TG-166
Outcome driven treatment planning

MEDICAL COLLEGE OF WISCONSIN

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On behalf of AAPM TG-166

AAPM, July 19, 2010

Evolution of biological (outcome-model) based treatment planning

Evolution stage	Plan optimization strategy	Plan evaluation strategy	Representative TPS
0	DV-based cost functions	DVHs	The majority of current TPS
1	EUD for OARs; EUD- and DV-based cost functions for targets	DVHs and relative values of TCP/NTCP	CMS Monaco Philips Pinnacle Varian Eclipse
2	EUD-based cost functions for all structures	Absolute values of TCP/NTCP	Future developments
3	Absolute values of TCP/NTCP	Absolute values of TCP/NTCP	Future developments

AAPM Task Group 166:

The use and QA of biologically related models for treatment planning

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- **To discuss strategies, limitations, conditions and cautions for using these models and parameters in clinical treatment planning**
- **To point out dosimetric differences between outcome-model based and dose-volume based plan optimization and evaluation**
- **To provide general guidelines and methodology for commissioning and routine QA of outcome-model based TPS**

Outcome modeling for treatment planning

- Survival probability (LQ)
- Equivalent Uniform Dose (EUD/gEUD)
- TCP (Poisson model)
- NTCP (LKB, Serial, Parallel)
- Clinical Response Models (Maximum likelihood analysis)

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But still useful (pushing individual DVHs towards less toxicity) !

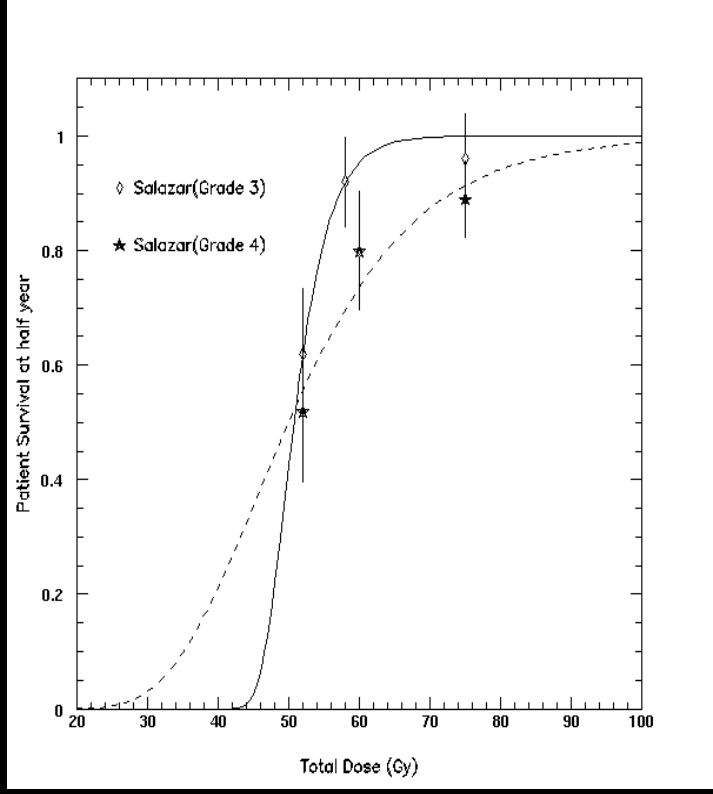
LQ parameters: Malignant gliomas

MG $\alpha = 0.06 \pm 0.05 \ Gy^{-1}$
$\alpha/\beta = 10.0 \pm 15.1 \ Gy$

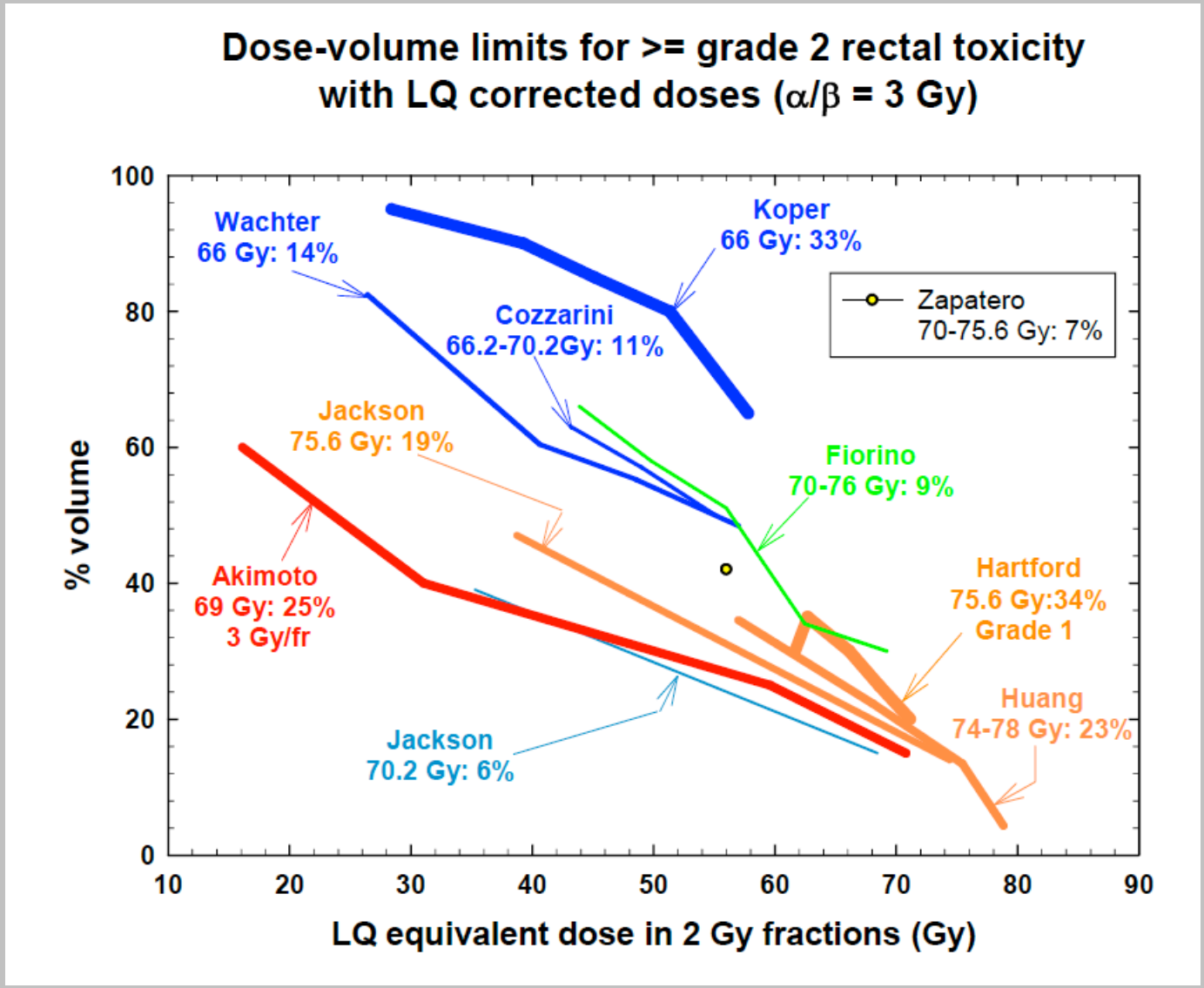
Grade 1&2 $\alpha = 0.35 \pm 0.07 \ Gy^{-1}$
$\alpha/\beta = 4.3 \pm 5 \ Gy$

Grade 3 $\alpha = 0.11 \pm 0.10 \ Gy^{-1}$
$\alpha/\beta = 5.8 \pm 11.8 \ Gy$

Grade 4 $\alpha = 0.04 \pm 0.06 \ Gy^{-1}$
$\alpha/\beta = 5.6 \pm 9.4 \ Gy$

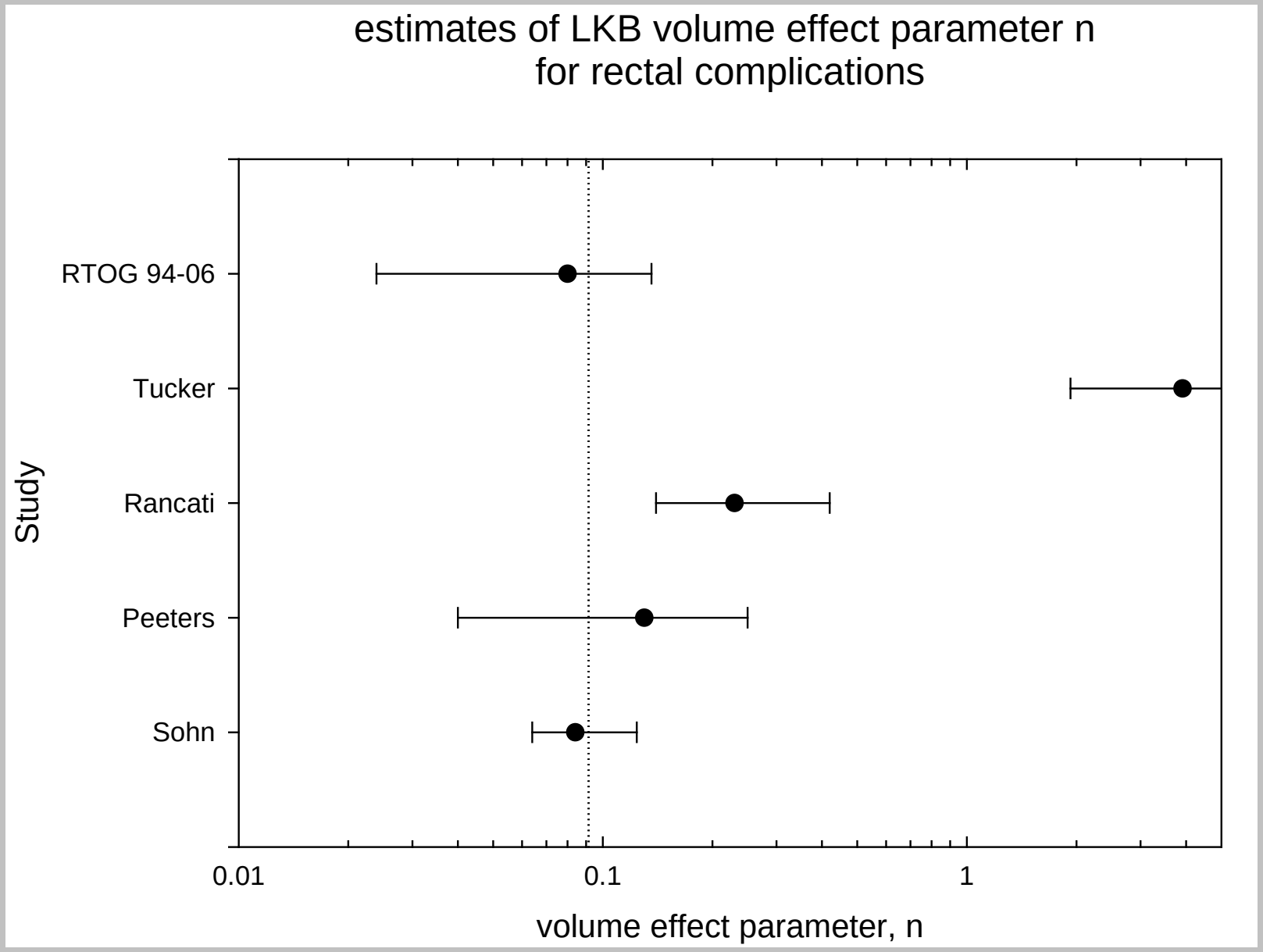


Qi, Schultz, Li , IJROBP, 2006.



QUANTEC, IJROBP 2010

(Slide courtesy J. Deasy)



(Slide courtesy A. Jackson et al.)

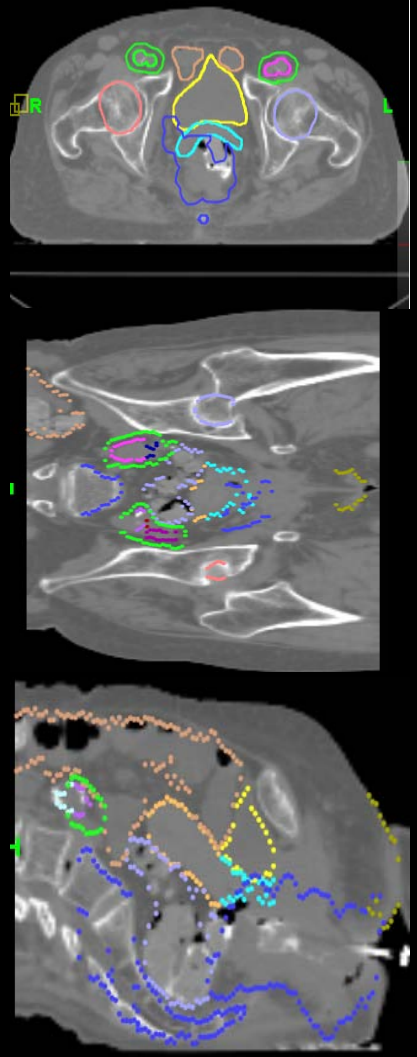
(Note: a = 1/n)

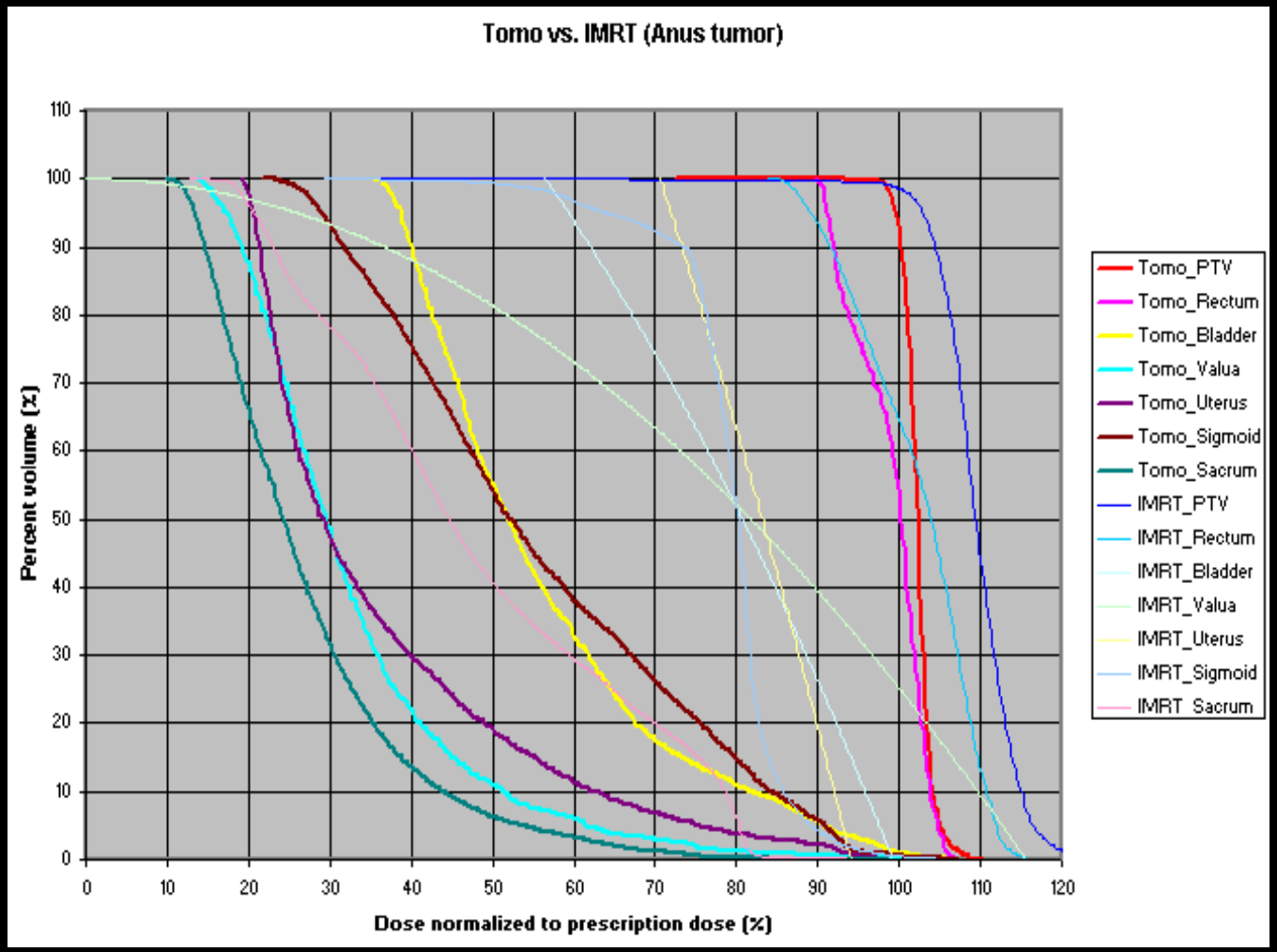
Use of outcome models in computerized treatment planning

- Plan evaluation
- Plan optimization

Plan Ranking: Tomo vs IMRT
Case example: Female Anus

Figure-of-merit TOMO: *fEUD* = 0.613 IMRT: *fEUD* = 0.600



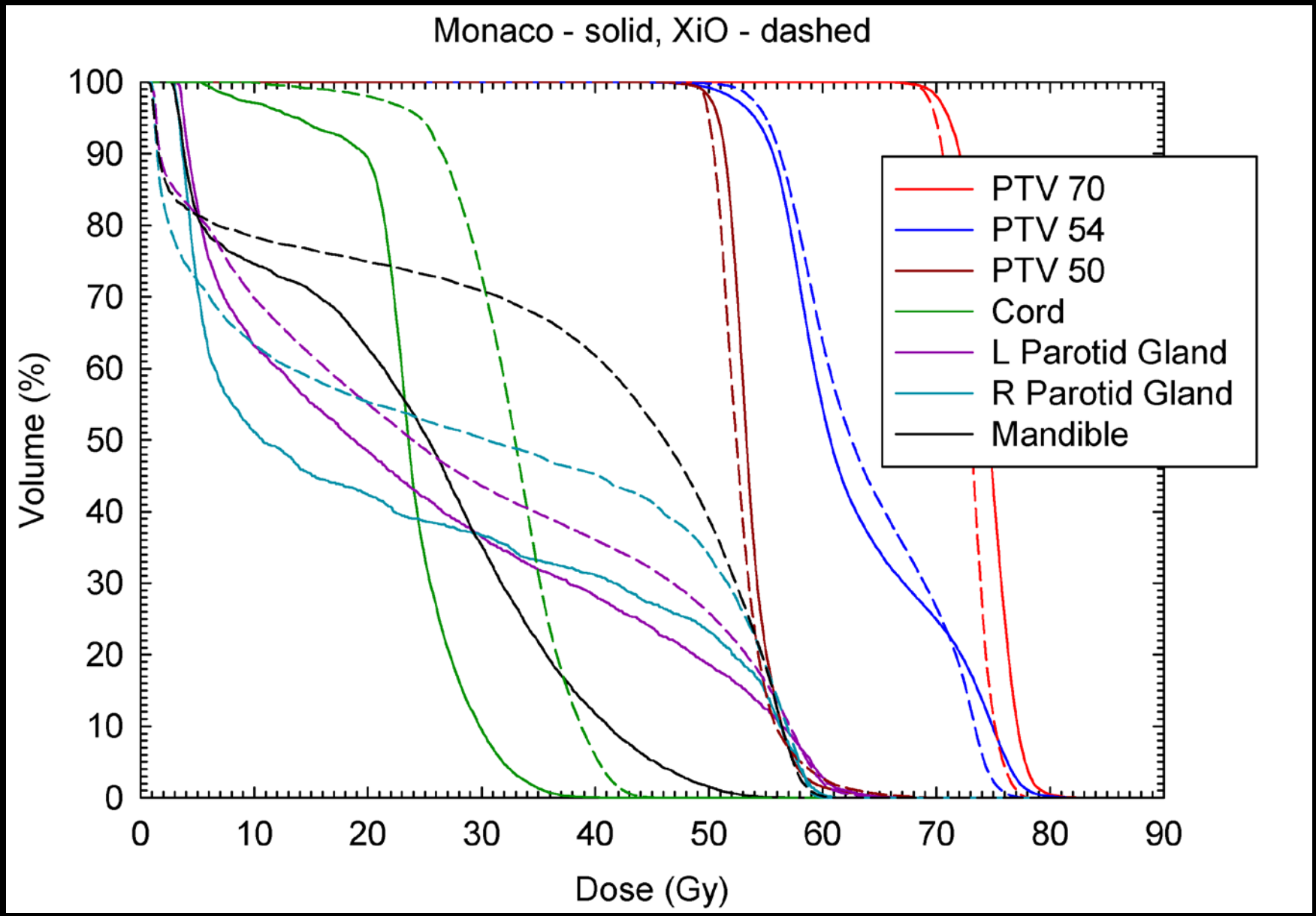


Plan Optimization

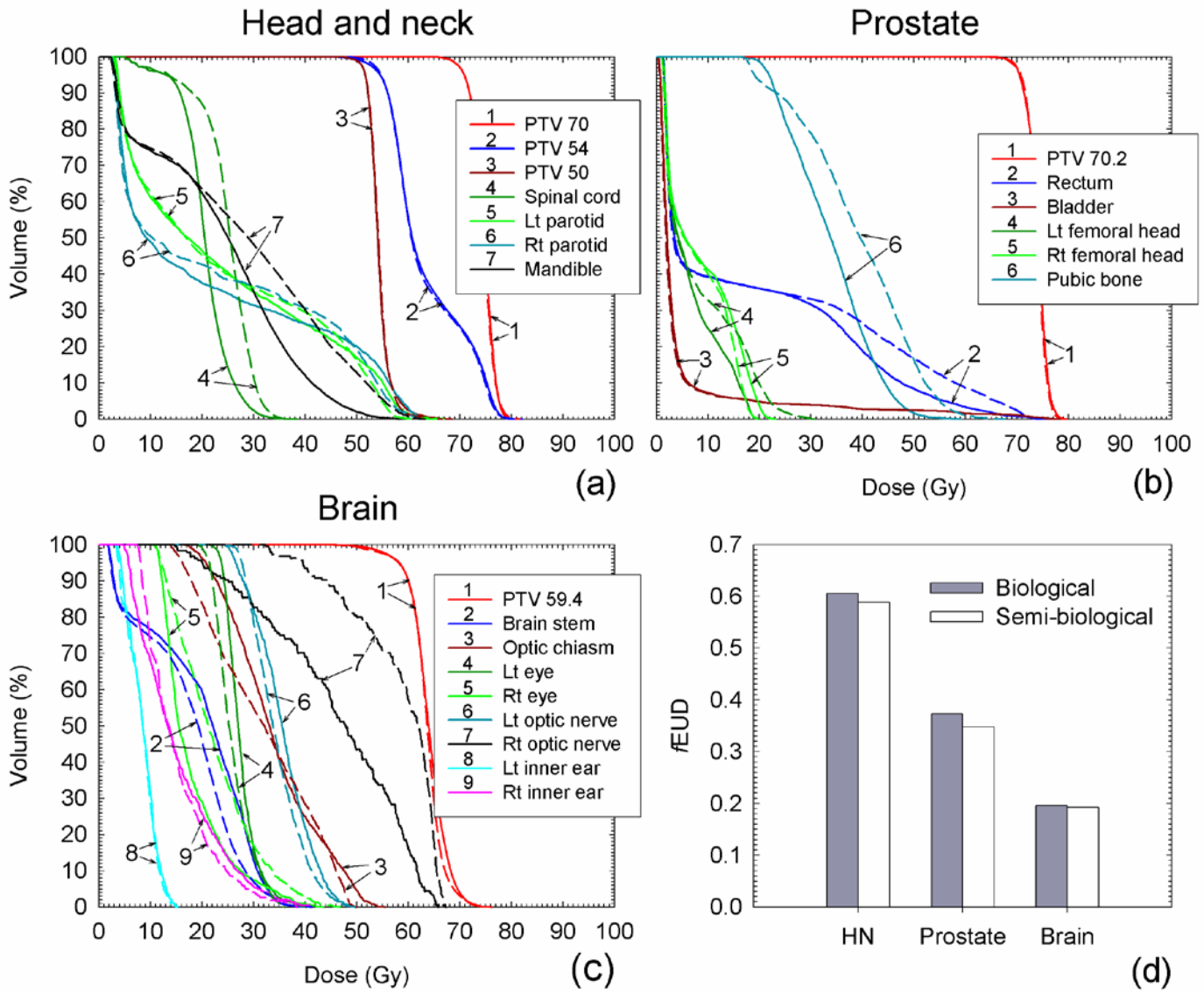
Cost Functions: Mathematical forms of treatment goals

- Physical (dose-volume based) cost functions
  - Overdose/underdose volume constrains
  - Maximum/minimum doses
- Biological (outcome-model based) cost function.
  - Target/OAR EUDs
  - TCP/NTCP.

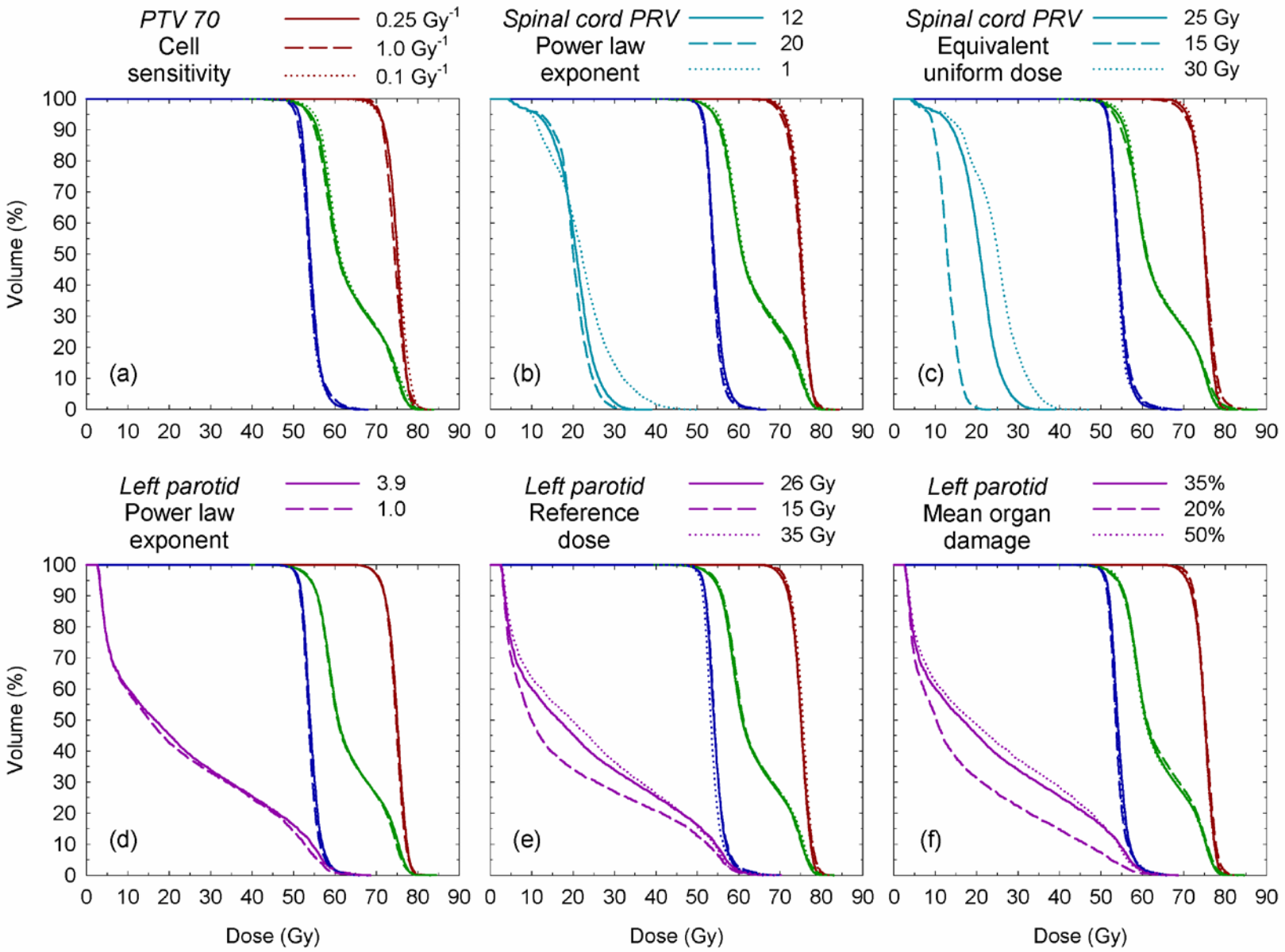
H&N case: Physical (XiO) vs Biological (Monaco)



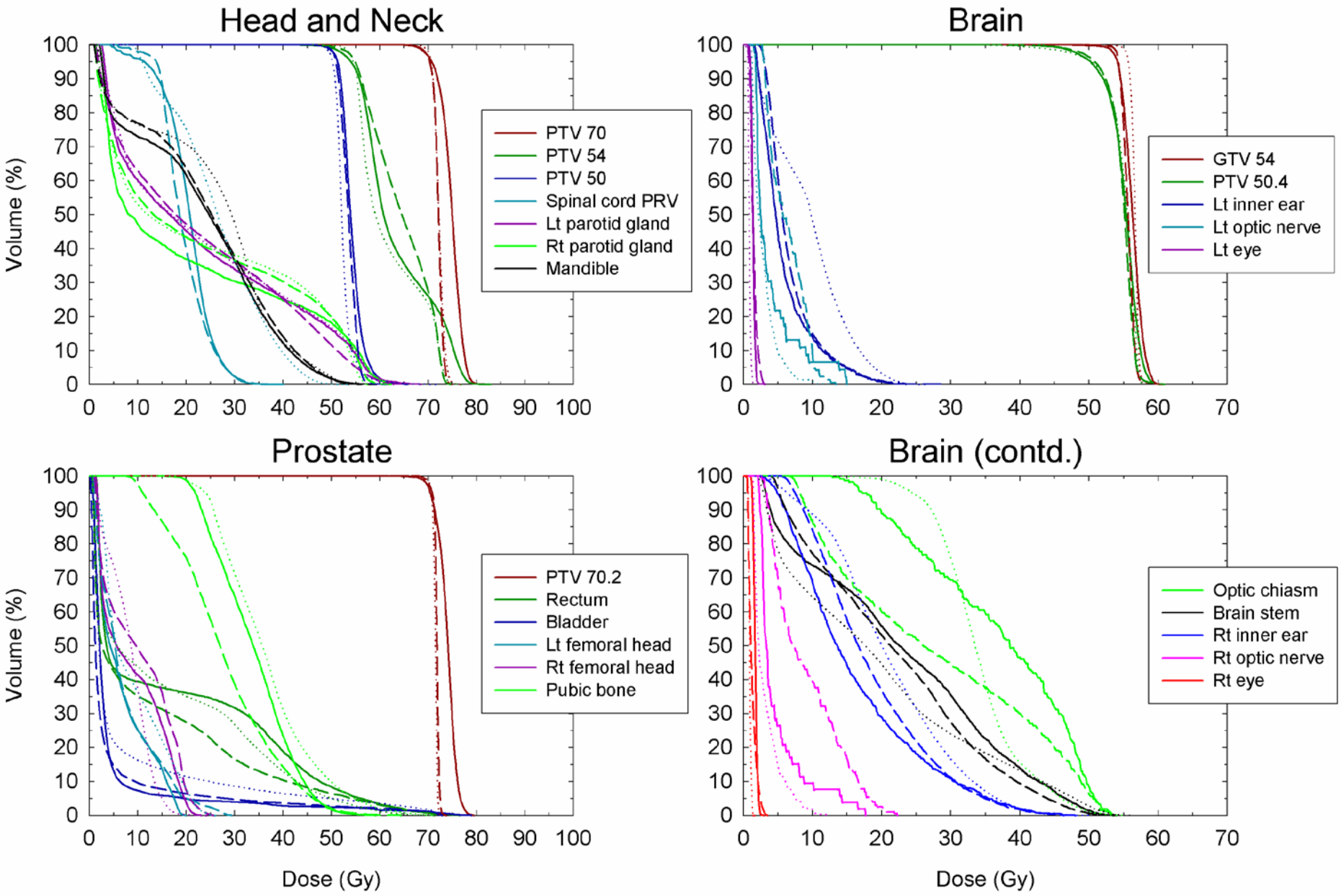
Biological (solid) vs. dose-based (dashed) cost functions for OARs Monaco



Sensitivity on model parameters: Monaco



Comparison: Monaco (solid), Pinnacle (dashed), Eclipse (dotted)



Why does outcome model work?

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We know how to ask and what to ask !

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- Since, by definition, there are an infinite # of DVHs that leads to an EUD for a given organ, outcome-model based cost functions can lead to the desired EUD directly.

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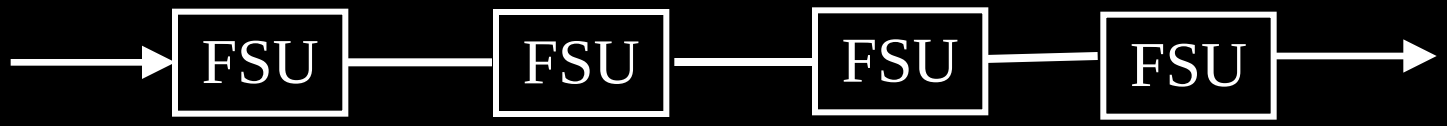
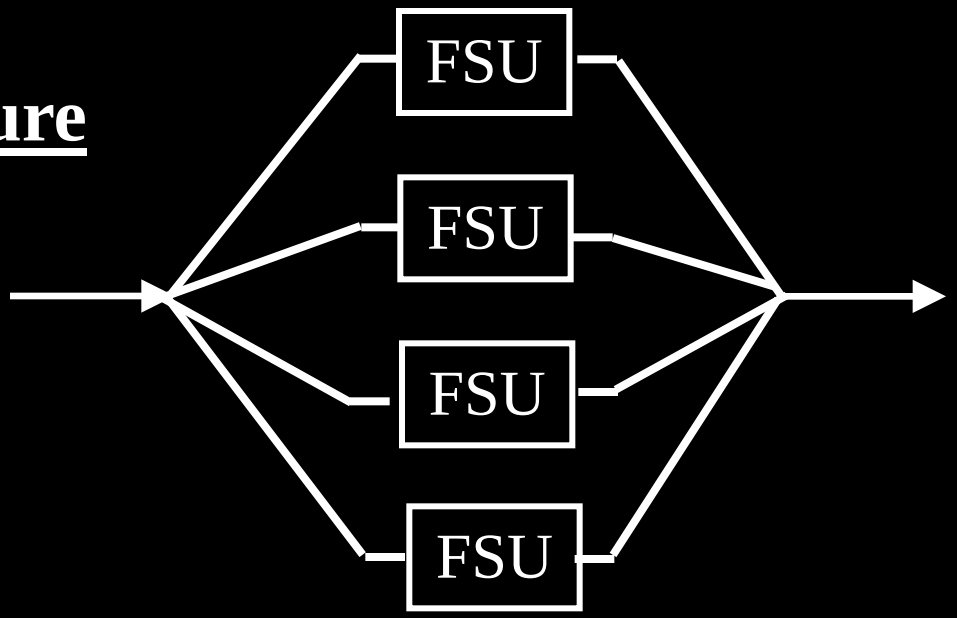
- Since, by definition, there are an infinite # of DVHs that leads to an EUD for a given organ, outcome-model based cost functions can lead to the desired EUD directly.
- Can get the best possible result (not just any acceptable result) and will get it more quickly and easily

Serial structure (spinal cord, rectum)

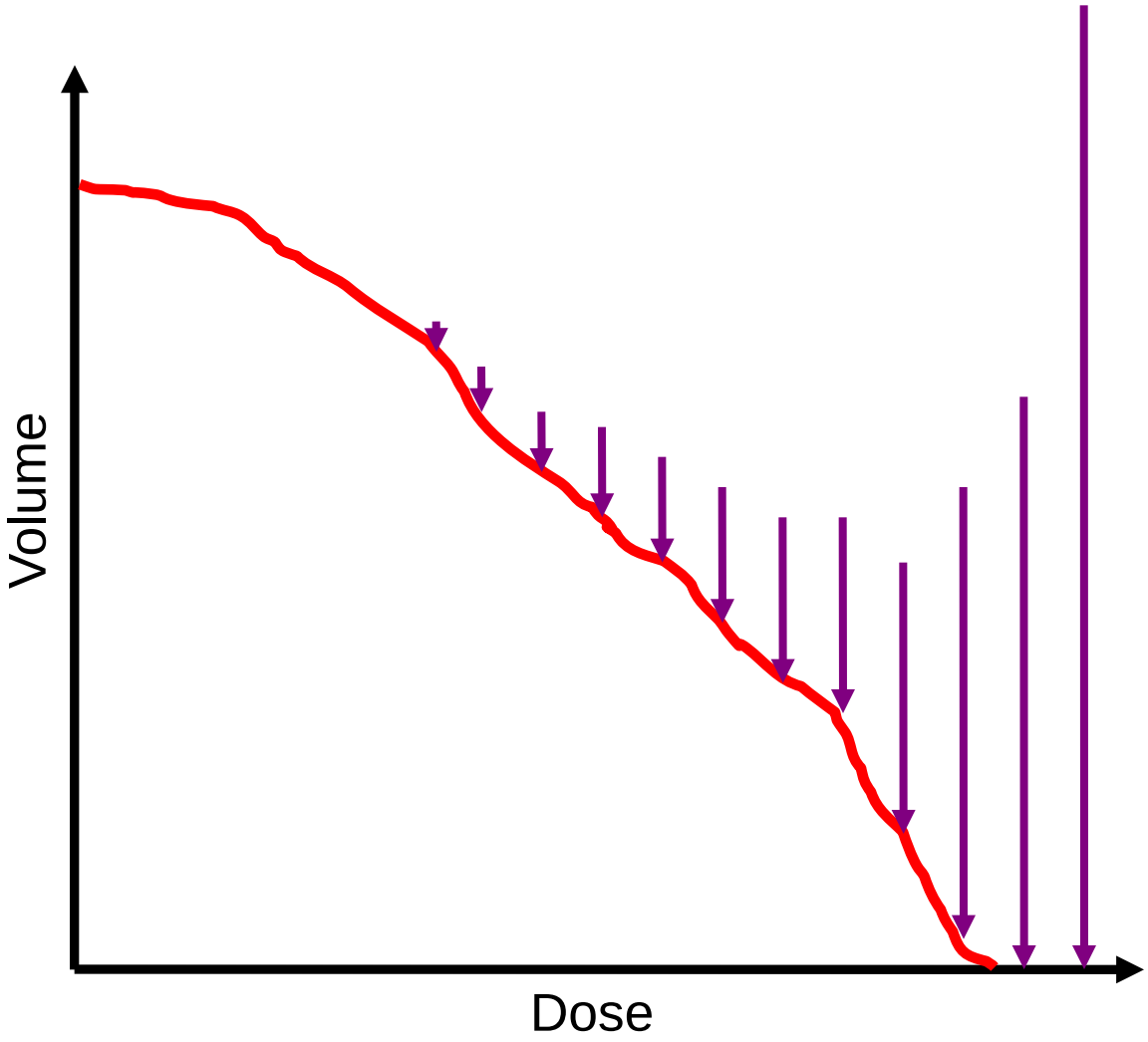


Parallel structure

lung, liver



How does a serial complication model control the DVH ?



The length of the weight arrow grows as

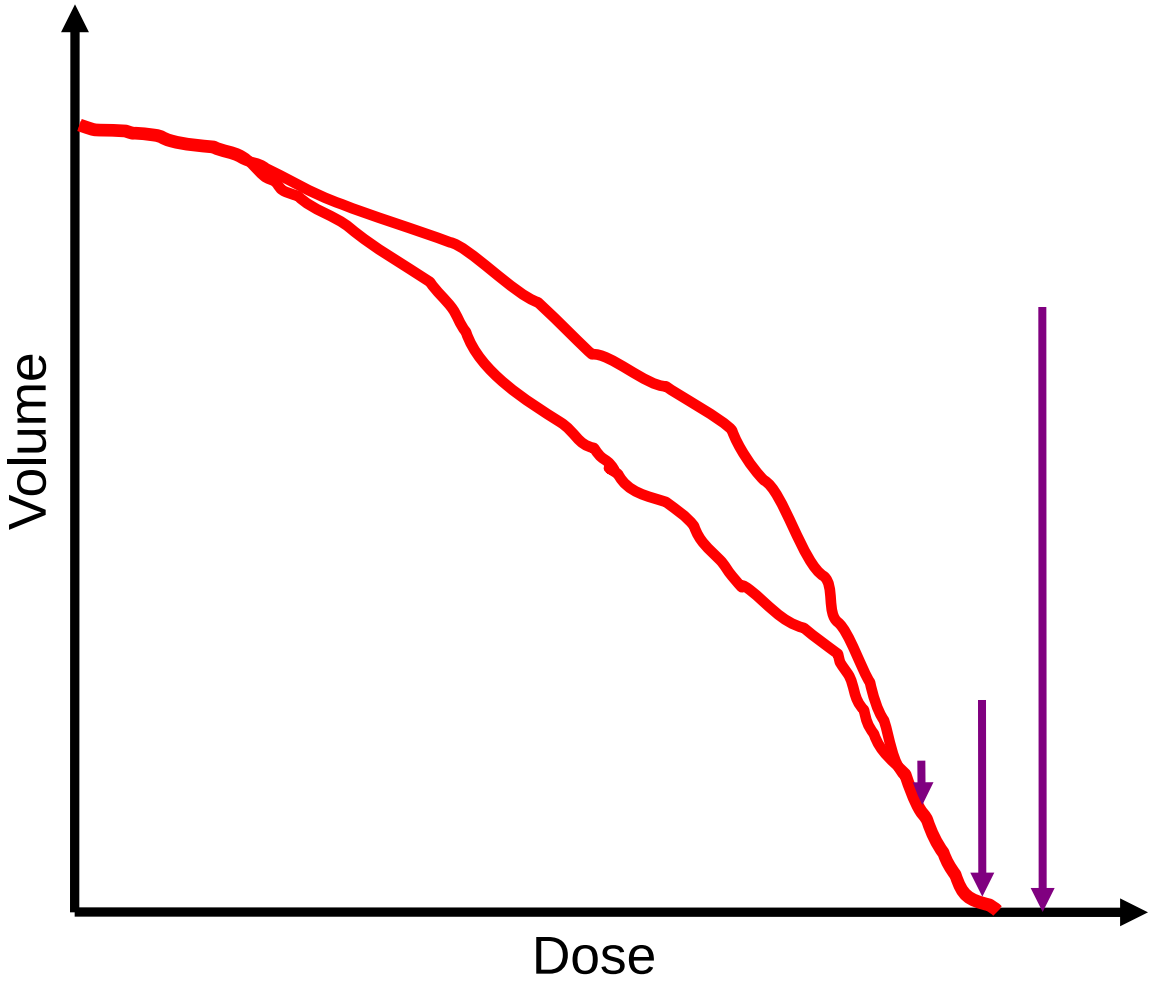
$$D^{k-1}$$

$$\exp(\alpha D)$$

or similar functions

Courtesy M. Alber

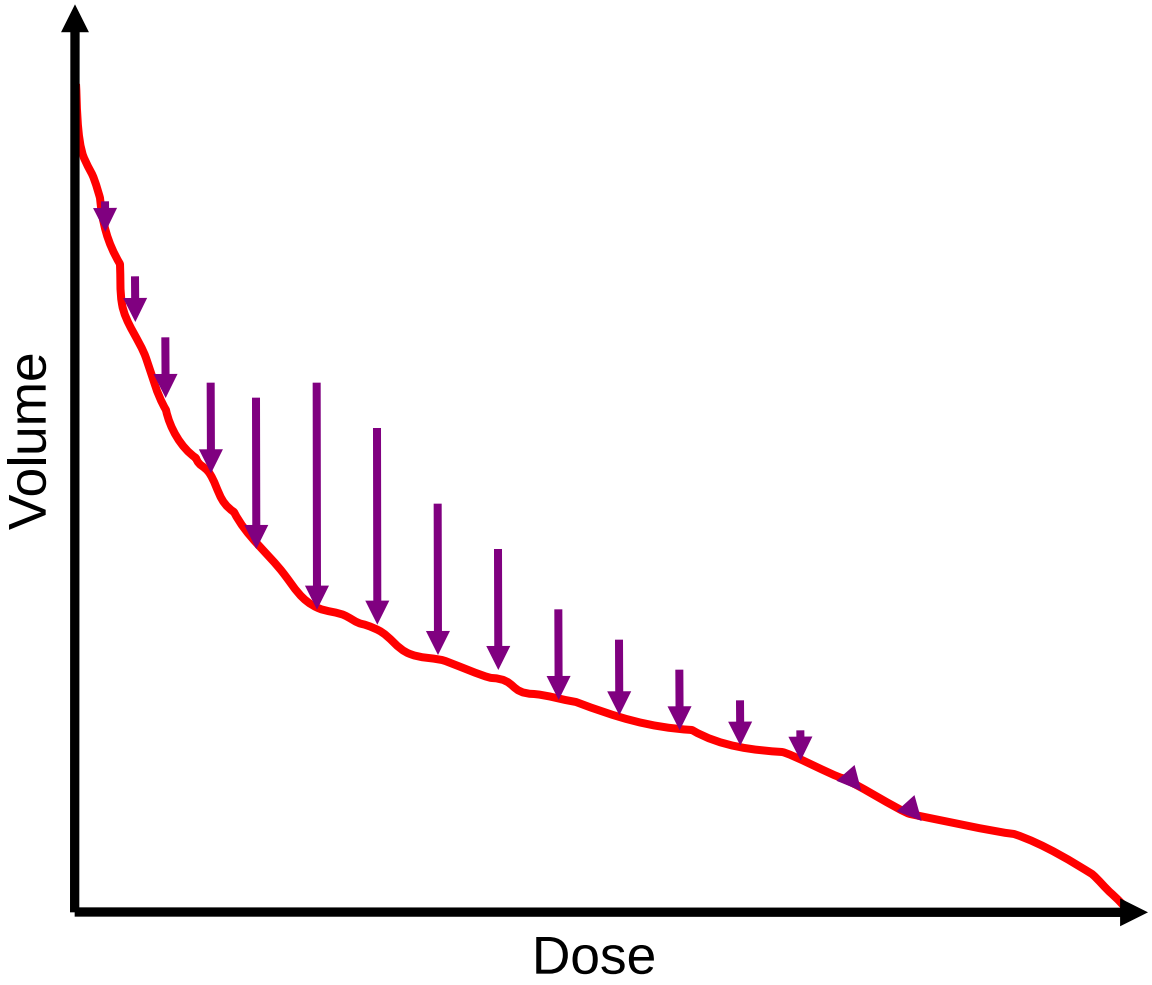
In contrast, a quadratic penalty:



DVH control
only for doses
greater than threshold

Courtesy M. Alber

How does a parallel complication model control the DVH ?



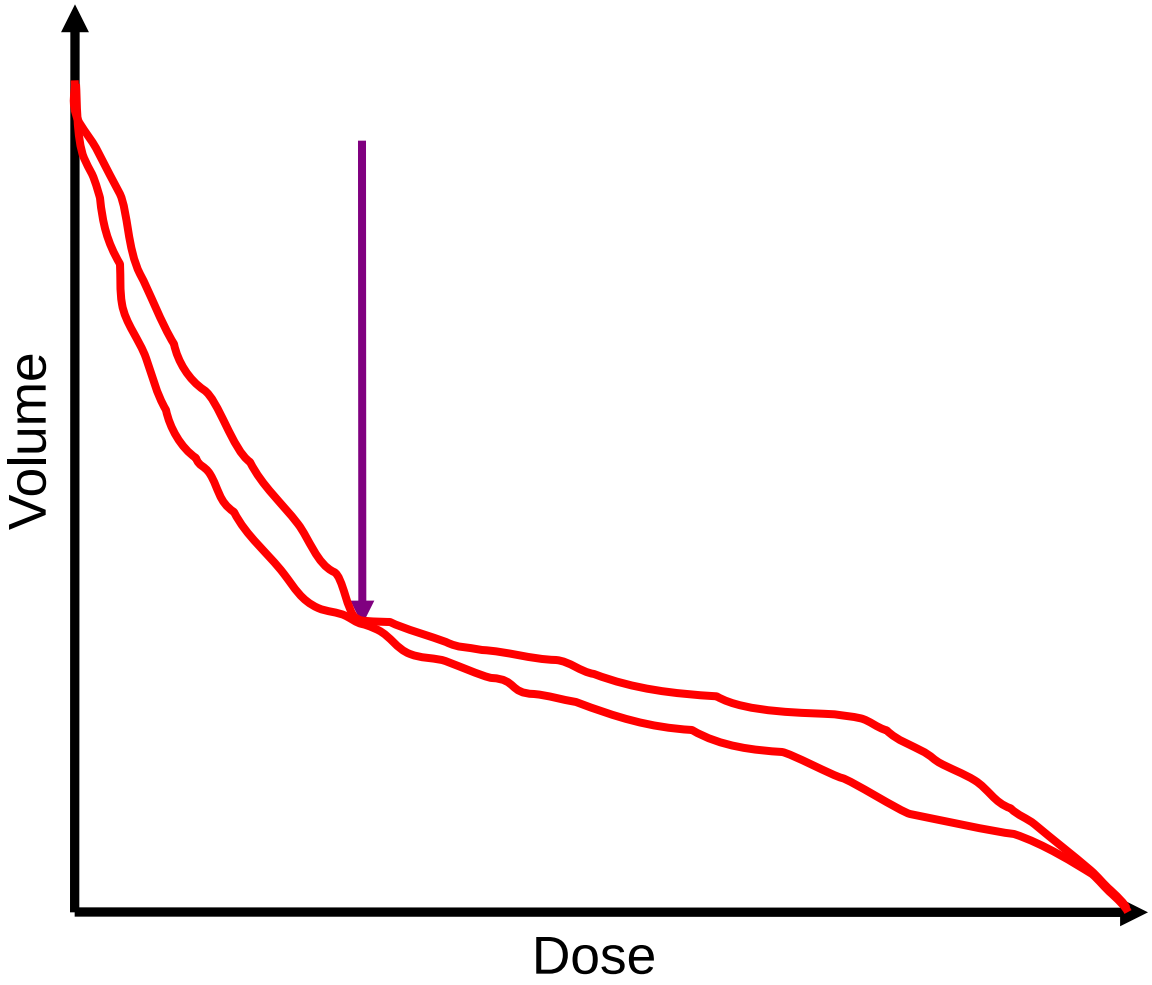
The length of the weight arrow grows as

$$\frac{\exp(-\alpha D)}{(1+\exp(-\alpha D))^2}$$

or similar functions

Courtesy M. Alber

In contrast, a DVH constraint :



The constraint controls only a single point

Courtesy M. Alber

Cautions
for using outcome-model based TPS

- **Cold and hot spots**
- **Sensitivity of model parameters**
- **Extrapolation/interpolation between fractionations (EUD, DVH)**

TG-166 General Recommendations

- **Outcome-model based cost functions for OARs are *more effective* towards OAR sparing**

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- **Outcome-model based TPS could generate highly non-uniform dose distributions.** Unless for deliberate and tested situations, such highly non-uniformity should be avoided by using min and/or max dose constraints.

TG-166 General Recommendations

- **Outcome-model based cost functions for OARs are *more effective* towards OAR sparing**

- **Outcome-model based TPS could generate highly non-uniform dose distributions.** Unless for deliberate and tested situations, such highly non-uniformity should be avoided by using min and/or max dose constraints.

- **At present, plan evaluation should base on established dose-volume criteria (3D dose distribution, DVH)**. Biological indices may be used to help select rival plans. Use of absolute estimates of TCP/NTCP as main indicators of plan quality is not warranted at this time.

Commissioning of biologically based TPS

- **Verification of model calculations (EUD/TCP/NTCP)**

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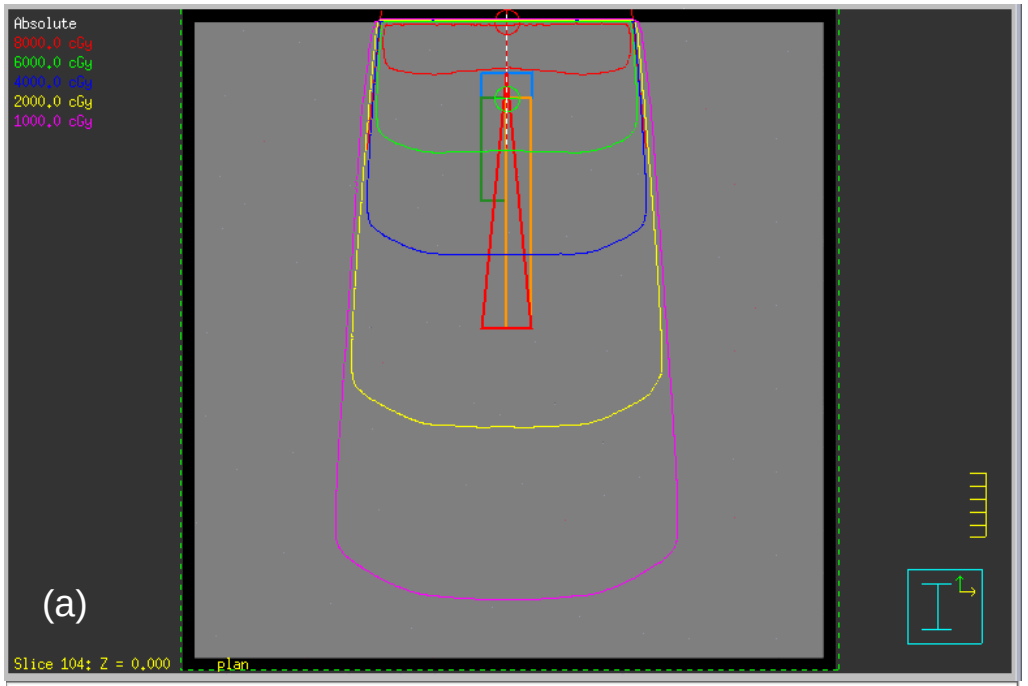
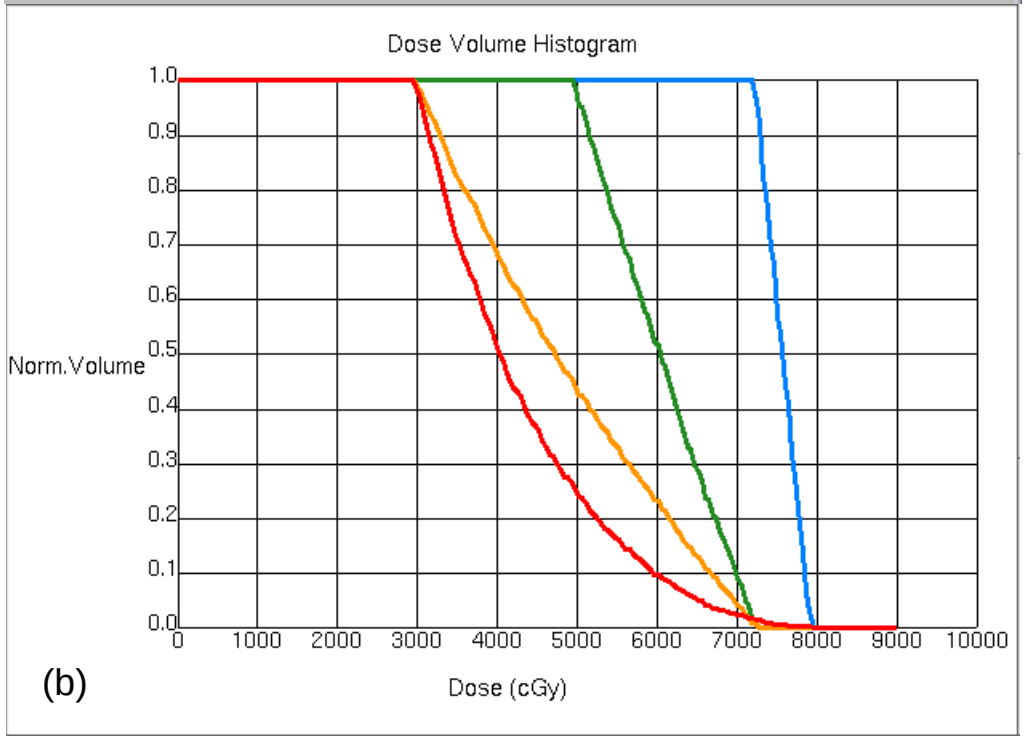
Benchmark Phantom for verification of EUD, TCP and NTCP calculation





TCP/NTCP calculated for benchmark phantom

Structure	PTV Rectangle	Rectangle 1	PTV Rectangle	Rectangle 1	Rectangle 2	Triangle 1
D50 (Gy)	63.3	44.2	80	75.1	55.3	46
γ	5	1.6	3	2.8	3.1	1.8
α/β (Gy)	10	10	3	3	3	3
Seriality	N/A	N/A	0.18	8.4	0.69	1
Function	TCP	TCP	NTCP	NTCP	NTCP	NTCP
Value (%)	94.1	80.3	26.6	18.1	23.5	29.5

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- **Double planning for first several cases from each representative tumor site using the outcome-model based TPS and the standard dose-based TPS**

Routine QA for outcome-model based TPS

- **Establish a sample plan with baseline data (e.g., DVH, EUD, TCP, NTCP) at commissioning**

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- **Establish a sample plan with baseline data (e.g., DVH, EUD, TCP, NTCP) at commissioning**

- **Replan the sample case annually or after a major upgrade and compare to the baseline data, to ensure that models, parameters, and algorithms implemented in the TPS remain the same**

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- needs to be implemented with cautions.
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- is coming into clinic and is here to stay !

Acknowledgement

Members of TG-166

(Vladimir Semenenko, Chuck Mayo….)

- An Tai, Ph.D
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