MEDICAL UNIVERSITY OF VIENNA

New approach to IMRT optimization: clinical experience with „Monaco“ (CMSSOFTWARE/Elekta)

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Commissioning of TPS in the Department of Radiotherapy, Medical University Vienna/AKH Wien

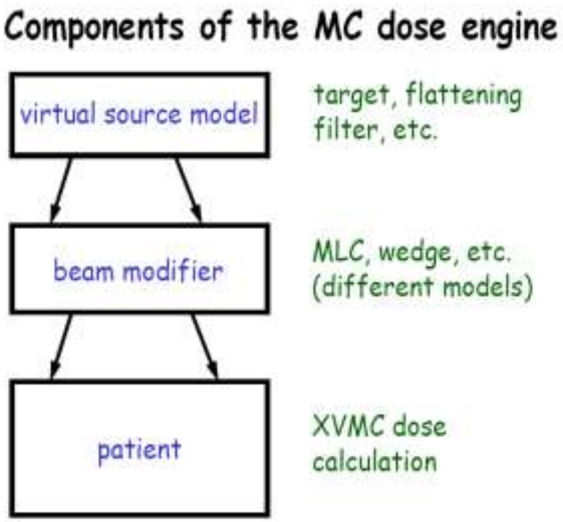
- ***Dosimetric verification of MC algorithm***
- ***IMRT comparison study – advantage of biological cost functions over traditional dose-volume approach:***
  - ***EUD-based formalism of cost functions***
  - ***Combination of "hard constraints" and "objectives" for the control of optimization process***
  - ***Advanced structure control***
  - ***Sensitivity analysis tool***
- ***Since June 2008 – commissioned for the clinical routine use***
- ***Now – Monaco V 1.0.2***

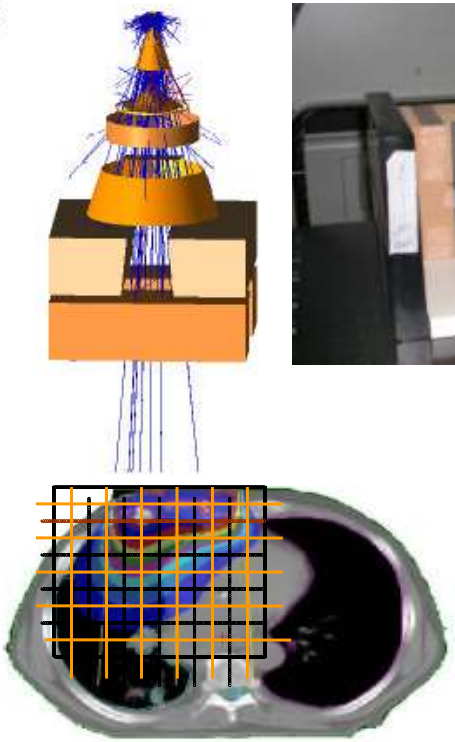
Dosimetric verification of MC algorithm

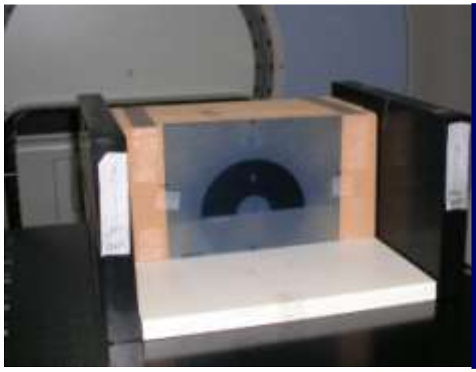
- *Need for high accuracy in dose calculation for advanced treatment techniques*
  - *Small fields as used for SBRT, IMRT, dose painting, ….*
  - *Low density regions are still challenging*
  - *Biological modeling*
- *Everlasting competition between speed and accuracy*
- *Is there an advantage of (commercially available) MC methods over advanced kernel algorithms?*

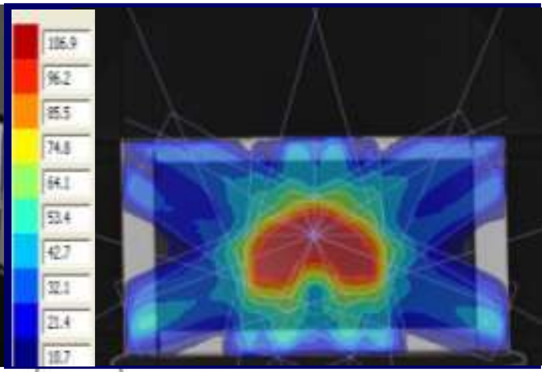
Dosimetric verification of MC algorithm

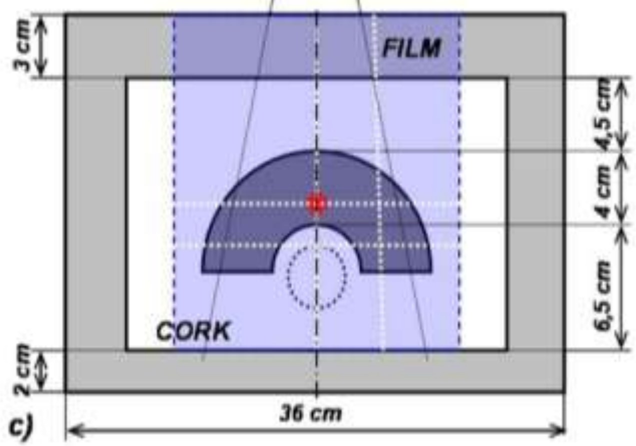
- *MC dose calculation in **Monaco** – based on XVMC*

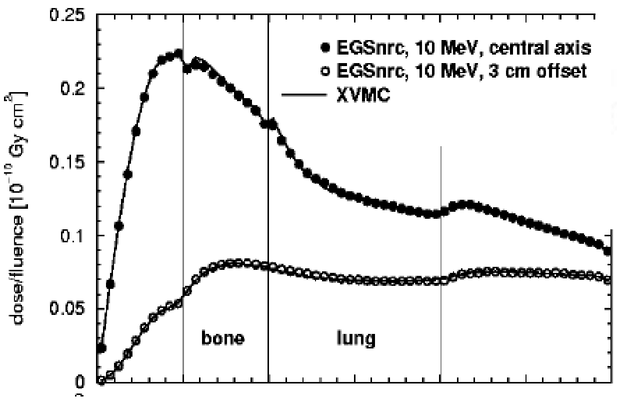








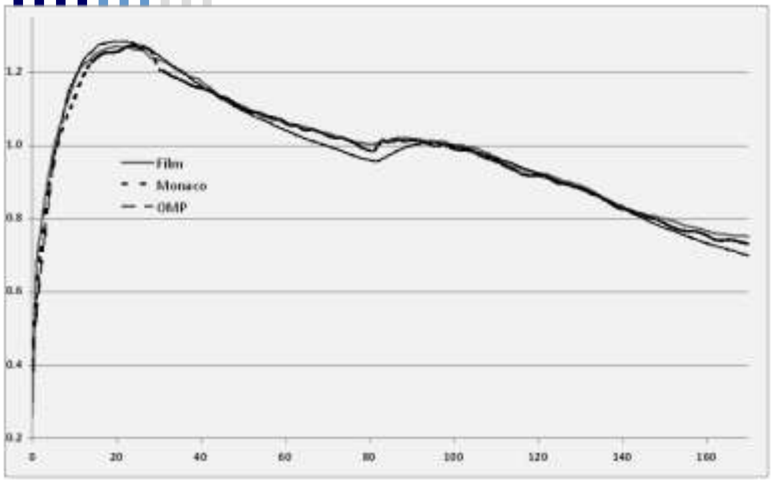


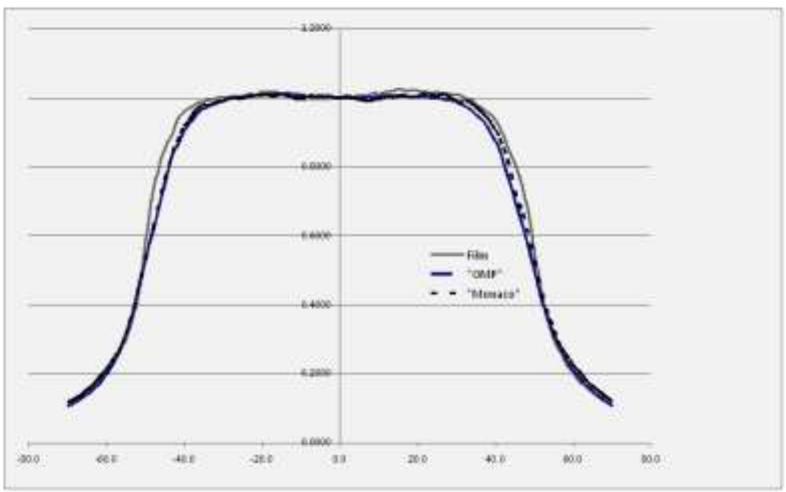


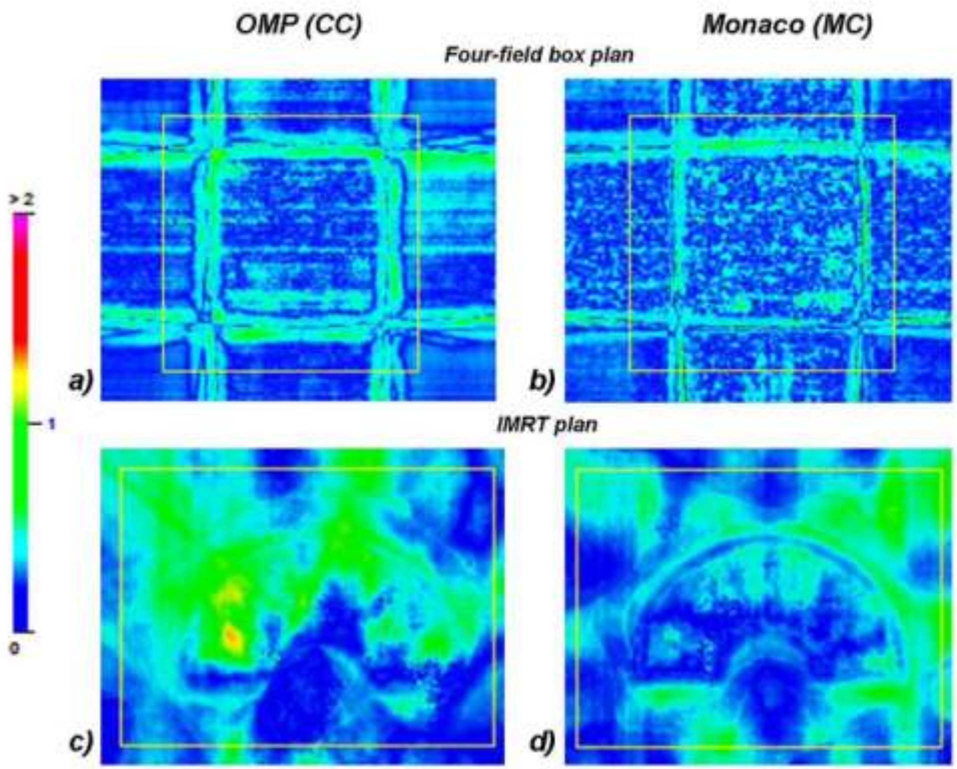
Single field profiles, PDDs (1D gamma)

IMRT 2D gamma verification

Results:





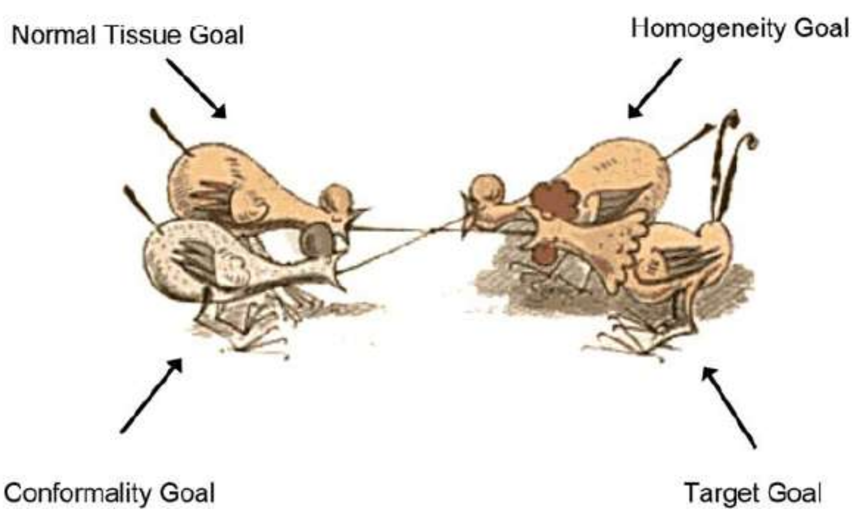


- Commercially available in Monaco TPS Monte Carlo algorithm is able to predict the dose in heterogeneous media and at interfaces slightly more accurate than advanced kernel algorithms.

IMRT optimization with Monaco

- **Typical Treatment Goals:**
- *Sufficient target dose*
- *Don‘t exceed acceptable doses in OARs*
- *Target dose should be conformal –spare normal tissue*
- *No large or excessive hot spots in target*

These goals need to be communicated to the planning algorithm in a ***concise****,* ***comprehensive****,* ***transparent*** *and* ***numerically expedient*** *manner.*



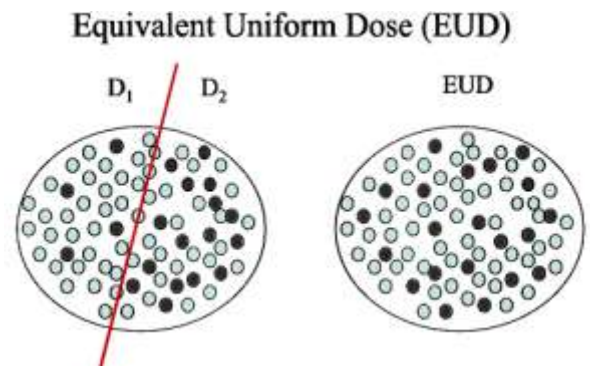
Biological formalism of the cost functions in Monaco +

2 stages of the optimization process

Biological formalism of the cost functions in Monaco

EUD-based formalism

- EUD represents dose that is equivalent (*in terms of the same level of the probability of a local control or complication*) to a given non-uniform dose distribution.
- EUD-based cost functions allow exploration of a larger solution space than dosimetry-based objective functions (Wu Q.,Mohan R. et al 2002)



- ***Targets***
- ***Poisson Cell Kill Cost Function***
- **Primary cost function for targets, treated as an objective**
- **Required parameters: *Prescription* – in terms of EUD, the desirable dose for the structure and *Cell sensitivity* – default value of 0,25**

Based on Poisson Dose Response Model (Munro,Guilbert 1961)/TCP model (W.Tome,S.Bentzen 2005)

Biological formalism of the cost functions in Monaco

OARs -Biological volume effect

- Serial Response – organ behaves like a chain
- Volume effect is small
- Partial loss of function equal to a total loss of function
- Spinal cord, peritoneum, nerves

Serial Complication Model Cost Function

Preferred constraint for serial OARs

Power law exponent $k=0,15*D_{50}$

EUD – value in between of D_{max} (k is high) and mean dose (k=1)

OAR	K value
Rectum	12-14
Spinal cord	12-14
Optic nerve	12-16
Inner ear	12
Brainstem	10-12
Larynx	6-8
Esophagus	10-12
Bladder	8-10

The values are the combination of recommended by CMS values and data obtained from practical experience in AKH Vienna.

General rule: higher K-value implies higher penalty on the high dose region of the DVH curve

Biological formalism of the cost functions in Monaco

- Parallel Response – organ behaves like a rope
- Partial loss of a function is tolerable
- Volume effect is large
- Kidney, liver, lung

Parallel Complication Model Cost Function

Preferred constraint for parallel OARs
Reference dose (EUD), Mean organ damage (%), power law exponent k

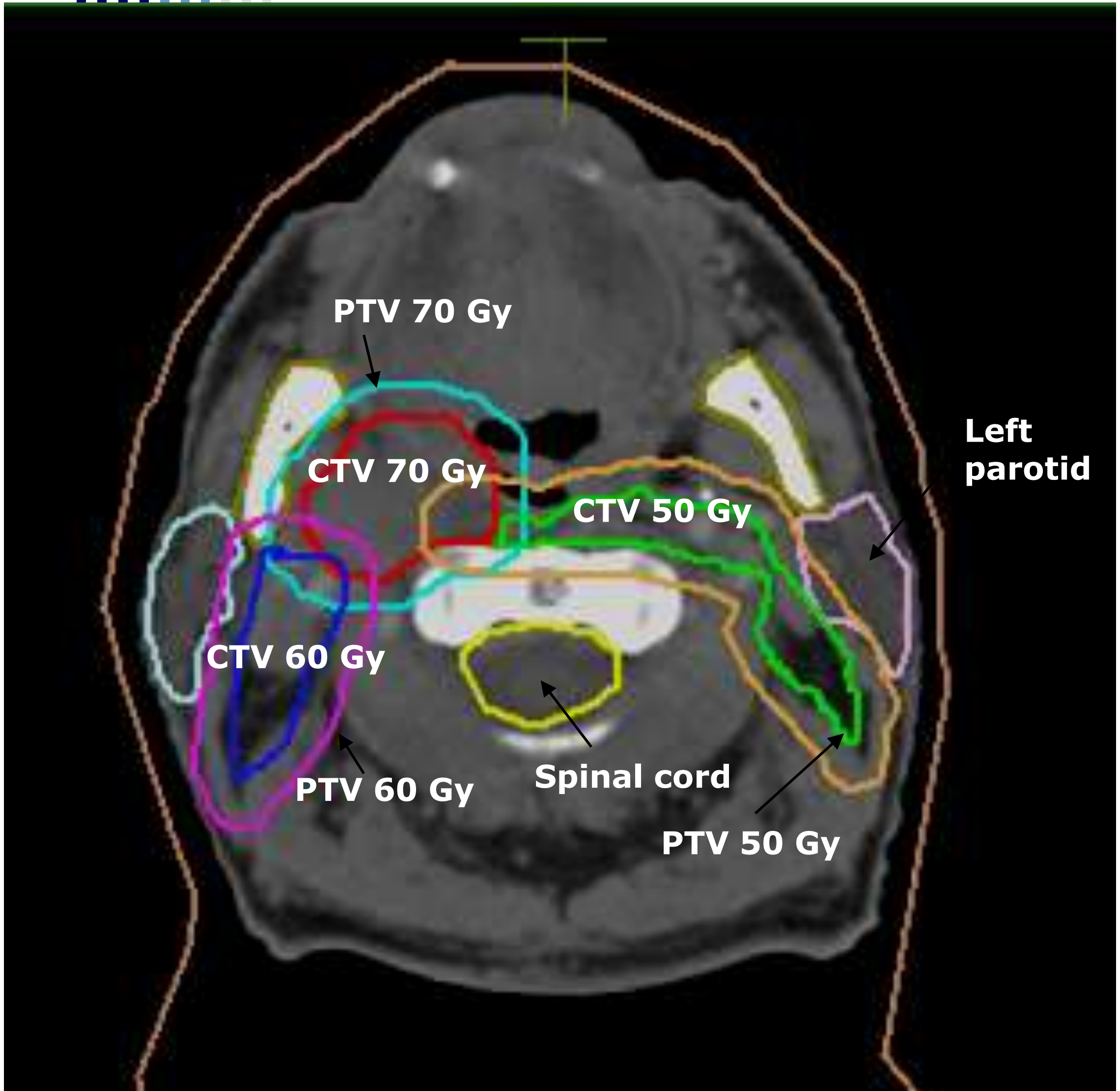
OAR	K-value
Lung	3-3,5
Parotid	3,5 -3.9
Kidney	2,1
Heart	2,5 -3
Liver	3,5 -4
Mean damage: 20-50%	

The values are the combination of recommended by CMS values and data obtained from practical experience in AKH Vienna.
General rule: higher K-value implies higher penalty for the control of the mean dose

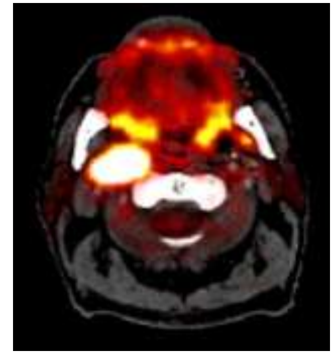
IMRT optimization with Monaco-practical examples…

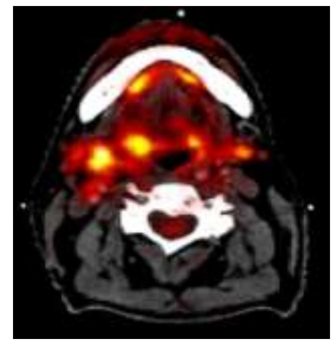
- ***<u>Head-and-neck case</u>***
- ***Age: 69 y.o.***
- ***Tumor location: right tonsil + parapharyngeal space***
- ***Stage: T3N2aM0***
- ***CT+PET data are available***
- ***Radical external beam radiotherapy –***
- ***IMRT (simultaneous integrated boost)***
- ***Chemotherapy – concurrent Cis-Pt or Cis-Pt-5FU***
- ***<u>Prostate case</u>***
- ***<u>Anus case</u>***
- ***Other indications for the IMRT planning in AKH – gyn. cervix IMRT, pleura***

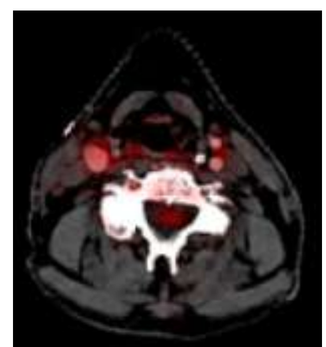
Target and structure delineation

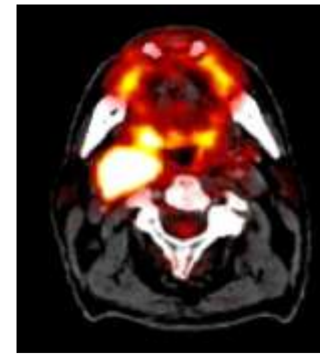


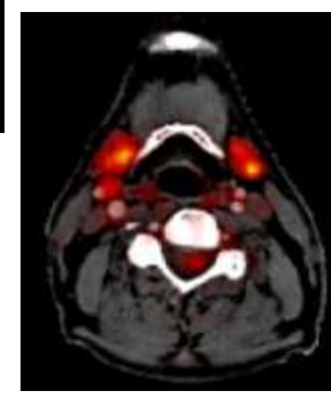
CTV to PTV margin: 5 mm



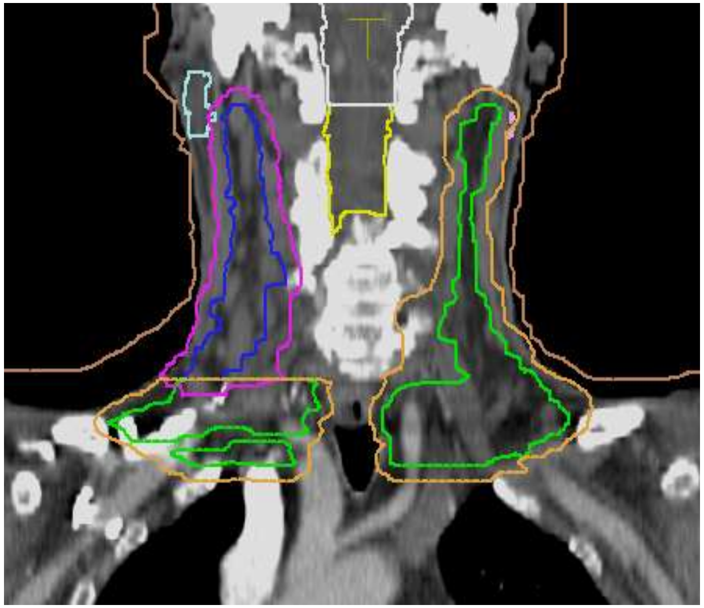


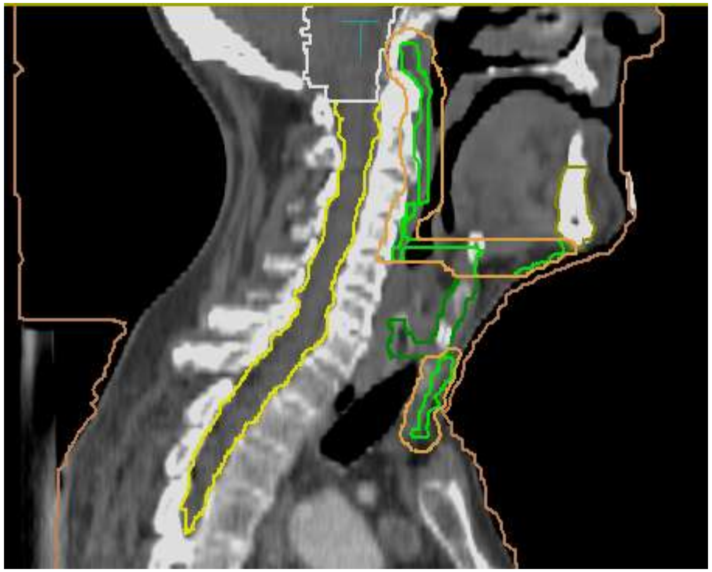




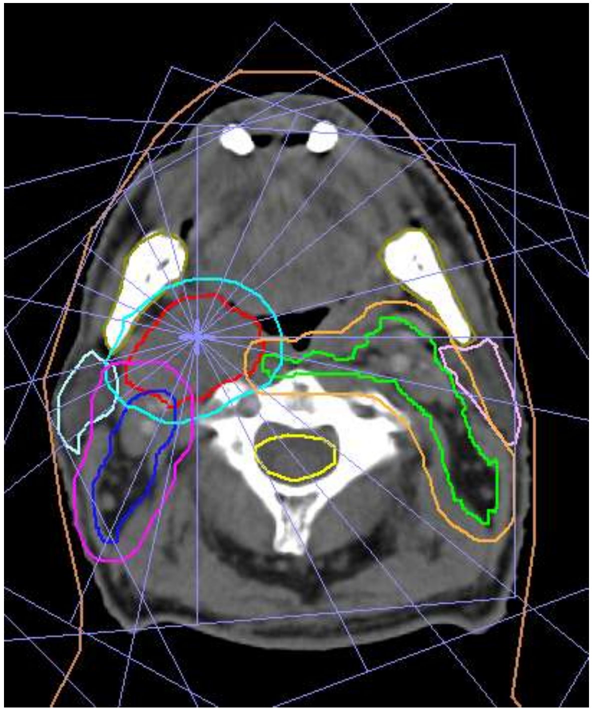


Target and structure delineation



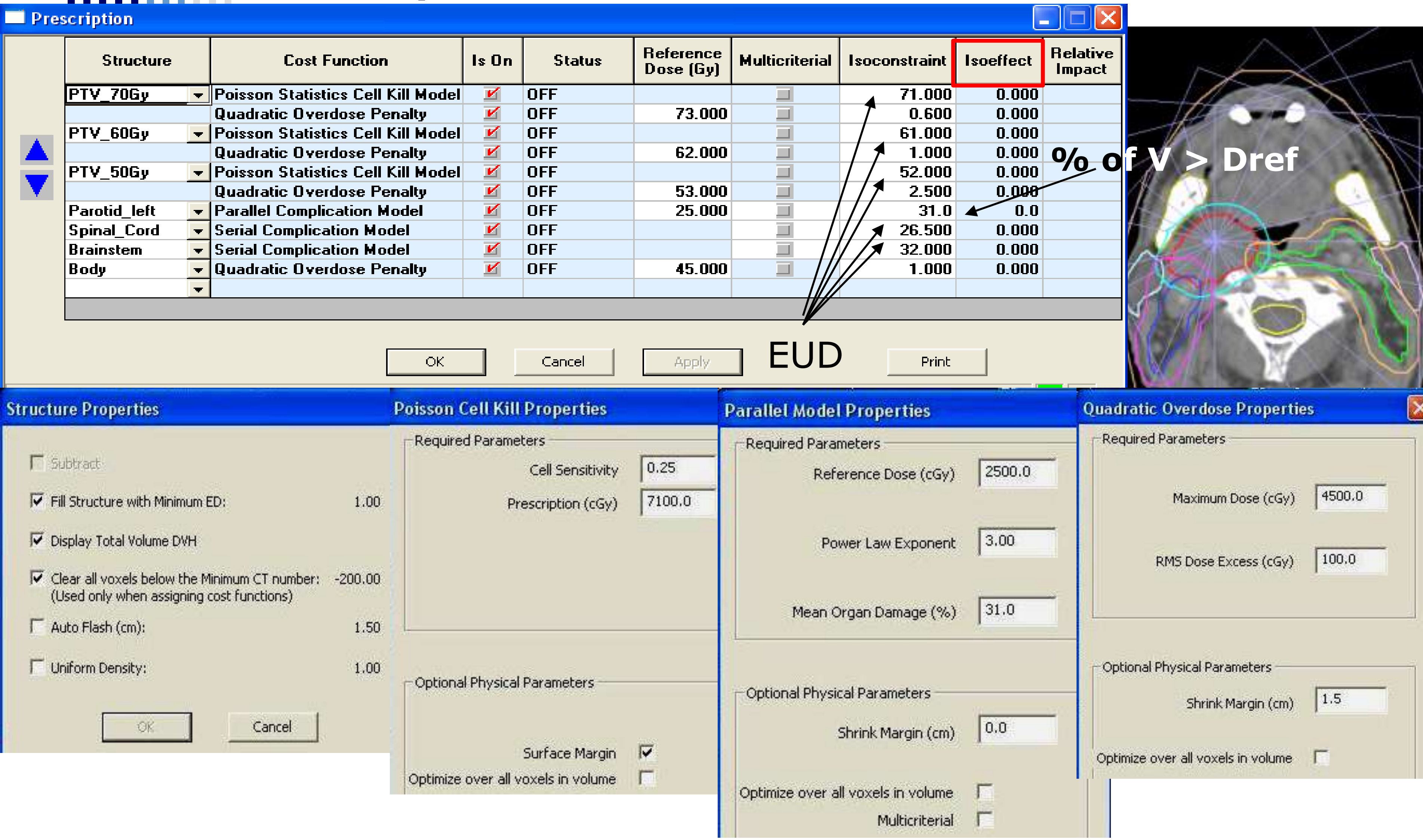


IMRT treatment planning



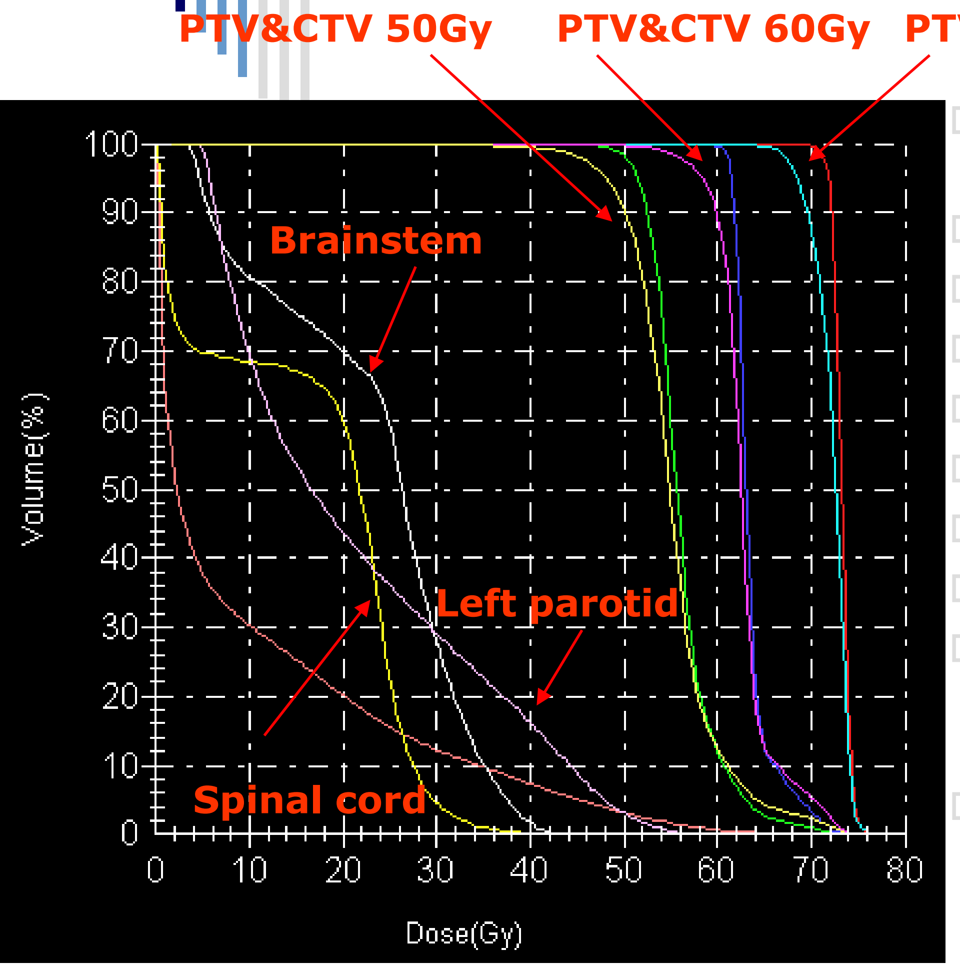
- ***7 equidistant beams** (gantry:90-141-192-243-294-345-39) – parotid sparing technique*
- ***10 MV Elekta Synergy Platform linac, sMLC** (40 pairs, 1 cm leaf width)*
- *Isocenter – PTV 70 Gy*
- ***TPS - Monaco 1.0.2 (CMS software/Elekta):***
- *XVMC dose calculation*
- *3 mm dose calculation grid, 3% MC variance*
- *Min. segment size – 4 cm2, Min.MU per segment – 4 MU*

Prescription and advanced structure control

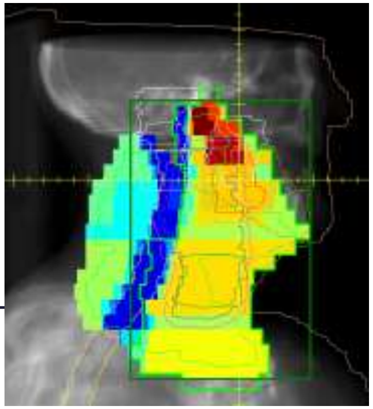


Structure	Cost Function	Is On	Status	Reference Dose (Gy)	Multicriterial	Isoconstraint	Isoeffect	Relative Impact
PTV_70Gy	Poisson Statistics Cell Kill Model	✓	OFF			71.000	0.000	
	Quadratic Overdose Penalty	✓	OFF	73.000		0.600	0.000	
PTV_60Gy	Poisson Statistics Cell Kill Model	✓	OFF			61.000	0.000	
	Quadratic Overdose Penalty	✓	OFF	62.000		1.000	0.000	
PTV_50Gy	Poisson Statistics Cell Kill Model	✓	OFF			52.000	0.000	
	Quadratic Overdose Penalty	✓	OFF	53.000		2.500	0.000	
Parotid_left	Parallel Complication Model	✓	OFF	25.000		31.0	0.0	
Spinal_Cord	Serial Complication Model	✓	OFF			26.500	0.000	
Brainstem	Serial Complication Model	✓	OFF			32.000	0.000	
Body	Quadratic Overdose Penalty	✓	OFF	45.000		1.000	0.000	

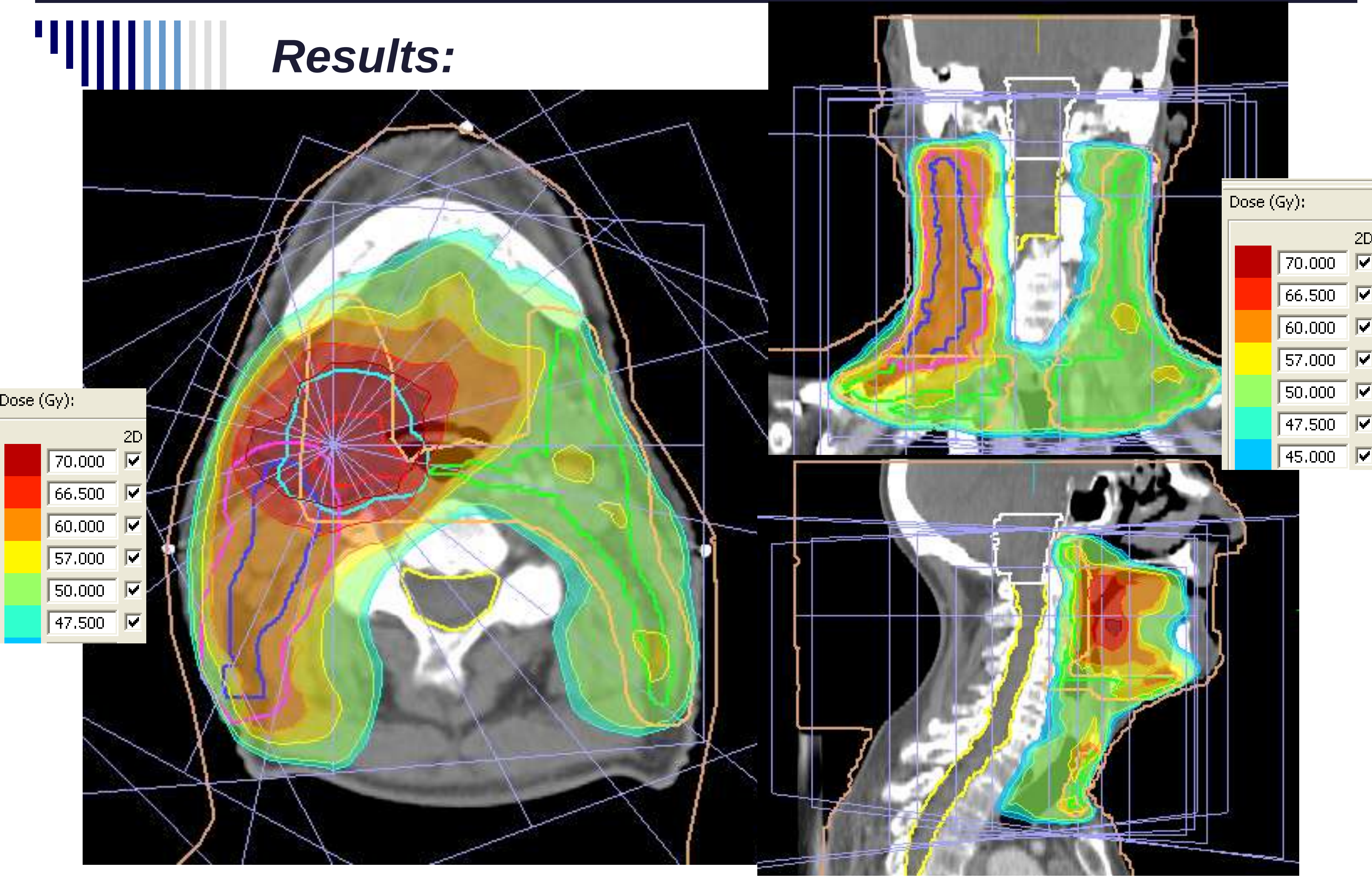
Results:



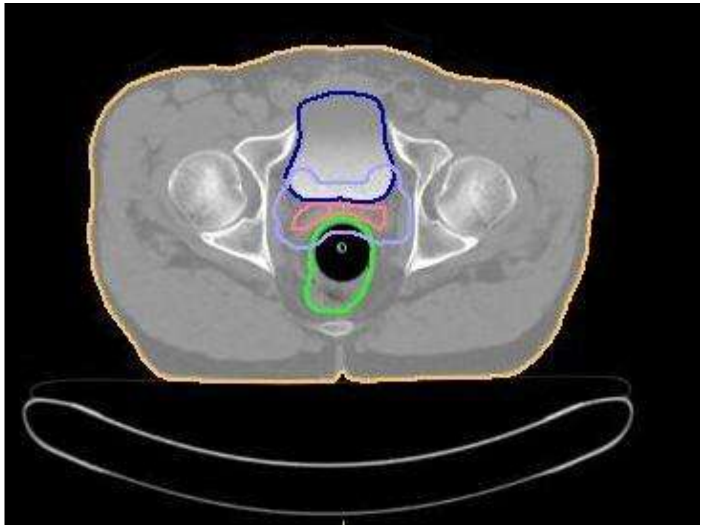
- ***PTV coverage with 95%** of the respective prescribed dose level:*
- *PTV 70 Gy – 98,8%*
- *PTV 60 Gy – 96,8%*
- *PTV 50 Gy - 95,6%*
- ***OARs:***
- *Max dose to spinal cord: **43,6 Gy***
- *Max dose to brainstem: **43,1 Gy***
- *Mean dose to cont. parotid: **21,2 Gy***
- *Abs. max dose:in CTV tumor -76,3 Gy - 109%, in normal tissue – 74,5 Gy - 106% of the prescr. dose*
- ***93** Segments, **739** MU*

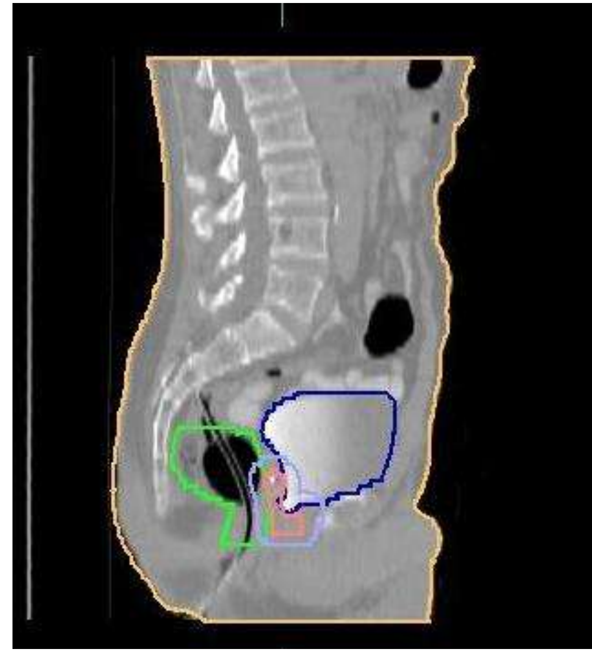


Results:


Dose (Gy):
2D
70.000
66.500
60.000
57.000
50.000
47.500
Dose (Gy):
2D
70.000
66.500
60.000
57.000
50.000
47.500
45.000

Prostate case





RT after transurethral prostate resection; Prescription – 66Gy

Prescription

Structure	Cost Function	Is On	Status	Reference Dose (Gy)	Multicriterial	Isoconstraint	Isoeffect	Relative Impact
PTV Prostatalo	Poisson Statistics Cell Kill Model	✓	OFF			68.500	0.000	
	Quadratic Overdose Penalty	✓	OFF	69.000		2.000	0.000	
Rektum	Maximum Dose Constraint	✓	OFF			64.000	0.000	
	Parallel Complication Model	✓	OFF	30.000	✓	30.5	0.0	
Blase	Maximum Dose Constraint	✓	OFF			64.000	0.000	
	Parallel Complication Model	✓	OFF	30.000	✓	17.3	0.0	
Body	Quadratic Overdose Penalty	✓	OFF	30.000		1.000	0.000	

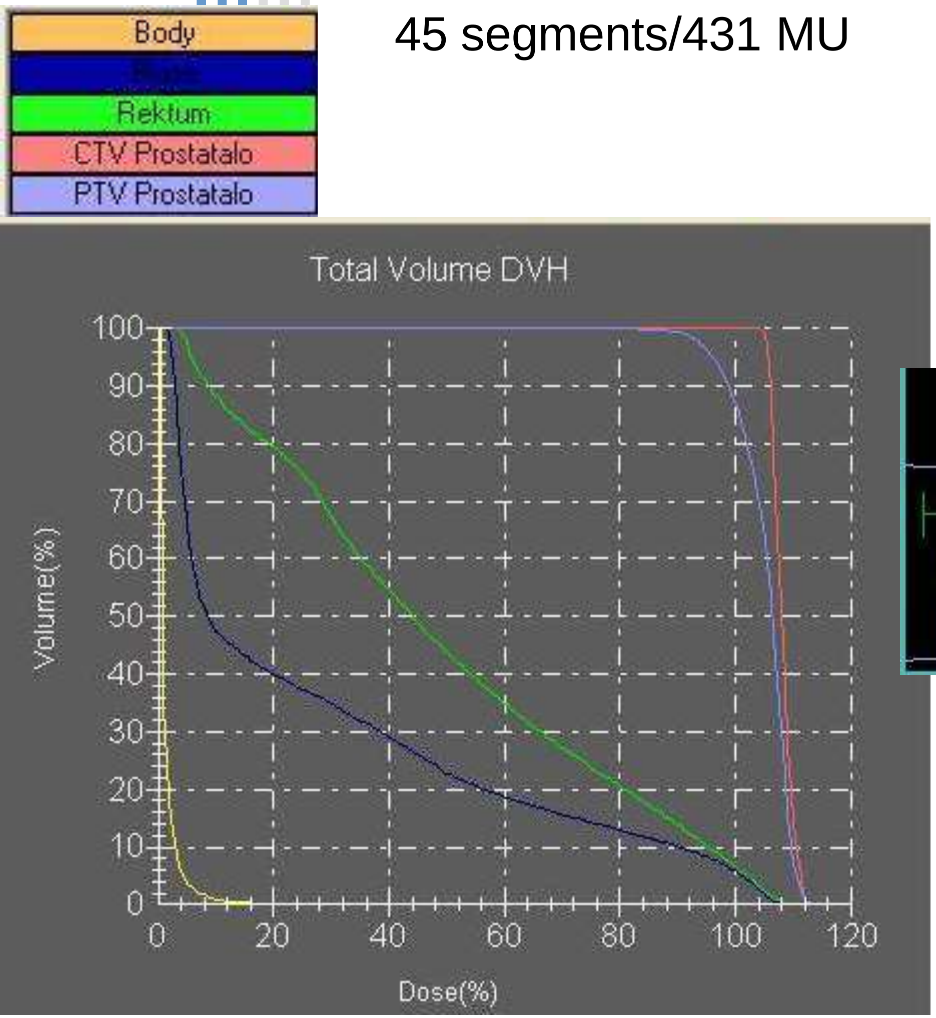
OK Cancel Apply Print

7 beams IMRT,
10 MV
3 mm grid/3% variance

NB: Contrast for Bladder – use structure control

Prostate case

45 segments/431 MU



Anus case

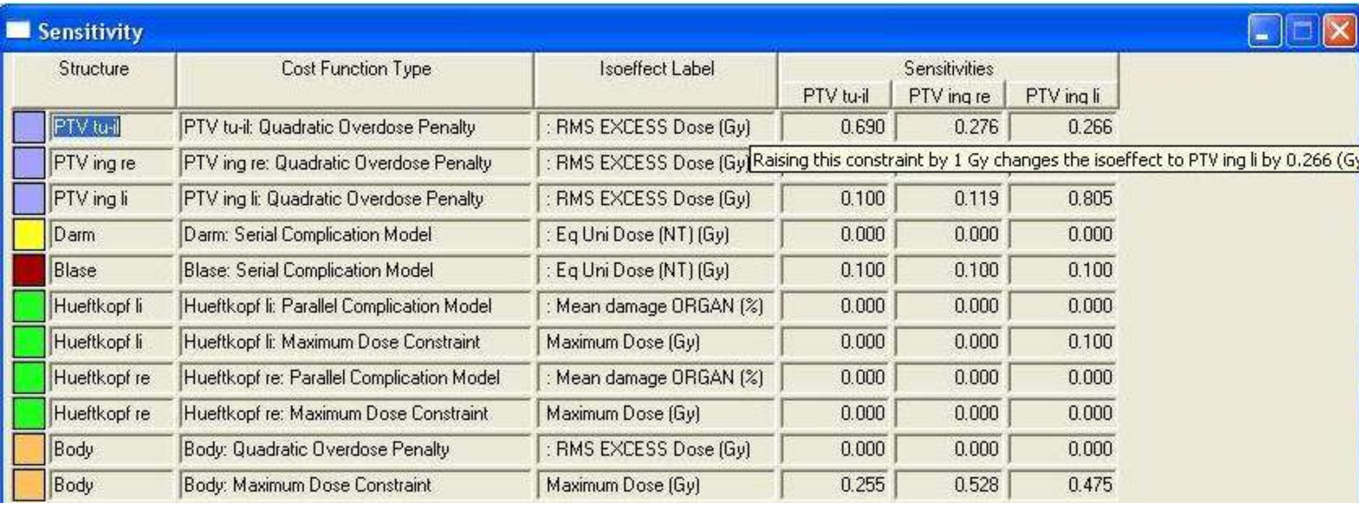
7 beams IMRT, 10 MV

Single isocenter – center-of-mass of all 3 PTVs

D_{prescr} = 46 Gy

3 PTVs (anorectal+lymph nodes); OARs – bladder, colon

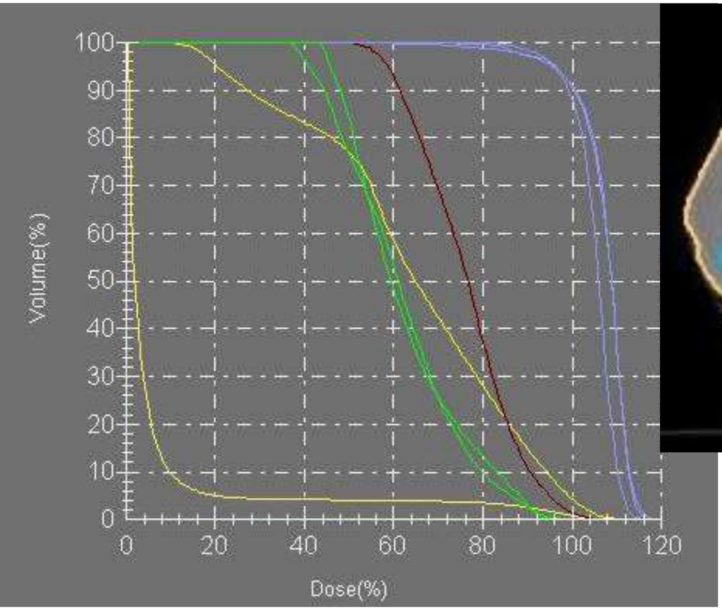
Additional requirements – dose to femoral heads + no high dose between PTVs

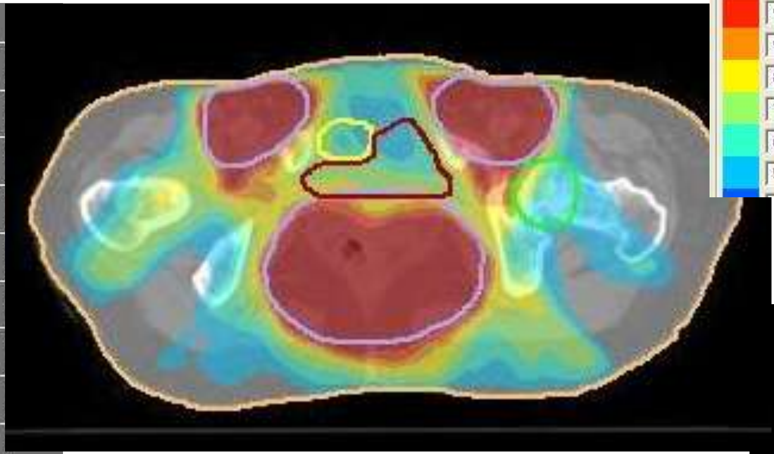


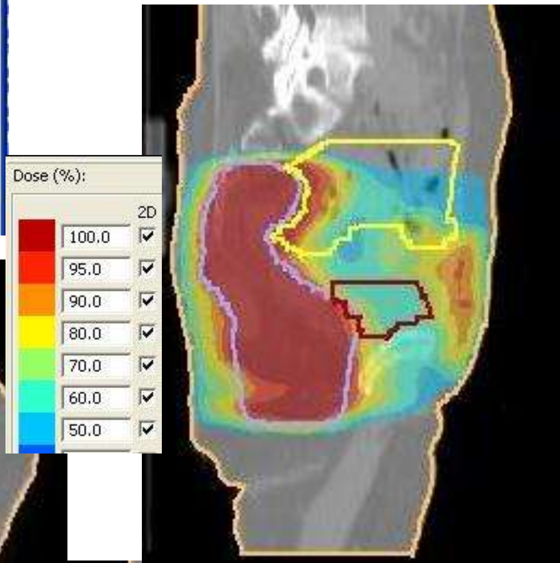
Sensitivity

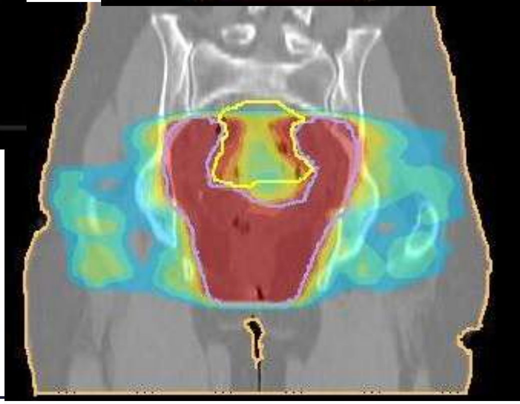
Structure	Cost Function Type	Isoeffect Label	Sensitivities		
			PTV tu-il	PTV ing re	PTV ing li
PTV tu-il	PTV tu-il: Quadratic Overdose Penalty	: RMS EXCESS Dose (Gy)	0.690	0.276	0.266
PTV ing re	PTV ing re: Quadratic Overdose Penalty	: RMS EXCESS Dose (Gy)			
PTV ing li	PTV ing li: Quadratic Overdose Penalty	: RMS EXCESS Dose (Gy)	0.100	0.119	0.805
Darm	Darm: Serial Complication Model	: Eq Uni Dose (NT) (Gy)	0.000	0.000	0.000
Blase	Blase: Serial Complication Model	: Eq Uni Dose (NT) (Gy)	0.100	0.100	0.100
Hueftkopf li	Hueftkopf li: Parallel Complication Model	: Mean damage ORGAN (%)	0.000	0.000	0.000
Hueftkopf li	Hueftkopf li: Maximum Dose Constraint	Maximum Dose (Gy)	0.000	0.000	0.100
Hueftkopf re	Hueftkopf re: Parallel Complication Model	: Mean damage ORGAN (%)	0.000	0.000	0.000
Hueftkopf re	Hueftkopf re: Maximum Dose Constraint	Maximum Dose (Gy)	0.000	0.000	0.000
Body	Body: Quadratic Overdose Penalty	: RMS EXCESS Dose (Gy)	0.000	0.000	0.000
Body	Body: Maximum Dose Constraint	Maximum Dose (Gy)	0.255	0.528	0.475

Raising this constraint by 1 Gy changes the isoeffect to PTV ing li by 0.266 (Gy)









89 segments/854 MU

Work in progress:

- *VMAT activities – currently ERGO++*
- *2 Linacs with VMAT-option: Elekta Synergy and Synergy S+*
- *Integration of VMAT in Monaco*
- *Beta-version scheduled for spring*
- *AIM – clinical implementation summer/autumn 2009*

Thank you for your attention!