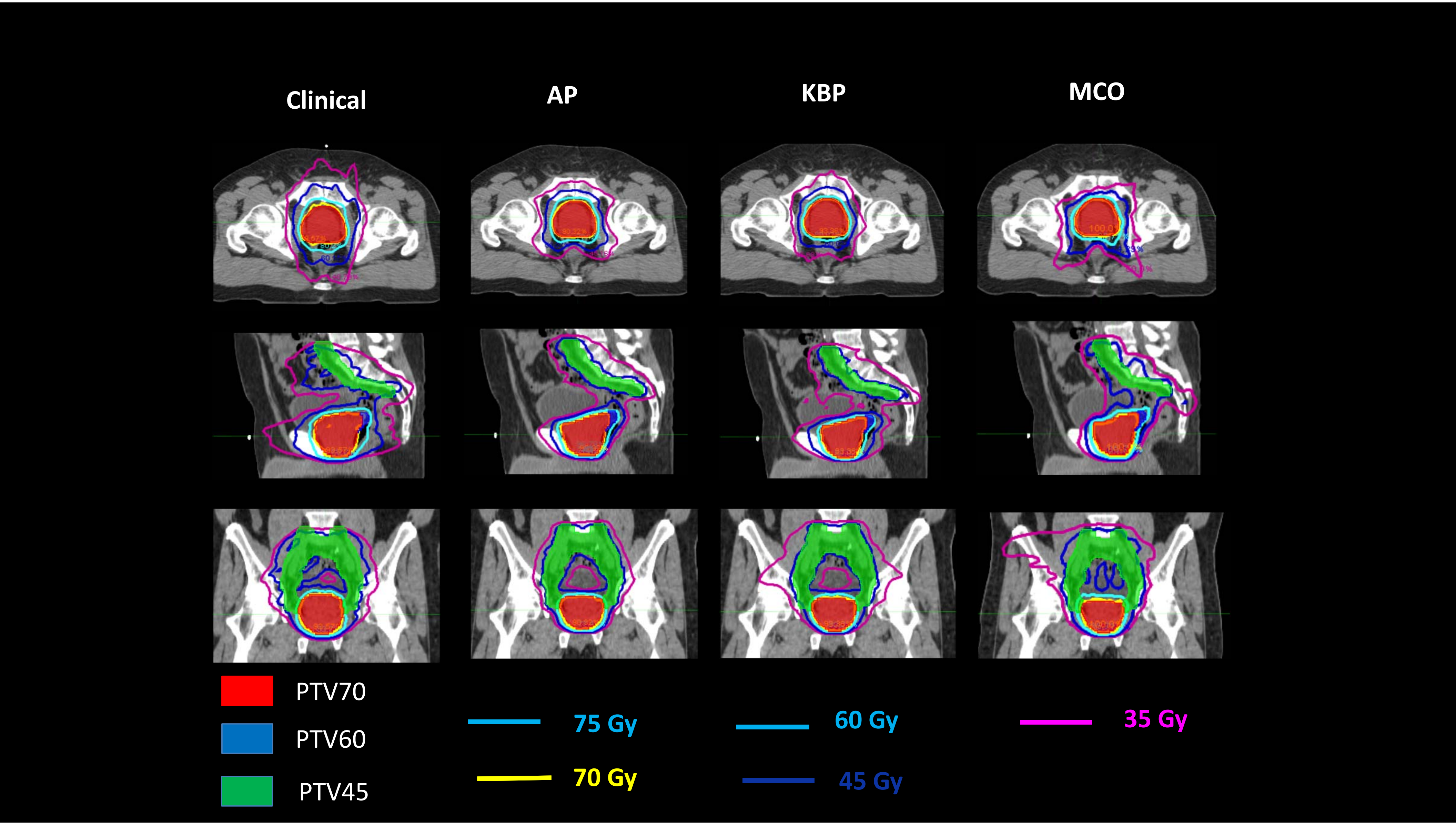
10 Gy

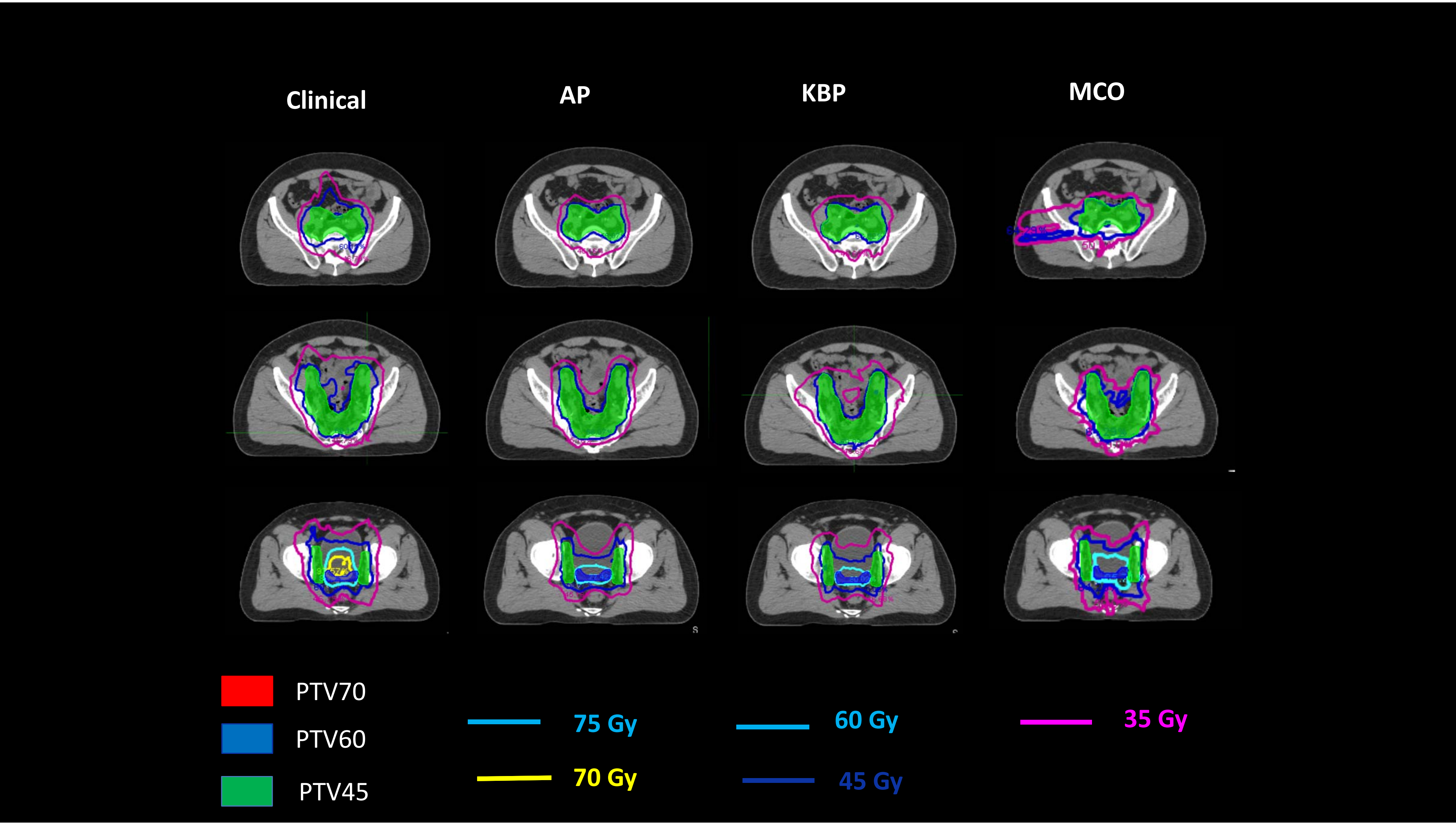
Lu L, et. al. JACMP, 2019.

Prostate + Pelvic LN Cases

Rx: PTV-protstae 70 Gy, PTV-LN 50.4 Gy in 28 Gy

	Goal	Clinical	AP	KBP	MCO
Bladder	V63Gy <10%	16.28%	7.40%	7.02%	11.18%
Rectum	V63Gy <10%	12.15%	7.00%	6.25%	5.95%
Rectum	V45Gy < 30%	44.47%	22.21%	27.40%	23.44%


Clinical
AP
KBP
MCO
PTV70
PTV60
PTV45
75 Gy
70 Gy
60 Gy
45 Gy
35 Gy

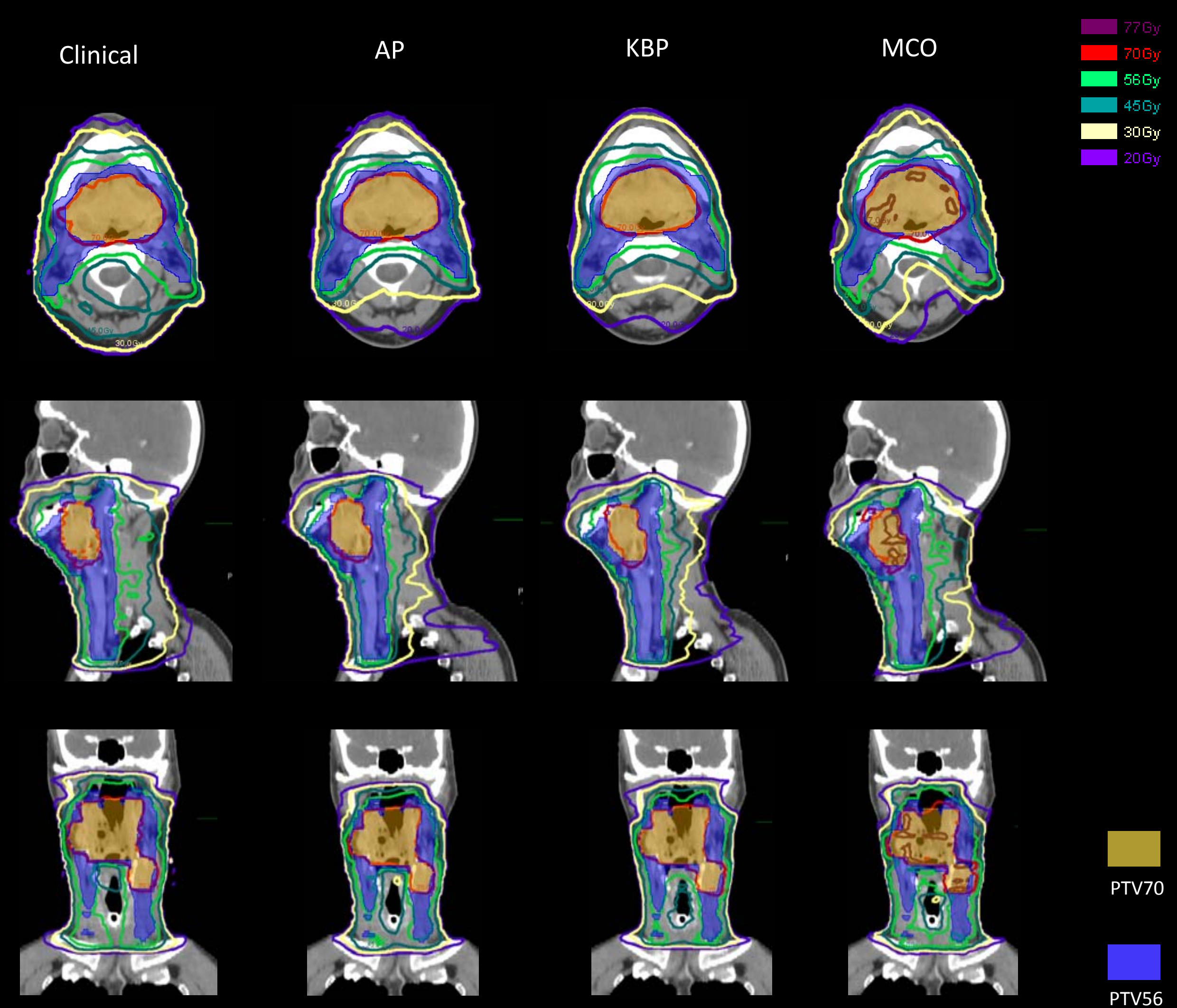


Clinical
AP
KBP
MCO
PTV70
PTV60
PTV45
75 Gy
70 Gy
60 Gy
45 Gy
35 Gy

Oropharynx Cases

Rx: PTV-HD 70 Gy, PTV-LD: 56Gy

	Goal	Clinical	AP	KBP	MCO
Spinal cord	D0.03cc< 45 Gy	46.61	37.48	42.05	39.32
Paratid L	Dmean <26 Gy	34.17	24.53	28.53	25.01
Paratid R	Dmean <26 Gy	35.16	35.46	29.29	23.78
Mandible	D0.03cc <73 Gy	73.69	73.83	75.95	73.26
Trachea	Dmean <45 Gy	32.04	24.52	31.03	22.27
Esophagus	Dmean < 50 Gy	18.77	16.52	19.8	12.34
Oral cavity	Dmean <35 Gy	30.81	28.14	29.99	22.1


Clinical
AP
KBP
MCO
77Gy
70Gy
56Gy
45Gy
30Gy
20Gy
PTV70
PTV56

Take Home Message

- DVHs and specific dosimetric end-points (e.g., mean dose) are not sufficient to assess plan quality. Carefully examining 3D dose distributions is important.
- Advance planning tools can assist dosimetrists to create plans with reduced variations but clinical judgment and experience are still important
- The pitfall is that the desired 3D dose distributions cannot be clearly described by the numeric planning objectives.

Acknowledgement

- Matt Kolar, M.S.
- Zhilei Liu Shen, Ph.D.
- Lan Lu, Ph.D.
- Jeremy Donaghue, M.S.
- Jackie Wu, Ph.D. Duke University

Cleveland Clinic

Cleveland Clinic Cancer Center at Main Campus