



NCCAAPM 2006 Fall Meeting

# Ranking Complex IMRT Plans Using an EUD-Based Figure-of-Merit Index

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<sup>2</sup>Tomotherapy Inc., Madison, WI

No Photo  
 Patient: [Redacted]  
 DOB: **Sep 29, 1911** Sex: **F**  
 ID: **TklsBE00059514**  
 Plan date: **Jan 13, 2005 12:34:30 PM**  
 Oncologist:  
 Disease: **963**

Plan: **Plan\_01**  
 Plan status: **Approved**  
 DQA plan:  
 Patient position: **HFS**

What's Next

Define Rx Constraints

- Define constraints for tumors.
  - Define constraints for sensitive structures.
  - Set isodose display options.
- ⌚ When you are satisfied, click **Start** to begin optimization.

User: System User



ROIs Optimization Fractionation Delivery QA Setup Delivery QA Analysis Biological Estimator

Prescription

% Vol For PTV55.8+0.5 95.0 % will receive ..... **55.8 Gy**

Stats

Field Width: Not Set Pitch: 0.287 Dose Calc Grid: Normal Batch beamlets

Dose Display

- Isodose
- 59.706
  - 55.8
  - 53.01
  - 50
  - 44.64
  - 36
  - 27.9
  - 16.74

Tumor Constraints

Name	Display	Color	Blocked	Use?	Importance	Max Dose [Gy]	Max Dose Pen.	DVH Vol [%]	DVH Dose [Gy]	Min Dose [Gy]	Min Dose Pen.
L-IntRectal	<input checked="" type="checkbox"/>	None	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	100	55.0	100	95.0	50.0	50.0	100
PTV55.8+0.5	<input checked="" type="checkbox"/>	None	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	100	60.0	100	95.0	55.8	55.8	100
PTV45+0.5	<input checked="" type="checkbox"/>	None	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	100	53.0	100	95.0	45.0	45.0	100
RECTUM+0.5	<input checked="" type="checkbox"/>	None	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	100	55.0	100	95.0	50.0	50.0	100

Sensitive Structure Constraints

Name	Display	Color	Blocked	Use?	Importance	Max Dose [Gy]	Max Dose Pen.	DVH Vol [%]	DVH Dose [Gy]	DVH Pt. Pen.
Rectum	<input checked="" type="checkbox"/>	None	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	1	1.0	1	1.0	1.0	1
Bladder	<input checked="" type="checkbox"/>	None	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	1	1.0	1	1.0	1.0	1
VaginalCuff	<input checked="" type="checkbox"/>	None	<input checked="" type="checkbox"/>	<input type="checkbox"/>						
R-IntRectal	<input checked="" type="checkbox"/>	None	<input checked="" type="checkbox"/>	<input type="checkbox"/>						

Density Image Viewer

Density Image

Optimize

Mode: **Beamlet**

Modulation Factor: 2.500

Initiate Full Dose after 20 iterations.

**Start**

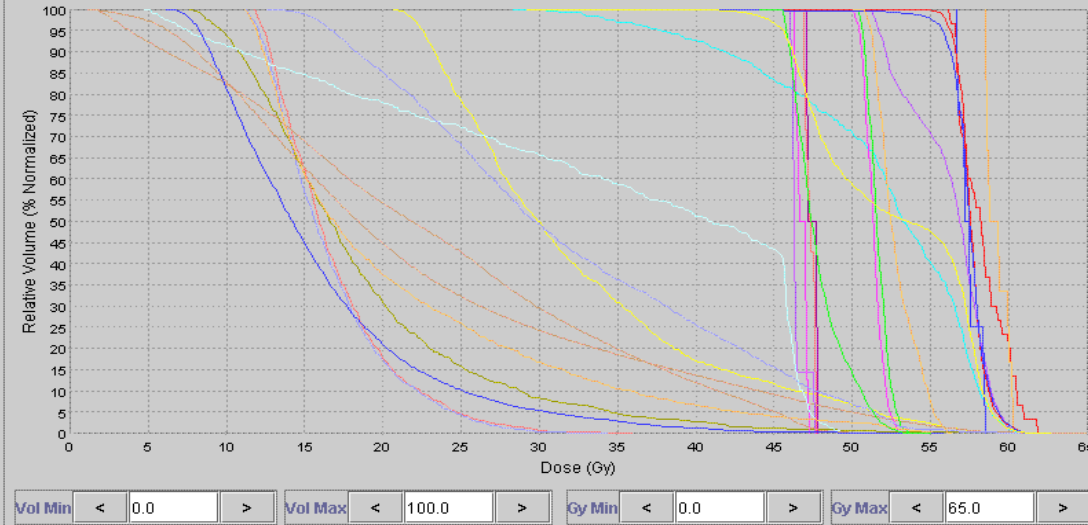
Pause

Resume

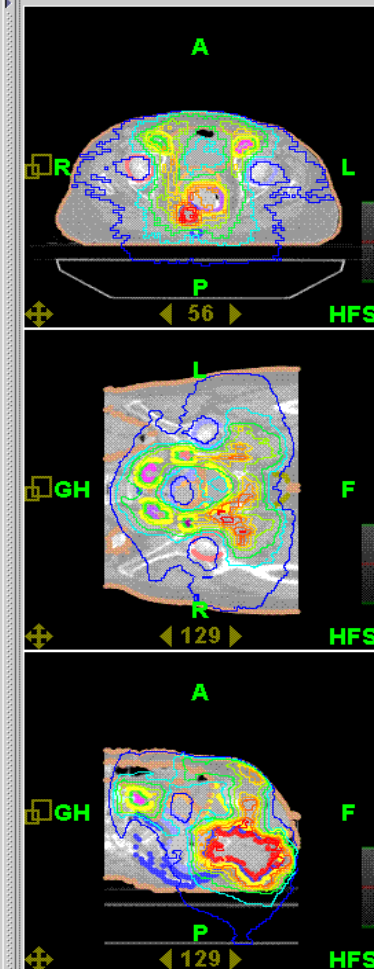
Get Full Dose

Cancel

Dose-Volume Histogram - Cumulative Mode Relative



Patient Images



# Problems to evaluate complex plans

- **Complicated anatomy, multiple OARs**
- **Complex/crossing DVHs**
- **Difficult for visual inspection of dose distributions/DVHs**
- **Plan merit not quantified**
- **DVH failure for spatial tumor heterogeneity**

**Quantitative evaluation and comparison of complicated plans based on biological effectiveness are desirable.**

# Solution: biologically based evaluation

- Tumor Control Probability (TCP)
- Normal Tissue Complication Probability (NTCP)
- Uncomplicated Tumor Control (P+)

$$S = T \cdot \prod_{i=1}^N (1 - p_i)$$

S: the figure-of-merit score

T: TCP

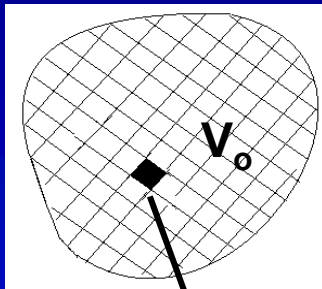
$P_i$ : NTCP for OAR<sub>*i*</sub>, where  $i=1,2,\dots,N$

*(IJROBP 41:451-7, 1998)*

- Equivalent Uniform Dose (EUD)

# Equivalent Uniform Dose

- DVHs account for dose heterogeneity



$V_i$ : a volume element

$$S = e^{-E}$$

$$E = \alpha D + \beta G D^2 - \gamma (T - T_k)$$

$$S = \sum_i \frac{V_i}{V_0} S(D_i)$$

S: Surviving fraction

- EUD for tumor :

$$EUD = \frac{-\ln(S)}{\alpha + \beta d - 1.4 \gamma / d}$$

- EUD for OAR:

$$EUD = \left( \sum_i v_i D_i^{1/n} \right)^n$$

n: adjustable parameter

# EUD-based Figure-of-merit index (fEUD)

$$fEUD = \frac{1.0}{1.0 + k \cdot \frac{\sum_{i=1}^n \omega_i \cdot EUD_{OAR}^i}{\sum_{j=1}^m \omega_j \cdot EUD_{Tumor}^j}}$$

**n, m** : number of OARs and targets;

**$\omega_i, \omega_j$**  : weighting factors for each OAR and target;

**k** : the relative importance factor between tumor and OAR.

Patient: [Redacted]  
 No Photo  
 DOB: Sep 29, 1911 Sex: F  
 ID: Tkl5BE00059514  
 Plan: Plan\_01  
 Plan status: Approved  
 Plan date: Jan 13, 2005 12:34:30 PM  
 DQA plan:  
 Oncologist:  
 Patient position: HFS  
 Disease: 963

User: System User

**What's Next**

**Define Rx Constraints**

- Define constraints for tumors.
- Define constraints for sensitive structures.
- Set isodose display options.

When you are satisfied, click **Start** to begin optimization.

ROIs Optimization Fractionation Delivery QA Setup Delivery QA Analysis Biological Estimator

**Prescription**

% Vol For PTV55.8+0.5  % will receive ..... **55.8 Gy**

Stats

Field Width: Not Set Pitch: 0.287 Dose Calc Grid: Normal Batch beamlets

**Tumor Constraints**

Name	Display	Color	Blocked	Use?	Importance	Max Dose [G]	Max Dose P	DVH Vol [%]	DVH Dose [G]	Min Dose [G]	Min Dose P
R Inguinal	<input checked="" type="checkbox"/>	None	<input type="checkbox"/>	<input checked="" type="checkbox"/>	100	55.0	100	95.0	50.0	50.0	100
L Inguinal	<input checked="" type="checkbox"/>	None	<input type="checkbox"/>	<input checked="" type="checkbox"/>	100	55.0	100	95.0	50.0	50.0	100
PTV55.8+0	<input checked="" type="checkbox"/>	None	<input type="checkbox"/>	<input checked="" type="checkbox"/>	100	60.0	100	95.0	55.8	55.8	100
PTV45.0+0.5	<input checked="" type="checkbox"/>	None	<input type="checkbox"/>	<input checked="" type="checkbox"/>	100	45.0	100	65.0	45.0	45.0	100

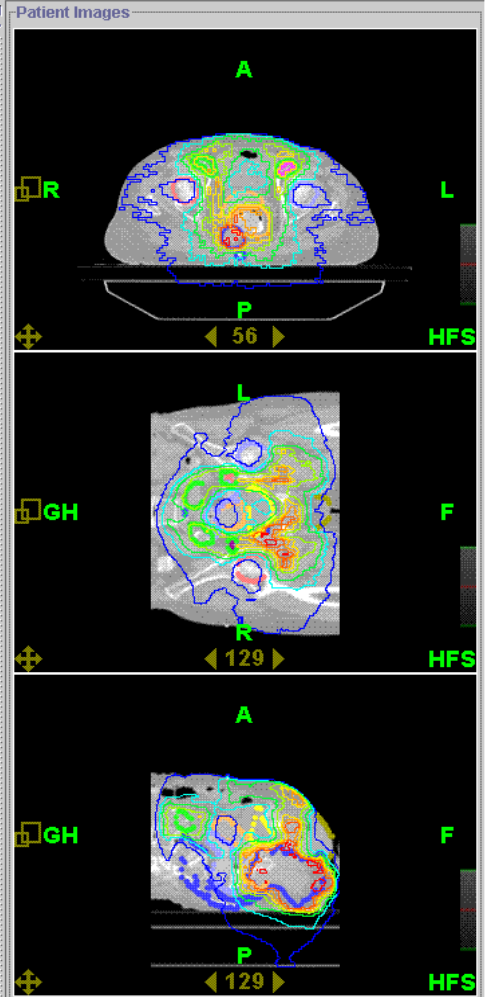
**Sensitive Structure Constraints**

Name	Display	Color	Blocked	Use?	Importance	Max Dose [Gy]	Max Dose Per	DVH Vol [%]	DVH Dose [Gy]	DVH Pt. Pen.
Rectum	<input type="checkbox"/>	None	<input type="checkbox"/>	<input checked="" type="checkbox"/>	1	1.0	1	1.0	1.0	1
Bladder	<input checked="" type="checkbox"/>	None	<input type="checkbox"/>	<input checked="" type="checkbox"/>	1	1.0	1	1.0	1.0	1
VaginalCuff	<input type="checkbox"/>	None	<input type="checkbox"/>	<input type="checkbox"/>						
R IntiliacN	<input checked="" type="checkbox"/>	None	<input type="checkbox"/>	<input type="checkbox"/>						

**Dose Display**

Isodose

- 59.706
- 55.8
- 53.01
- 50
- 44.64
- 36
- 27.9
- 16.74



**Density Image Viewer**

Density Image

**Optimize**

Mode: Beamlet

Modulation Factor: 2.500

Initiate Full Dose after 20 iterations.

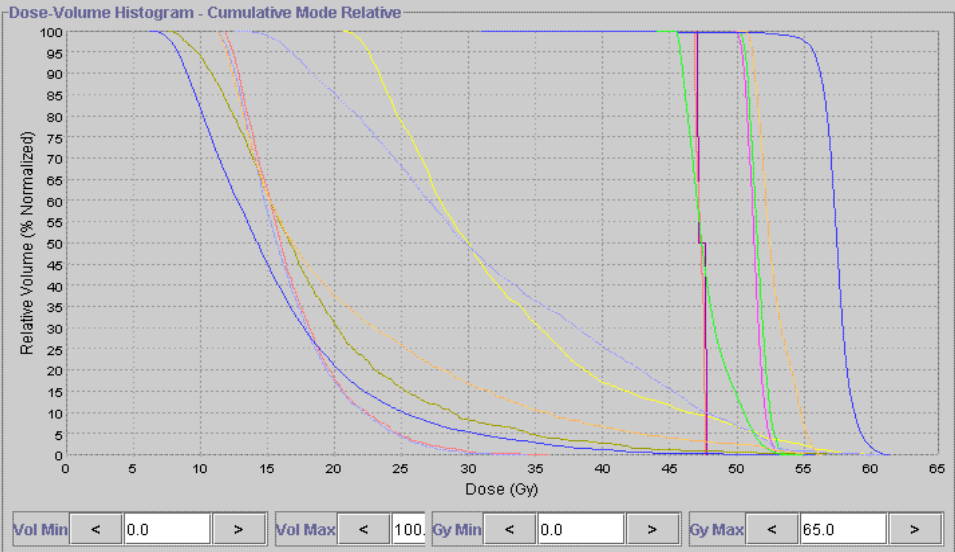
Start

Pause

Resume

Get Full Dose

Cancel



# Figure-of-merit index (fEUD)

- **Simple variable (fEUD) condenses all complex DVHs information;**
- **fEUD is in the range of (0-1);**
- **The larger fEUD is, the superior the plan is;**
- **fEUD enables quantitative evaluation and comparison of competing plans.**

**Building “Biological Estimator”  
on Hi-Art TomoTherapy planning  
system, work is in progress ...**

# **“Biological Estimator” on TomoTherapy**

- **Real time plan evaluation;**
- **Figure-of-merit score during optimization iteration;**
- **A database of updated tumor/organ-specific biological parameters;**
- **Digital format DVHs;**
- **User defined interface;**
- **.....**

**TomoTherapy Planning Station - Expedite**

Patient: [Redacted]    User: System User

DOB: Sep 29, 1911    Sex: F    Plan: Plan\_01

ID: TklsBE00059514    Plan status: Approved

Plan date: Jan 13, 2005 12:34:30 PM    DQA plan:

Oncologist:    Patient position: HFS

Disease: 963

**What's Next**

**Define Rx Constraints**

- Define constraints for tumors.
- Define constraints for sensitive structures.
- Set isodose display options.

When you are satisfied, click **Start** to begin optimization.

**Biological Estimator**

Prescription:  % Vol For PTV55.8+0.5    95.0 % will receive ..... **55.8 Gy**

Field Width: Not Set    Pitch: 0.287    Dose Calc Grid: Normal    Batch beamlets

**Tumor Constraints**

Name	Display	Color	Blocked	Use?	Importance	Max Dose [G]	Max Dose P	DVH Vol [%]	DVH Dose [G]	Min Dose [G]	Min Dose P
R Inguinal	<input checked="" type="checkbox"/>	[Green]	None	<input checked="" type="checkbox"/>	100	53.0	100	95.0	50.0	50.0	100
L Inguinal	<input checked="" type="checkbox"/>	[Magenta]	None	<input checked="" type="checkbox"/>	100	53.0	100	95.0	50.0	50.0	100
PTV55.8+0	<input checked="" type="checkbox"/>	[Blue]	None	<input checked="" type="checkbox"/>	100	60.0	100	95.0	55.8	55.8	100
PTV55.8-0	<input checked="" type="checkbox"/>	[Red]	None	<input checked="" type="checkbox"/>	100	53.0	100	95.0	45.0	45.0	100

**Sensitive Structure Constraints**

Name	Display	Color	Blocked	Use?	Importance	Max Dose [Gy]	Max Dose Per	DVH Vol [%]	DVH Dose [G]	DVH Pt. Pen.
Rectum	<input type="checkbox"/>	[Purple]	None	<input checked="" type="checkbox"/>	1	1.0	1	1.0	1.0	1
Bladder	<input checked="" type="checkbox"/>	[Yellow]	None	<input checked="" type="checkbox"/>	1	1.0	1	1.0	1.0	1
VaginalCuff	<input type="checkbox"/>	[Cyan]	None	<input type="checkbox"/>						
R IntIliacN	<input checked="" type="checkbox"/>	[Red]	None	<input type="checkbox"/>						

**Dose Display**

Isodose

- 59.706
- 55.8
- 53.01
- 50
- 44.64
- 36
- 27.9
- 16.74

**Density Image Viewer**

Density Image

Optimize

Mode: Beamlet

Modulation Factor: 2.500

Initiate Full Dose after 20 iterations.

Start

Pause

Resume

Get Full Dose

Cancel

**Dose-Volume Histogram - Cumulative Mode Relative**

Vol Min < 0.0 >    Vol Max < 100 >    Gy Min < 0.0 >    Gy Max < 65.0 >

**Patient Images**

Three axial CT slices showing the target and sensitive structures. The top slice is labeled 'A', the middle 'GH', and the bottom 'GH'. The patient position is 'HFS'. The dose distribution is overlaid on the images, with isodose lines corresponding to the values in the 'Dose Display' section.

Tuesday, February 7, 2006    18:26:56

Windows taskbar: Start, C:\tomo\psMCW, C:\tomo\psMCW\co..., C:\tomo\exports\pa..., Command Prompt, TomoTherapy Pla..., MCW\_autoEUD.jav..., Calculator, 6:26 PM



Patient: [Redacted]  
 No Photo  
 DOB: Sep 29, 1911 Sex: F  
 ID: TklsBE00059514  
 Plan date: Jan 13, 2005 12:34:30 PM  
 Oncologist:  
 Disease: 963

Plan: Plan\_01  
 Plan status: Approved  
 DQA plan:  
 Patient position: HFS



What's Next

Adjust Fractionization Schedule

- Modify the fraction count or adjust details for each fraction as necessary.
- Run Final Dose.
- When you are satisfied with the plan, click Final Accept.

User: System User



ROIs Optimization Fractionation Delivery QA Setup Delivery QA Analysis Biological Estimator

Biological Estimator

Summary

Alpha (Gy): 0.15  
 Alpha/Beta (Gy): 3.1  
 Repair Time (hours): 1  
 Double Time (days): 1,008  
 EUD (Gy): 47.9978  
 TCP (%): 0  
 LKB UCP (%): 0  
 RS UCP (%): 0  
 rEUD: 0.62  
 (User Defined): 0

Tumor Parameters

Tumor: PTV55.8+0.5  
 Dose Frac. of EUD: R inguinal, L inguinal  
 alpha/beta ratio: PTV55.8+0.5, PTV45+0.5, RECTUM+0.5  
 Mean Alpha: PTV45+0.5, RECTUM+0.5  
 Repair Time: 1  
 Doubling Time: 1,008  
 Treatment Duration: 1200  
 Number of Dose Fractions: 30

Sensitive Structure Parameters

OAR: Rectum  
 alpha/beta ratio: 3.0  
 LKB NTCP: 80.0  
 LKB NTCP (std. deviation): 0.0  
 LKB NTCP Model m: 0.15  
 LKB NTCP Model n: 0.12  
 RS NTCP: 80.0  
 RS NTCP Gamma: 2.56  
 RS NTCP Model s: 0.75

Structure name	Eud(Gy)	LKB NTCP	RS NTCP
Rectum	52.314763	0.22109	0.002446
Bladder	38.558712	0.846886	0.000027
VaginalCuff	46.057913	0.495517	0.000469
R-IntIliacN	2.1254578	0.02	0
L-IntIliacN	3.6745906	0.04	0
R-ExtIliacN	15.557141	1	0
L-ExtIliacN	18.889156	0.999596	0
R-FemoralHead	18.750014	0.154309	0
L-FemoralHead	18.238488	0.031769	0
Vulva	27.818693	0.991309	0
patient	72.400458	0.088149	0.03692
tumor	52.314763	0.00009	0.000004

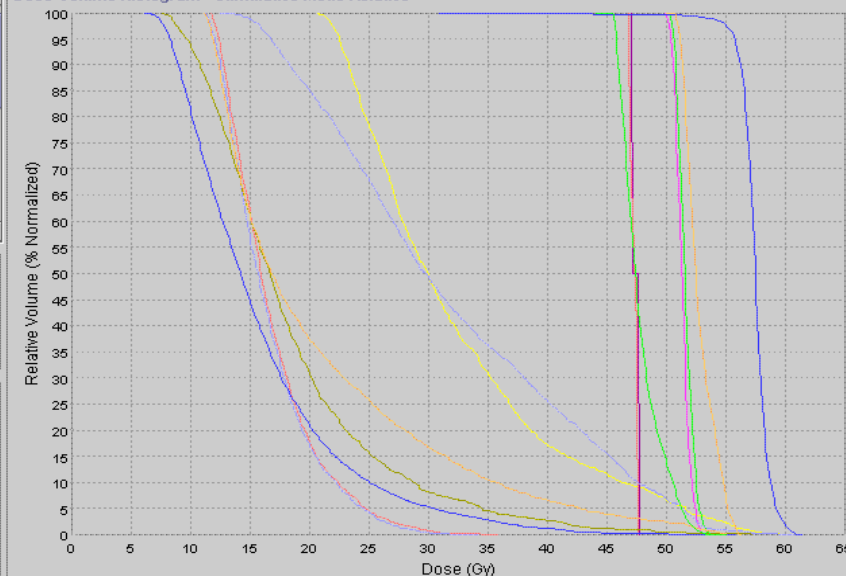
Tumor Constraints

Name	Color	Importance
PTV55.8+0.5	[Blue]	100
PTV45+0.5	[Green]	100
RECTUM+0.5	[Orange]	100

Sensitive Structure Constraints (OARs)

Name	Color	Importance	DVH Pt. Pen.
Rectum	[Purple]	1	1
Bladder	[Yellow]	1	1
VaginalCuff	[Cyan]		
R-IntIliacN	[Red]		
L-IntIliacN	[Dark Blue]		
R-ExtIliacN	[Magenta]		
L-ExtIliacN	[Red]		
R-FemoralHead	[Light Blue]	1	1
L-FemoralHead	[Light Blue]	1	1
Vulva	[Olive]	20	100

Dose-Volume Histogram - Cumulative Mode Relative



Vol Min < 0.0 > Vol M Gy Min < 0.0 > Gy Max < 65.0 >

Thursday, April 20, 2006

10:34:53

Patient:   
 No Photo   
 DOB: Sep 29, 1911 Sex: F   
 ID: TklsBE00059514   
 Plan date: Jan 13, 2005 12:34:30 PM   
 Oncologist:   
 Disease: 963   
 Plan: Plan\_01   
 Plan status: Approved   
 DQA plan:   
 Patient position: HFS

**What's Next**

**Adjust Fractionization Schedule**

- Modify the fraction count or adjust details for each fraction as necessary.
- Run **Final Dose**.

When you are satisfied with the plan, click Final Accept.



ROIs Optimization Fractionation Delivery QA Setup Delivery QA Analysis Biological Estimator

**Biological Estimator**

**Summary**

Alpha (Gy):	0.15
Alpha/Beta (Gy):	3.1
Repair Time (hours):	1
Double Time (days):	1,008
EUD (Gy):	47.9978
TCP (%):	0
LKB UCP (%):	0
RS UCP (%):	0
<b>EUD:</b>	<b>0.62</b>
(User Defined):	0

**Tumor Parameters**

Tumor: PTV55.8+0.5

Dose Frac. of EUD: R inguinal, L inguinal

alpha/beta ratio: PTV55.8+0.5, PTV45+0.5, RECTUM+0.5

Repair Time: 1

Doubling Time: 1,008

Treatment Duration: 1200

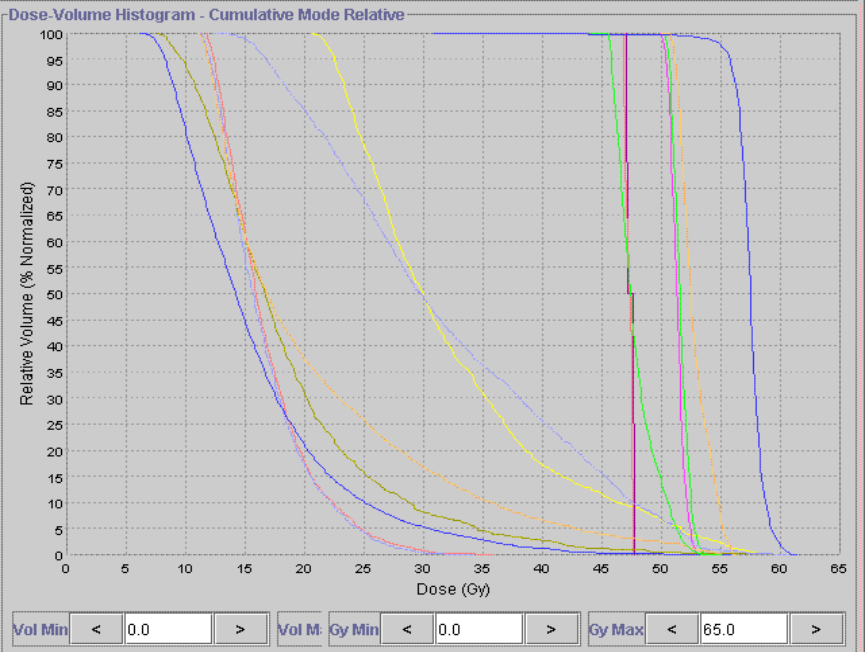
Number of Dose Fractions: 30

**Sensitive Structure Parameters**

OAR: Rectum

alpha/beta ratio	3.0
LKB NTCP	80.0
LKB NTCP (std. deviation)	0.0
LKB NTCP Model m	0.15
LKB NTCP Model n	0.12
RS NTCP	80.0
RS NTCP Gamma	2.56
RS NTCP Model s	0.75

Structure name	Eud(Gy)	LKB NTCP	RS NTCP
Rectum	52.314763	0.22109	0.002446
Bladder	38.558712	0.846886	0.000027
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L-IntIliacN	3.6745906	0.04	0
R-ExtIliacN	15.557141	1	0
L-ExtIliacN	18.889156	0.999596	0
R-FemoralHead	18.750014	0.154309	0
L-FemoralHead	18.238488	0.031769	0
Vulva	27.818693	0.991309	0
patient	72.400458	0.088149	0.03692
tumor	28.926244	0.00000	0.000004



**Tumor Constraints**

Name	Color	Importance
PTV55.8+0.5	Blue	100
PTV45+0.5	Green	100
RECTUM+0.5	Orange	100

**Sensitive Structure Constraints (OARs)**

Name	Color	Importance	DVH Pt. Pen.
Rectum	Purple	1	1
Bladder	Yellow	1	1
VaginalCuff	Cyan	1	
R-IntIliacN	Red		
L-IntIliacN	Dark Blue		
R-ExtIliacN	Pink		
L-ExtIliacN	Orange		
R-FemoralHead	Red	1	1
L-FemoralHead	Purple	1	1
Vulva	Green	20	100

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 Patient position: HFS

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When you are satisfied with the plan, click Final Accept.



ROIs Optimization Fractionation Delivery QA Setup Delivery QA Analysis Biological Estimator

**Biological Estimator**

**Summary**

Alpha (Gy):	0.15
Alpha/Beta (Gy):	3.1
Repair Time (hours):	1
Double Time (days):	1,008
EUD (Gy):	47.9978
TCP (%):	0
LKB UCP (%):	0
RS UCP (%):	0
EUD:	0.62
(User Defined):	0

**Tumor Parameters**

Tumor: PTV55.8+0.5

Dose Frac. of EUD: R inguinal, L inguinal

alpha/beta ratio: PTV55.8+0.5, PTV45+0.5, RECTUM+0.5

Mean Alpha: PTV45+0.5, RECTUM+0.5

Repair Time: 1

Doubling Time: 1,008

Treatment Duration: 1200

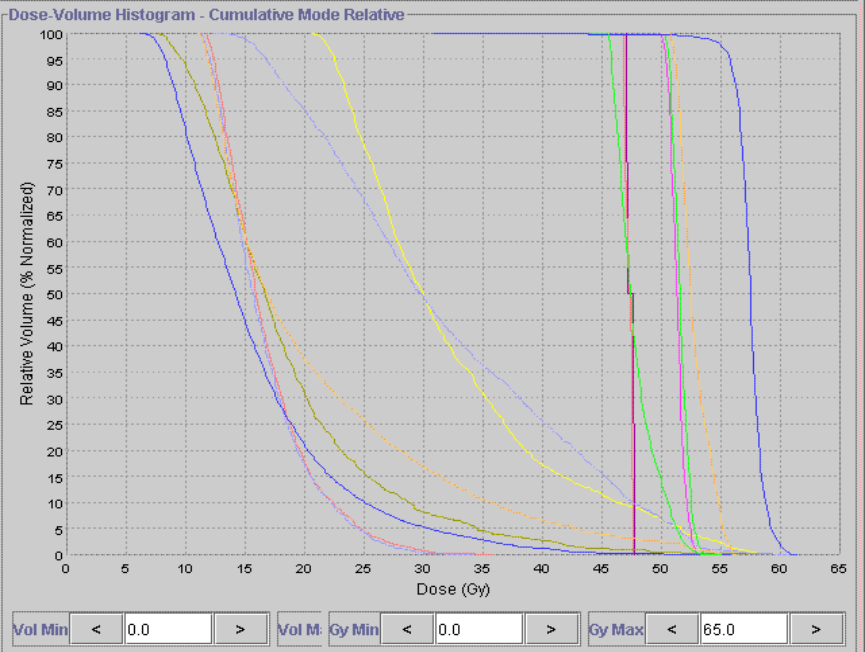
Number of Dose Fractions: 30

**Sensitive Structure Parameters**

OAR: Rectum

alpha/beta ratio	3.0
LKB NTCP	80.0
LKB NTCP (std. deviation)	0.0
LKB NTCP Model m	0.15
LKB NTCP Model n	0.12
RS NTCP	80.0
RS NTCP Gamma	2.56
RS NTCP Model s	0.75

Structure name	Eud(Gy)	LKB NTCP	RS NTCP
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R-FemoralHead	18.750014	0.154309	0
L-FemoralHead	18.238488	0.031769	0
Vulva	27.818693	0.991309	0
patient	72.400458	0.088149	0.03692
tumor	28.926244	0.00000	0.000004



**Tumor Constraints**

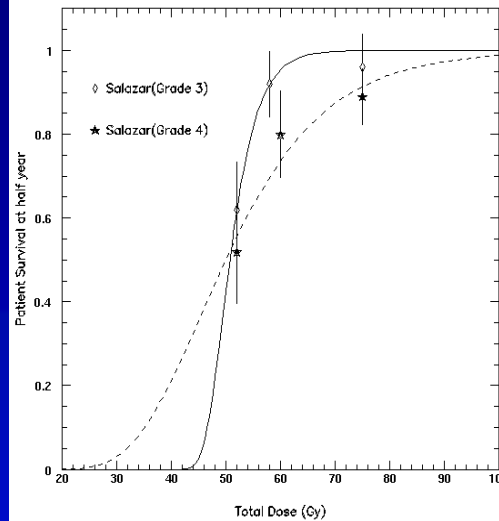
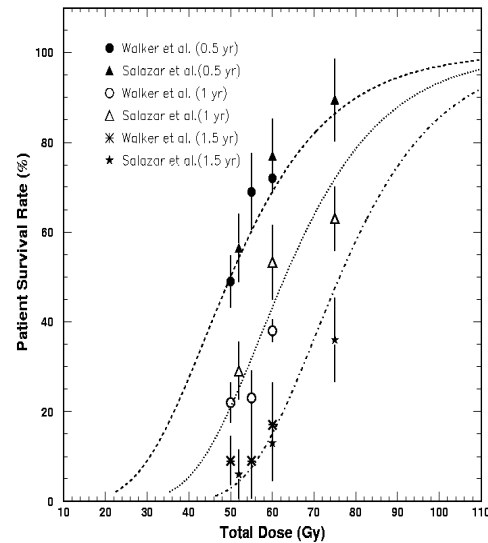
Name	Color	Importance
PTV55.8+0.5	[Blue]	100
PTV45+0.5	[Green]	100
RECTUM+0.5	[Orange]	100

**Sensitive Structure Constraints (OARs)**

Name	Color	Importance	DVH Pt. Pen.
Rectum	[Purple]	1	1
Bladder	[Yellow]	1	1
VaginalCuff	[Cyan]	1	
R-IntIliacN	[Red]		
L-IntIliacN	[Blue]		
R-ExtIliacN	[Purple]		
L-ExtIliacN	[Red]		
R-FemoralHead	[Red]	1	1
L-FemoralHead	[Blue]	1	1
Vulva	[Green]	20	100

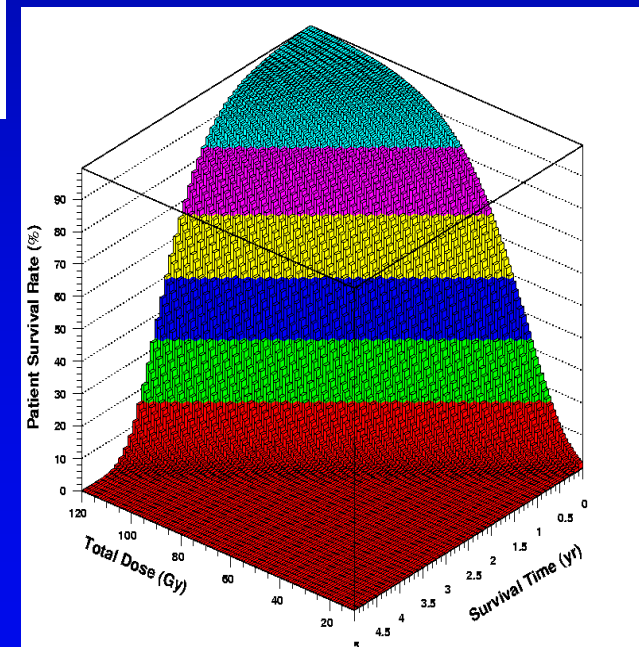
Reliable radiobiological parameters  
are crucial !

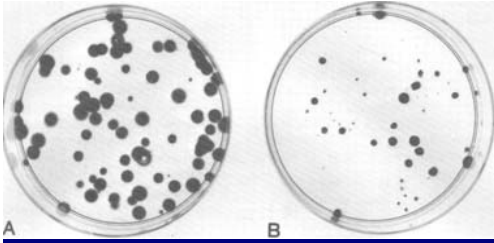
# Brain tumor



**Patient survival rate as a function of dose at survival time**

	<i>Clinical data</i> (95% CL)	<i>In vitro</i>
<b>MG</b>	$\alpha = 0.06 \pm 0.05 \text{ Gy}^{-1}$ $\alpha/\beta = 10.0 \pm 15.1 \text{ Gy}$	
<b>Grade 3</b>	$\alpha = 0.11 \pm 0.10 \text{ Gy}^{-1}$ $\alpha/\beta = 5.8 \pm 11.8 \text{ Gy}$	$\alpha = 0.20 \pm 0.02 \text{ Gy}^{-1}$ $\alpha/\beta = 5.6 \pm 0.7 \text{ Gy}$
<b>Grade 4</b>	$\alpha = 0.04 \pm 0.06 \text{ Gy}^{-1}$ $\alpha/\beta = 5.6 \pm 9.4 \text{ Gy}$	$\alpha = 0.30 \pm 0.07 \text{ Gy}^{-1}$ $\alpha/\beta = 6.7 \text{ Gy}$

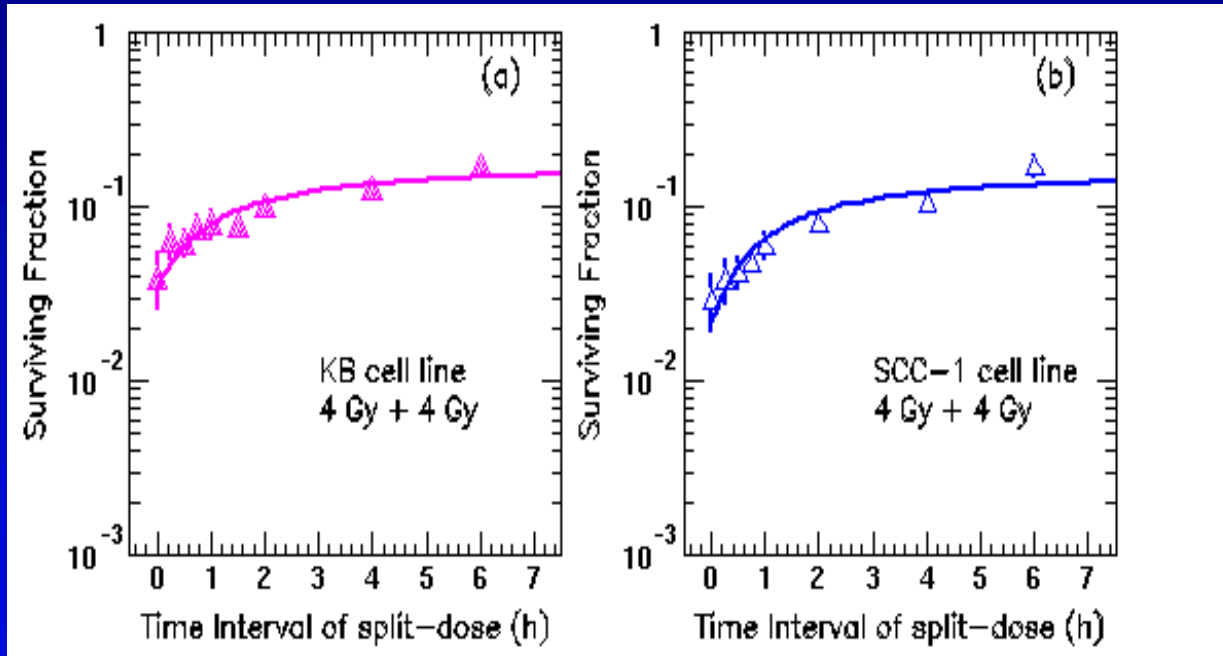




# H & N tumor



*In vitro* measurement



$$\alpha = 0.22 \pm 0.08 \text{ Gy}^{-1}$$

$$\alpha/\beta = 8.3 \pm 4.1 \text{ Gy}$$

$$T_{\text{rep}} = 17 \pm 21 \text{ min}$$

$$T_d = 2 \pm 1 \text{ days}$$



RTOG (9003) randomized clinical trial



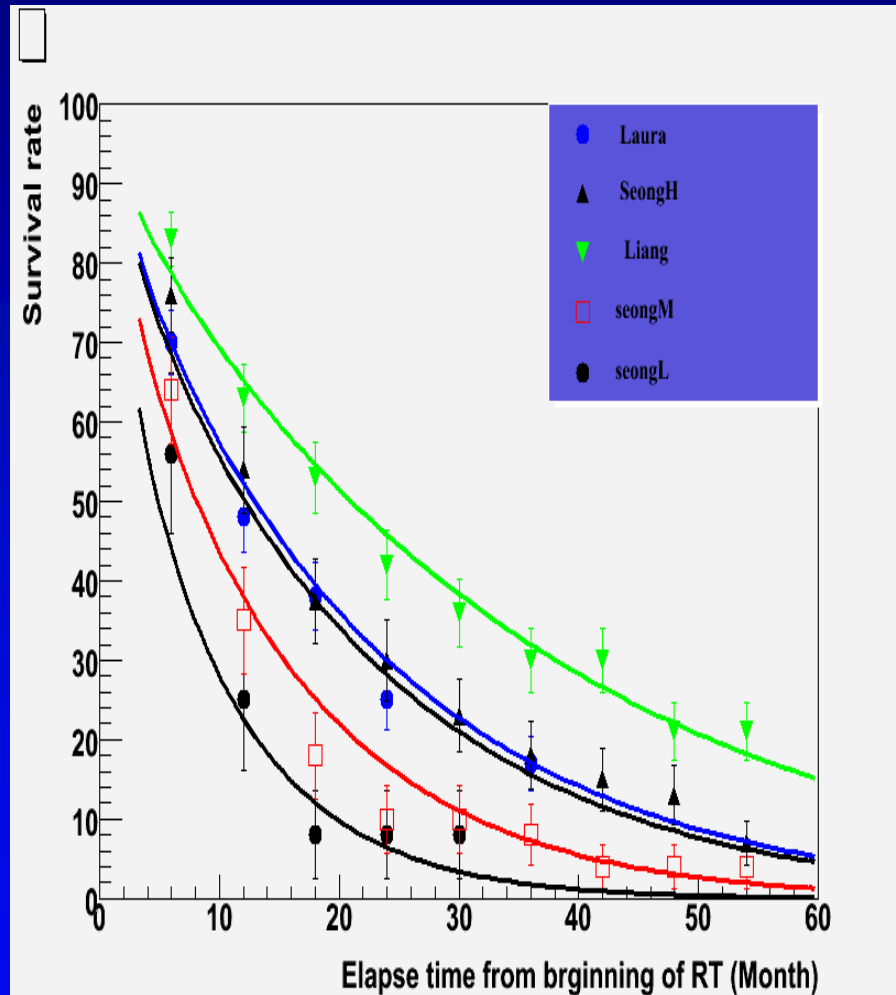
$$\alpha = 0.2 - 0.35 \text{ Gy}^{-1}$$

$$\alpha/\beta = 8.6 \pm ?? \text{ Gy}$$

$$T_d = 2 - 4 \text{ days}$$

Qi, Yang, Wang, Li, AAPM 06

# Liver Cancer



A plausible set of parameters for liver tumor:

$$\alpha = 0.029 \pm 0.004 \text{ Gy}^{-1}$$

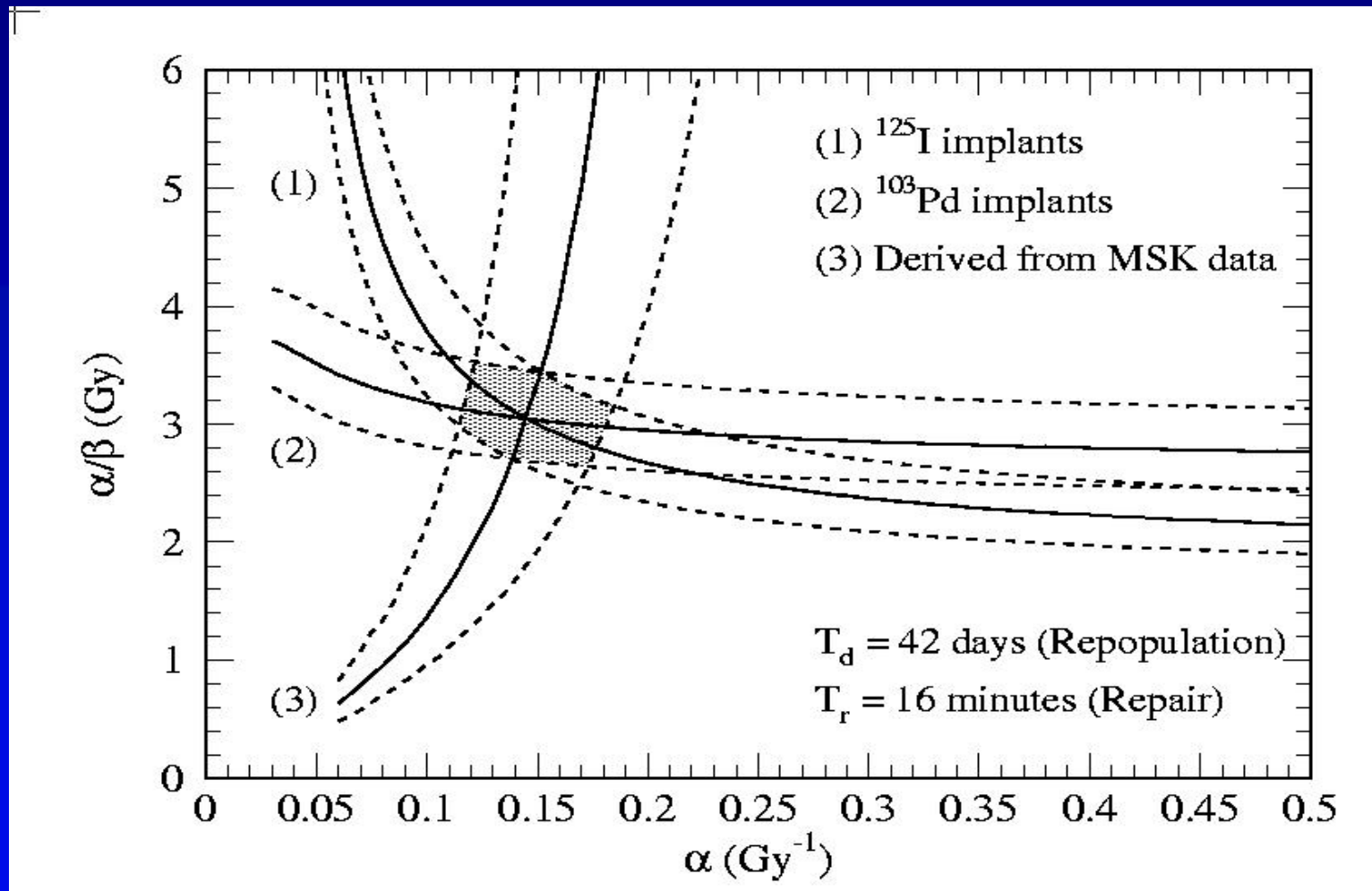
$$\alpha / \beta = 9.9 \pm 1.8 \text{ Gy}$$

$$T_d = 100 \pm 18 \text{ days}$$

	Num. of patient	Median Dose (Gy)	Fraction scheme (Gy/fx)	Reference
Liang	128	53.6	4.88	Cancer Vol103,218 (2005)
Dawson	128	61.5	1.5	J. Clin Onco Vol18, 2210 (2000)
Seong H	83	55	1.8	IJROBP Vol.55 329 (2003)
Seong M	51	45	1.8	
Seong L	24	32.5	1.8	

Tai, Khater, Erickson, Li AAPM 06 .

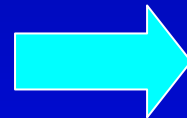
# Prostate cancer



# Breast cancer

## Three Clinical studies:

- Resch *et al* (2002): BCS then 48Gy + 20Gy LDR or 52 Gy + 9.7Gy HDR. Same TCP.
- Fourquet *et al* (1995): RT alone 58Gy + 20Gy boost using  $^{192}\text{Ir}$  LDR or  $^{60}\text{Co}$  EBRT  
TCP<sub>Ir</sub>=76% vs TCP<sub>Co</sub>=61%.
- Mazon *et al* (1991): RT alone 45Gy + 37Gy  $^{192}\text{Ir}$  LDR  
R=0.32- 0.49Gy/h TCP=60%  
R=0.5- 0.59Gy/h TCP=72%  
R=0.6- 0.9Gy/h TCP=84%



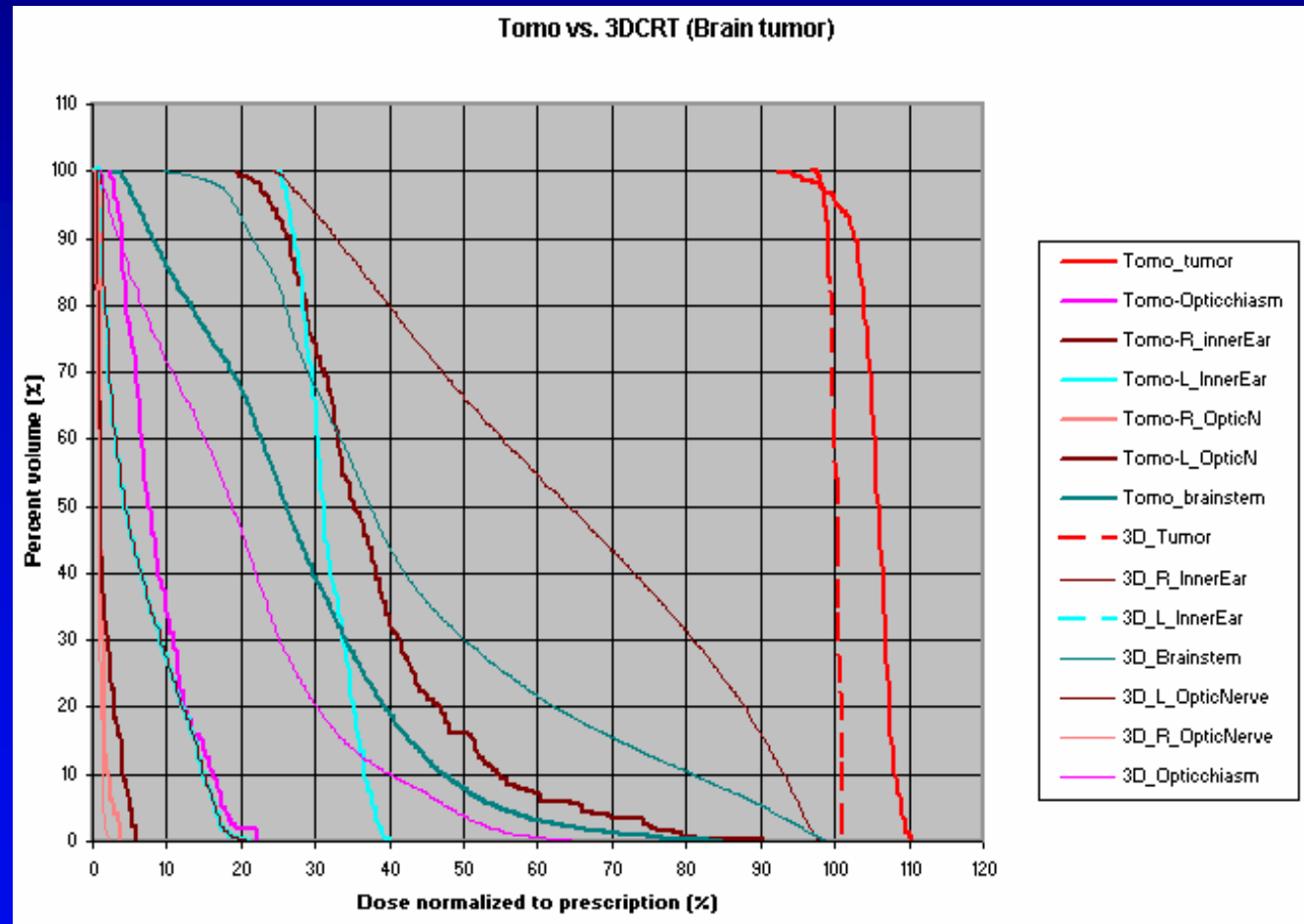
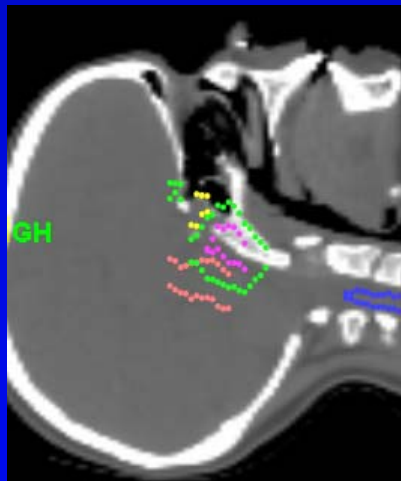
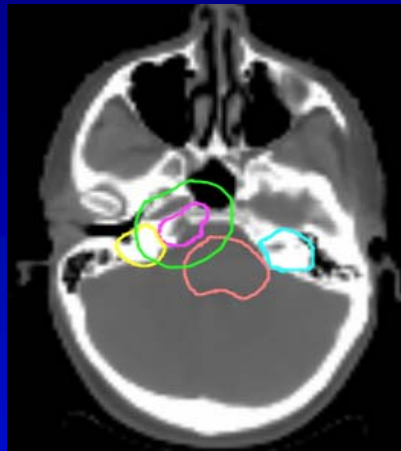
$$\alpha = 0.3 \text{ Gy}^{-1}$$
$$\alpha/\beta = 10 \text{ Gy}$$
$$T_{\text{rep}} = 1 \text{ hour}$$

# Updated biological parameters for tumor

Tumor	$\alpha / \beta$ ratio (Gy)	$\alpha$ (Gy <sup>-1</sup> )	Repair time $T_y$ (h)	Doubling Time $T_d$ (day)	Reference
Prostate	3.1	0.15	0.27	42	Wang et al. (2003)
Breast	10	0.3	1.0	15	Guerrero et al. (2003)
Glioma	6.0	0.06	0.5	50	Qi et al. (2005)
H&N	8.3	0.22	0.267	2	Qi et al. (2006)
Liver	9.9	0.03	1.0	100	Tai et al. (2006)
AVM	2.1	0.02	—	—	Qi et al. (2005)
...					

# Case 1: Brain

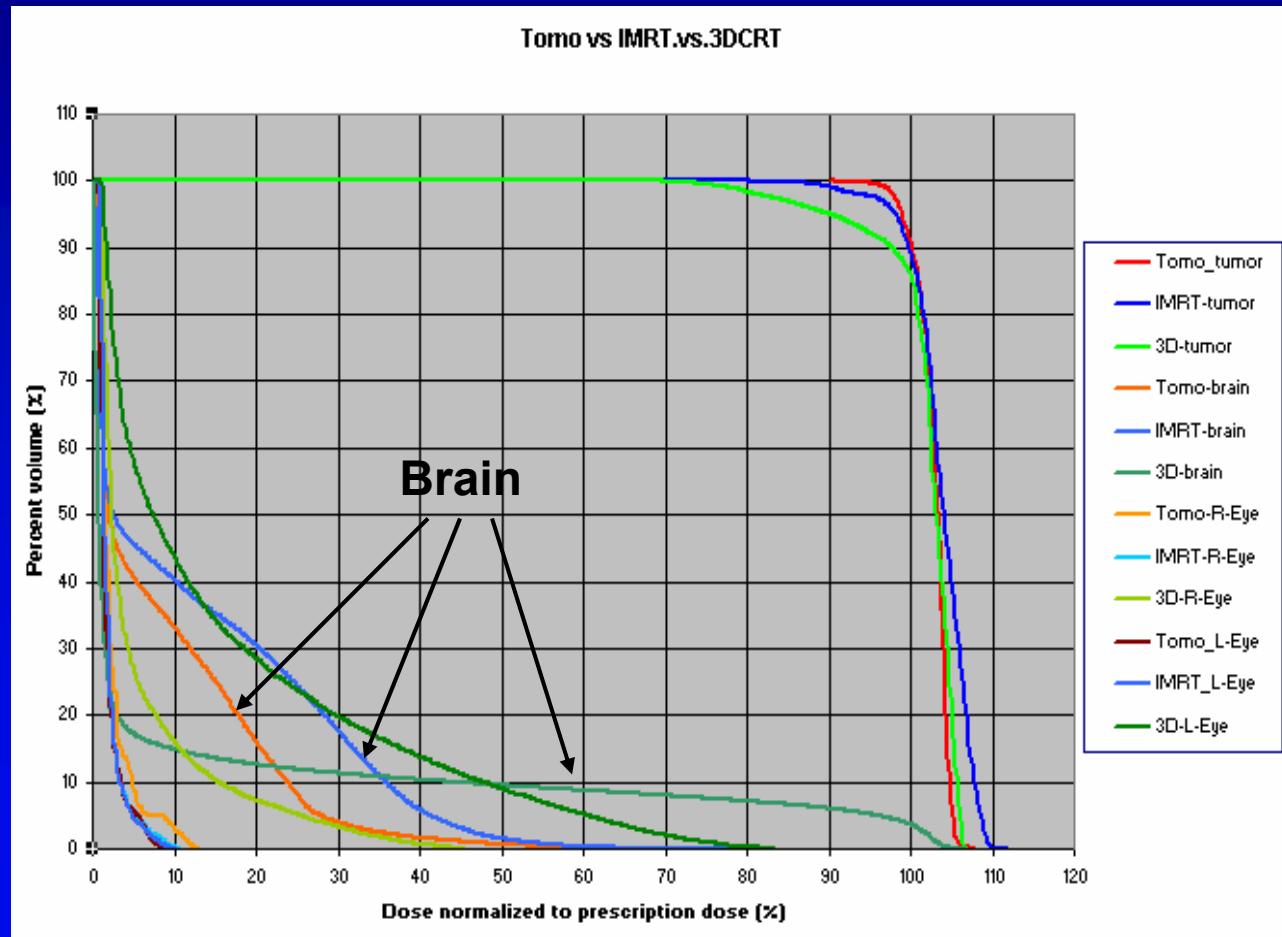
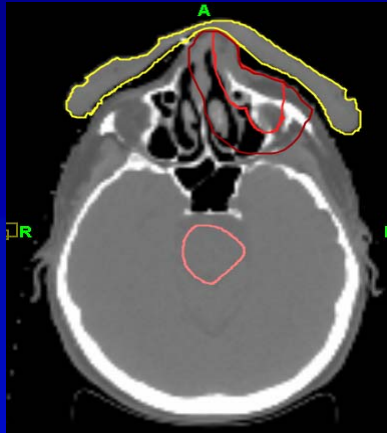
Figure-of-merit TOMO:  $fEUD = 0.780$  3DCRT:  $fEUD = 0.750$



# Case 2: H & N

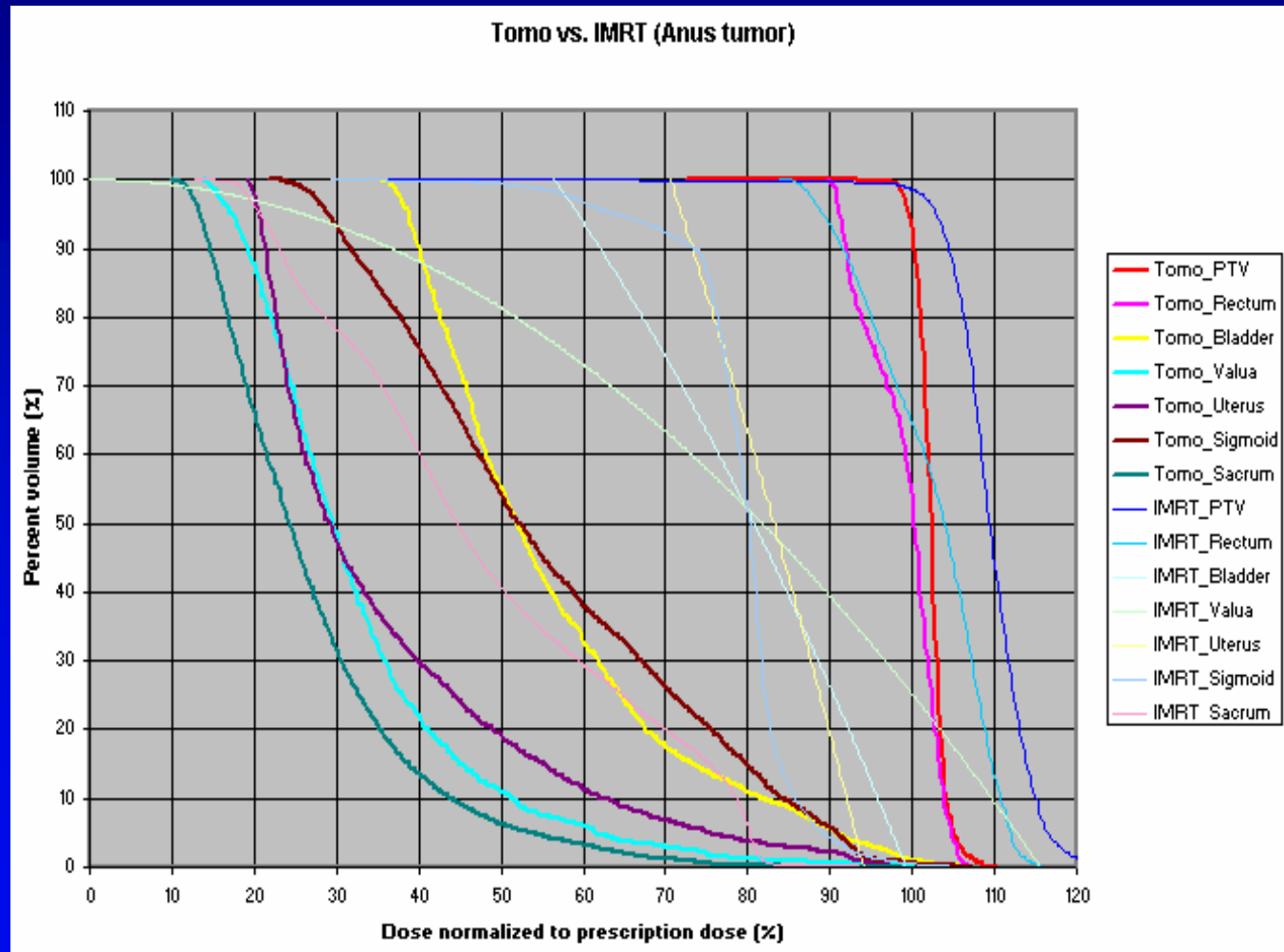
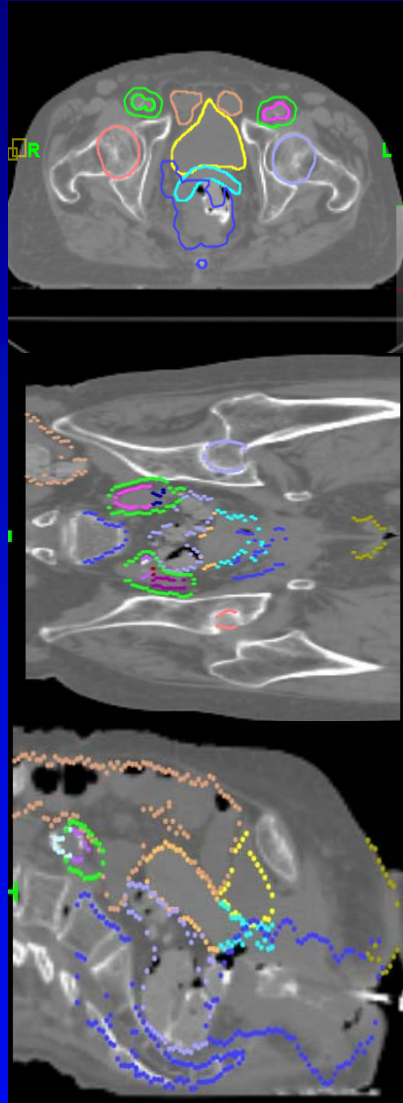
## Figure-of-merit

Tomo:  $FEUD = 0.816$  IMRT:  $FEUD = 0.787$  3DCRT:  $FEUD = 0.771$



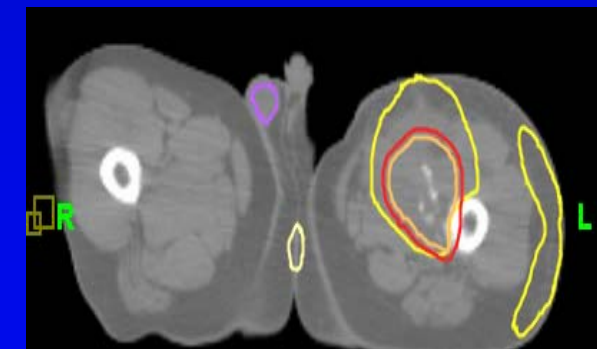
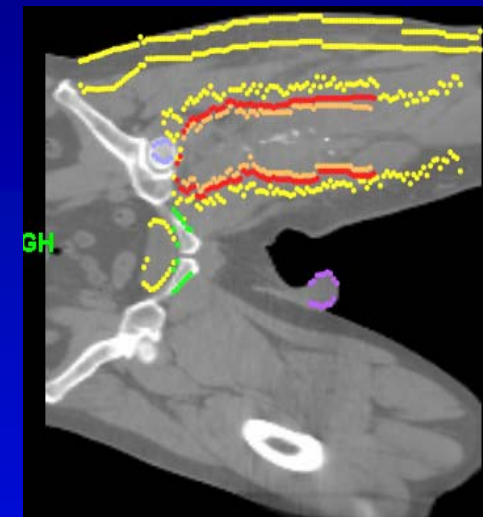
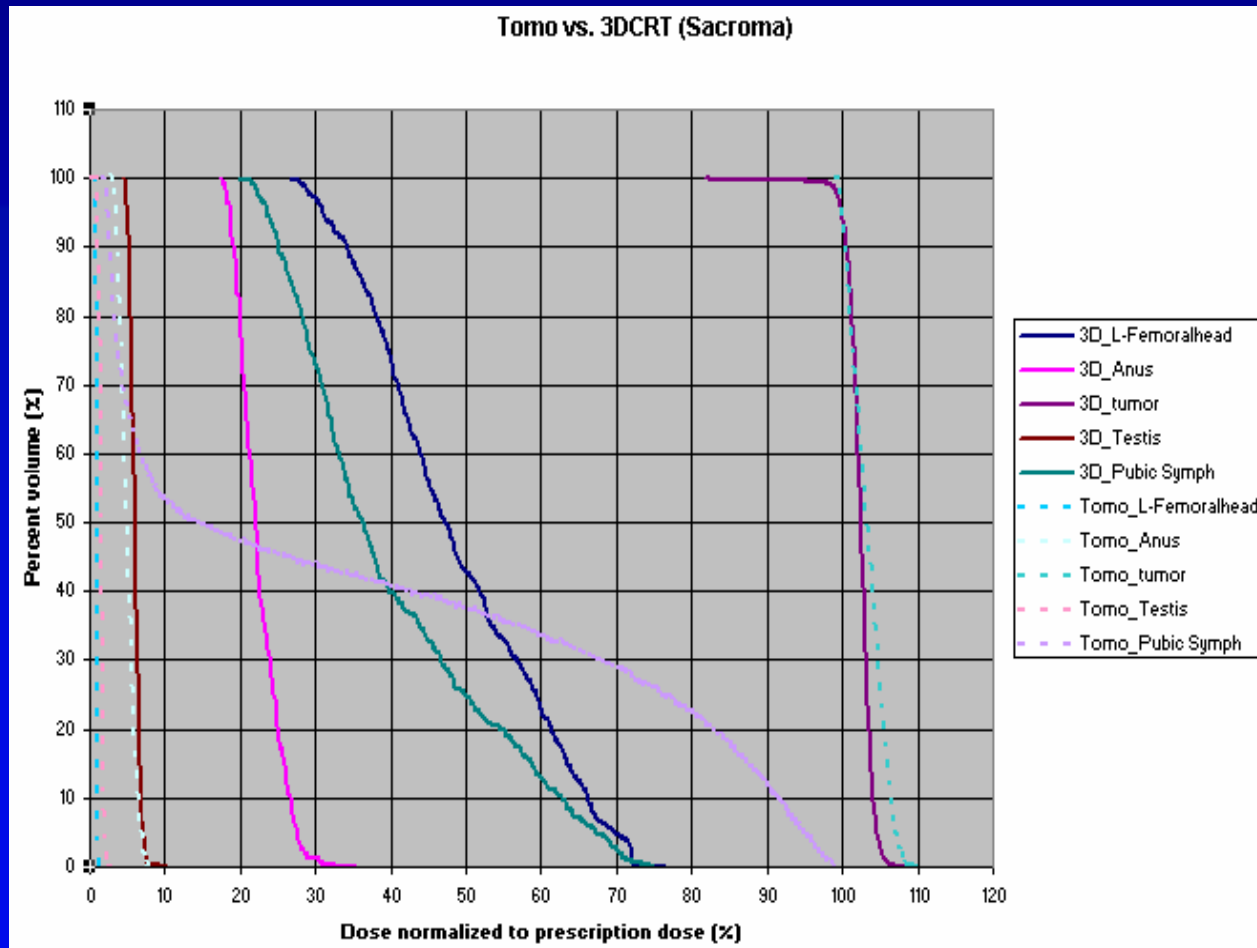
# Case 3: Female Anus

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



# Case 4: Sarcoma

Figure-of-merit TOMO:  $FEUD = 0.709$  3DCRT:  $FEUD = 0.512$



# Ranking a plan based on EUD

	TOMO		IMRT		3DCRT	
	EUD (Gy)	$f_{EUD}$	EUD (Gy)	$f_{EUD}$	EUD (Gy)	$f_{EUD}$
<b>Head &amp; Neck</b>	62	<b>0.816</b>	59	<b>0.787</b>		
Normal tissue	23		27			
<b>Anus</b>	56	<b>0.613</b>	58	<b>0.600</b>		
Bladder	26		33			
Rectum	52		53			
Normal tissue	28		30			
<b>Skull</b>	62	<b>0.873</b>	65	<b>0.864</b>		
Brain	7.4		9.8			
Normal tissue	17		18			
<b>Brain</b>	59	<b>0.780</b>			55	<b>0.760</b>
Brainstem	36				39	
Normal tissue	6				6	

Figure-of-merit:  $f_{EUD} = 1 / \left( (1+k) \cdot \sum_{i=1}^n \omega_i \cdot OAR^i \right) / \left( \sum_{j=1}^m \omega_j \cdot Tumor^j \right)$

# Summary

- HT used for complicated clinical situations, resulting in complex plans.
- Current visual inspection of dose/DVH is difficult to evaluate/select plan.
- EUD based biological criteria are useful for Tomo and other plan evaluation, may be used to improve optimization.
- Radiobiological parameters of tumors and OARs for many sites have been studied based on clinical data, such as breast, prostate, brain, H&N, liver, etc.
- Work is in progress, any suggestion please contact me at [xqi@radonc.mcw.edu](mailto:xqi@radonc.mcw.edu).

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**E. Ahunbay, Ph.D.**



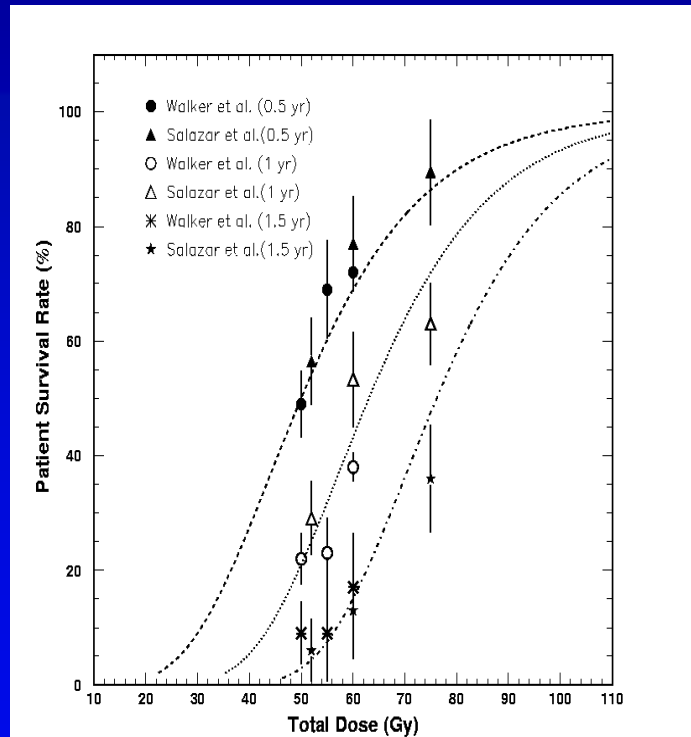
# Sensitivity on parameters

Parameters	Tomo	IMRT	Diff
<b>Tumor: <math>\alpha / \beta = 10</math>, <math>\alpha = 0.3</math>. OAR: <math>\alpha / \beta = 3</math>, <math>\alpha = 0.1</math></b>	<b>0.889</b>	<b>0.825</b>	<b>0.064</b>
<b>Tumor: <math>\alpha / \beta = 6</math>, <math>\alpha = 0.1</math>. OAR: <math>\alpha / \beta = 1</math>, <math>\alpha = 0.1</math></b>	<b>0.891</b>	<b>0.828</b>	<b>0.063</b>
<b>Tumor: <math>\alpha / \beta = 20</math>, <math>\alpha = 0.5</math>. OAR: <math>\alpha / \beta = 5</math>, <math>\alpha = 0.2</math></b>	<b>0.887</b>	<b>0.822</b>	<b>0.065</b>

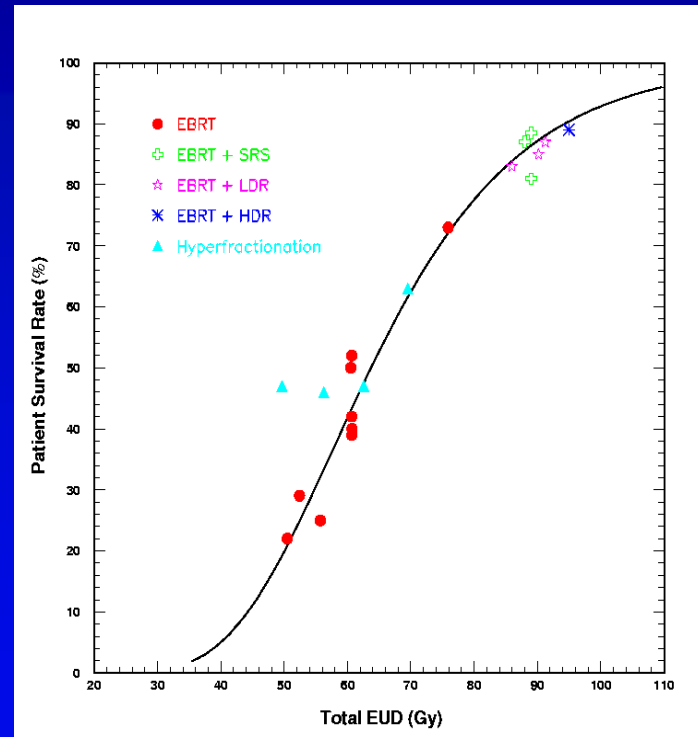
# Malignant Gliomas

Derivation with clinical data:

- Walker et al., EBRT
- Salazar et al., EBRT



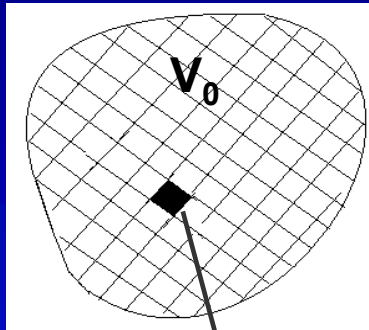
Validation with other clinical Data:  
EBRT+SRS, EBRT+LDR, EBRT+HDR,  
Hyperfractionation, etc



Qi, Schultz, Li, IJROBP, 2006;64(5):1570-80.

# EUD for OARs

- Non-uniform dose distribution



$V_i$ : a volume voxel

$$v = \frac{V_{eff}}{V_0} = \sum_i \frac{V_i}{V_0} \left( \frac{D_i}{D_{max}} \right)^{1/n} = \sum_i v_i \left( \frac{D_i}{D_{max}} \right)^{1/n}$$

Kutcher GJ, Burman C, IJROPB. 1989; 16 1623-1630.

$$t(EUD) = \frac{EUD - TD_{50}(1)}{m \bullet TD_{50}(1)}$$

$$\frac{EUD - TD_{50}(1)}{m \bullet TD_{50}(1)} = \frac{D_{max} - TD_{50}(v)}{m \bullet TD_{50}(v)}$$

$$EUD = \left( \sum_i v_i D_i^{1/n} \right)^n$$

n: adjustable parameter