



*Human Care Makes
the Future Possible*



ELEKTA

Monaco VMAT

The Next Generation in IMRT/VMAT
Planning

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Customer Support TPS Application

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Background

What is Monaco?

- Advanced IMRT/VMAT treatment planning system from Elekta Software
- Collaboration with University of Tübingen (UKT)
- Based on the Hyperion project started in 2000 (M. Alber, et al)
- Monaco 1.0 released July 2007

Unique Features

Biological Modeling

Constrained Optimization

Voxel-based Structure Control

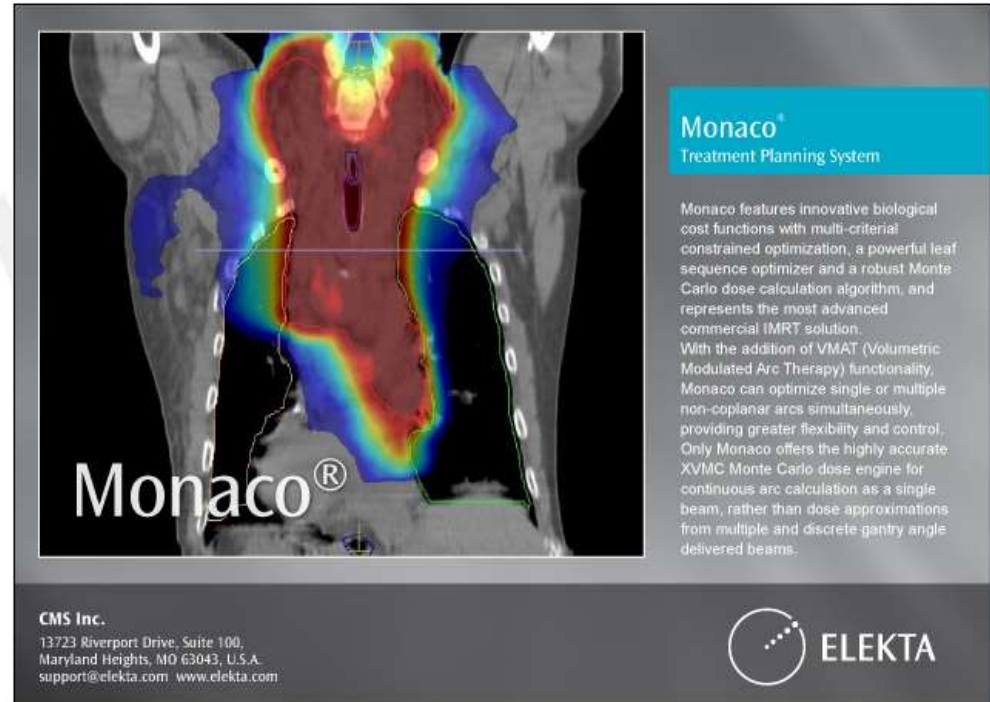
Sensitivity Analysis

Smart Sequencing™

Monte Carlo Dose Algorithm

VMAT

SRS Planning/Dynamic Conformal Arc



Monaco®
Treatment Planning System

Monaco features innovative biological cost functions with multi-criterial constrained optimization, a powerful leaf sequence optimizer and a robust Monte Carlo dose calculation algorithm, and represents the most advanced commercial IMRT solution.

With the addition of VMAT (Volumetric Modulated Arc Therapy) functionality, Monaco can optimize single or multiple non-coplanar arcs simultaneously, providing greater flexibility and control. Only Monaco offers the highly accurate XVMC Monte Carlo dose engine for continuous arc calculation as a single beam, rather than dose approximations from multiple and discrete gantry angle delivered beams.

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Biological Modeling

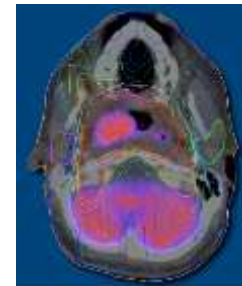
Biological cost functions allow us to model tissue-specific dose responses, that is the *volume effect*.



Serial
(small volume effect)



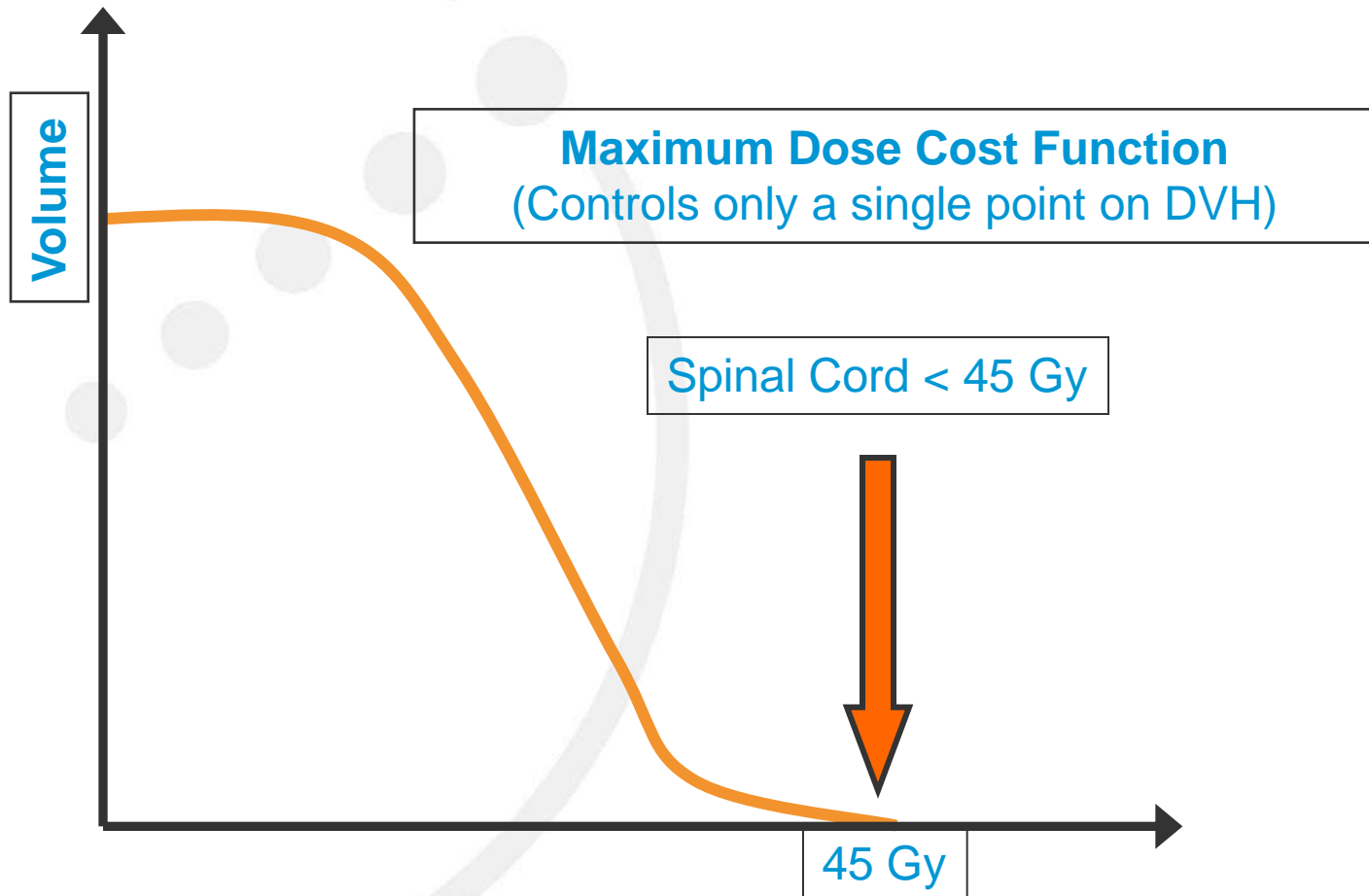
Parallel
(large volume effect)



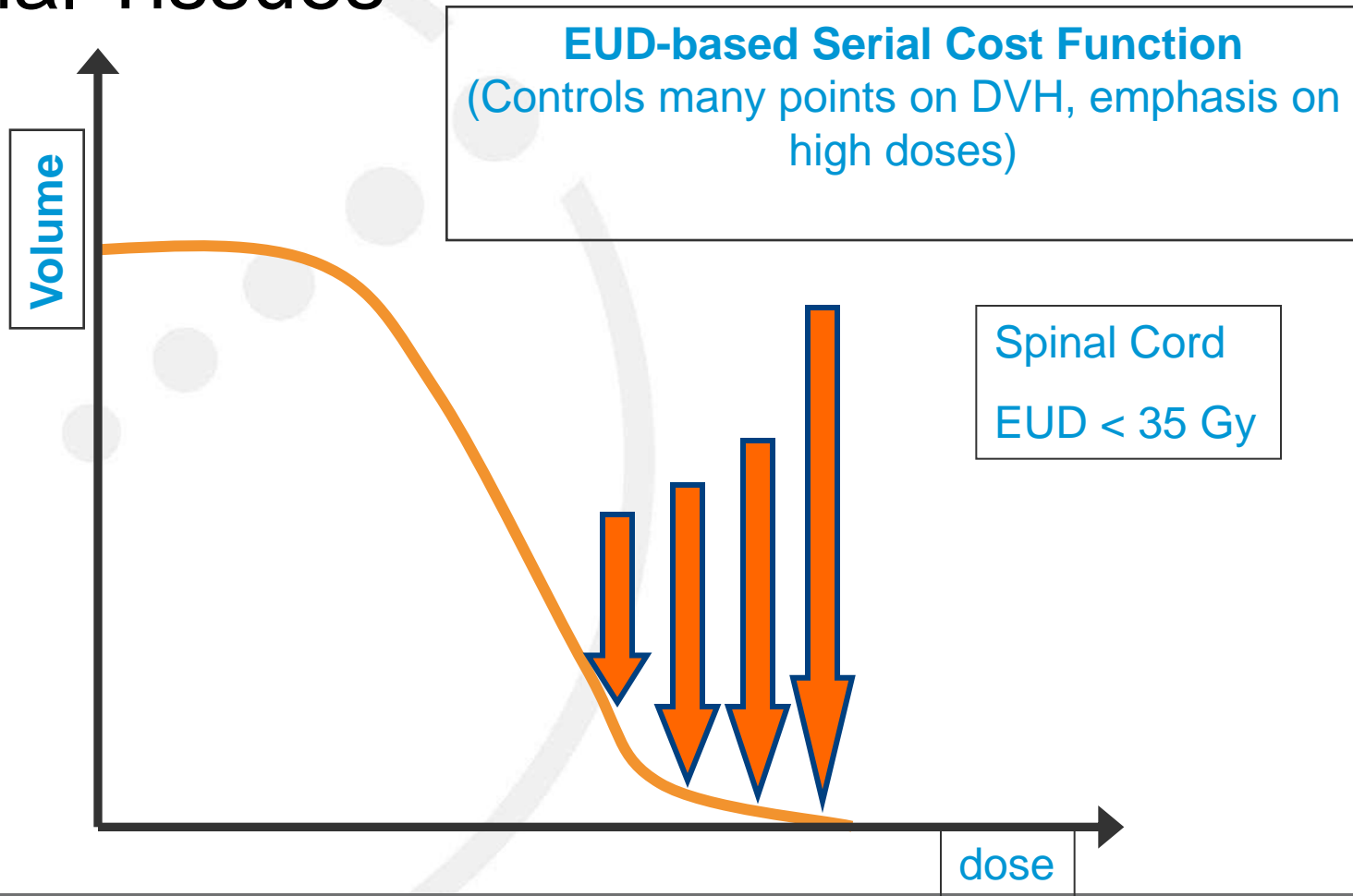
Tumor
(sensitive to cold spots)

But, for treatment planning, these cost functions really allow us to *control the shape of the DVH...*

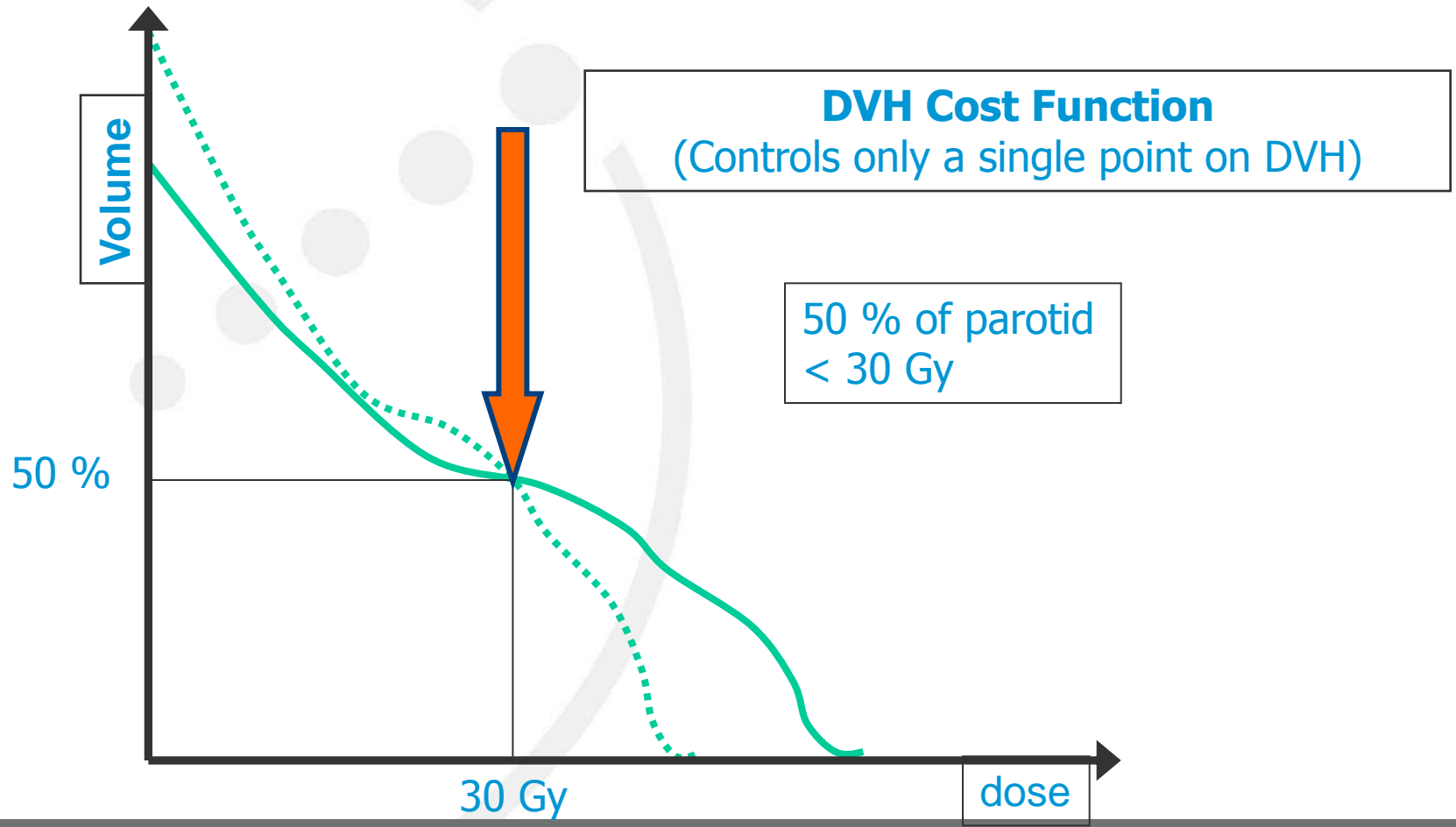
Biological Modeling: Controlling the DVH Serial Tissues



Biological Modeling: Controlling the DVH Serial Tissues

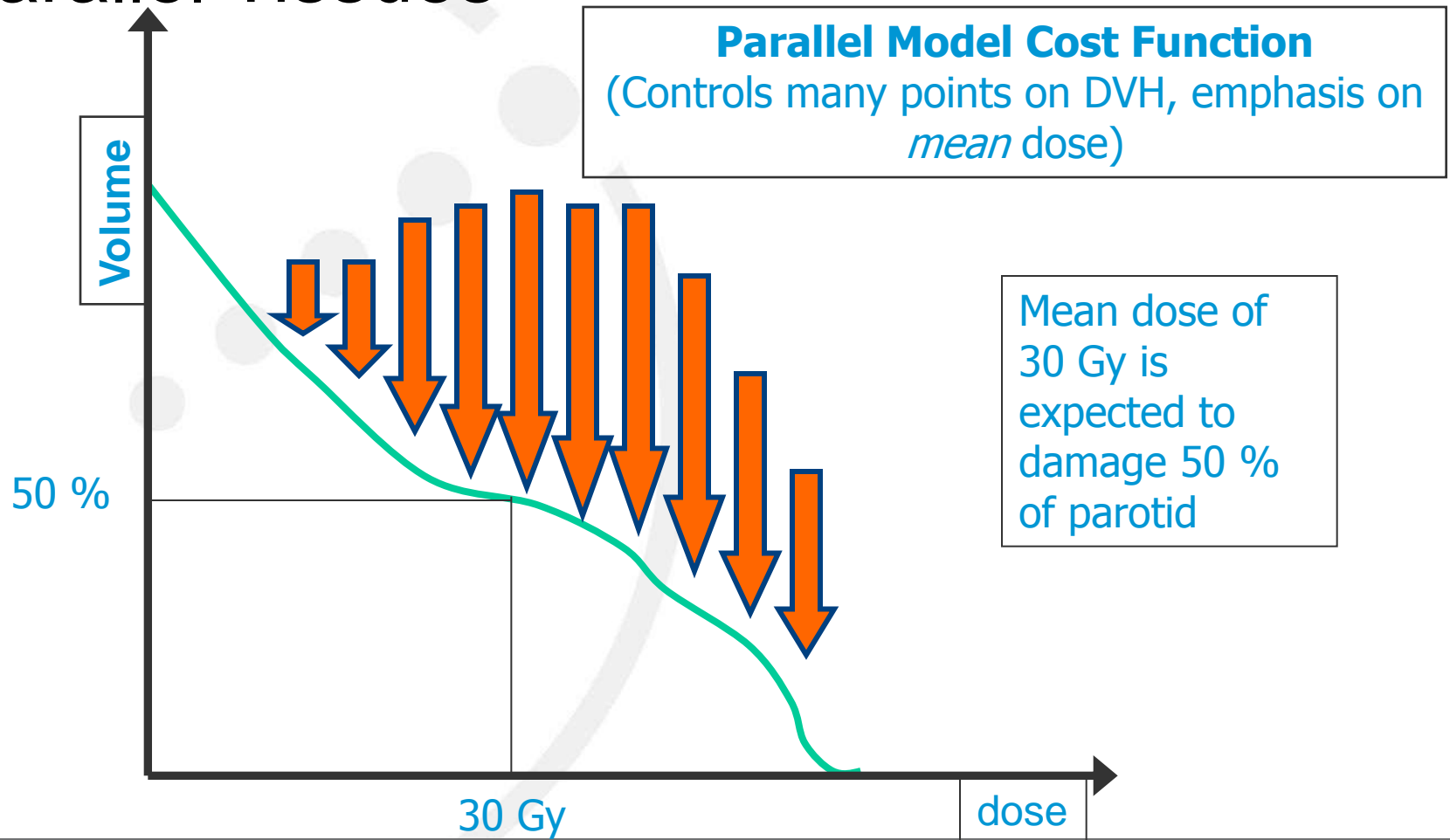


Biological Modeling: Controlling the DVH Parallel Tissues



Biological Modeling: Controlling the DVH

Parallel Tissues



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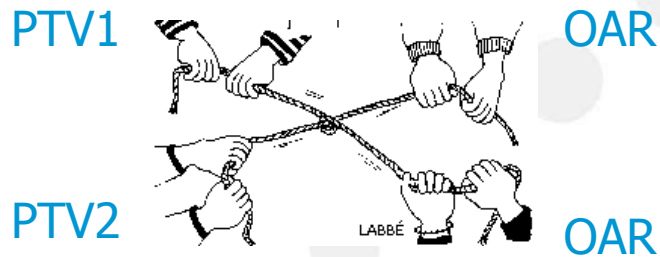
VMAT

SRS Planning/Dynamic Conformal Arc

Constrained Optimization

Unconstrained Optimization

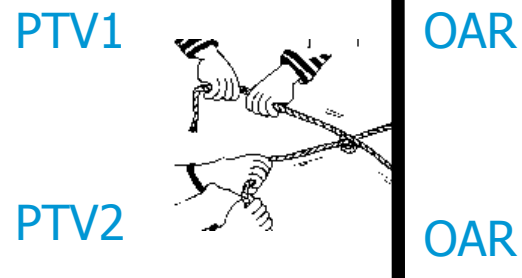
(Most current IMRT systems)



Trade off between all objectives

Constrained Optimization

(Monaco)



Constraints may limit target objectives

But conflicts become apparent!

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Sensitivity Analysis

Changing the isoconstraint of PAROTID_RT by 1% improves the dose to PTV4 by 52 cGY

Prescription

Constraints Sensitivities

Structure	Cost Function	Isoconstraint	Isoeffect	Relative Impact	ptv1	ptv2	ptv3	ptv4	Point Se
ptv1	Target EUD	6600.0	6806.0						
	Quadratic Overdose	120.0	116.0	++	75.8	14.7	10.1	10.0	
	Underdose DVH	90.00	96.98	+	10.0	0.0	0.0	0.0	
ptv2	Target EUD	6000.0	6378.3						
	Quadratic Overdose	150.0	145.7	+	10.3	28.6	10.0	10.0	
	Underdose DVH	90.00	99.84		0.0	0.0	0.0	0.0	
ptv3	Target EUD	5400.0	5810.3						
	Quadratic Overdose	50.0	44.5	+	25.8	10.4	10.0	10.0	
	Quadratic Overdose	300.0	298.4	++	11.2	10.0	10.0	10.0	
ptv4	Target EUD	5400.0	5781.4						
	Quadratic Overdose	50.0	38.3		10.0	10.0	10.0	10.0	
	Quadratic Overdose	300.0	301.1	+++	21.6	16.4	10.3	38.3	
cordplus	Underdose DVH	90.00	99.24		0.0	0.0	0.0	0.0	
	Serial	3300.0	3231.7	+	10.0	0.0	10.0	0.0	
	Parallel	55.00	49.58	++++	11.1	24.9	37.9	11.8	
rtpar	Parallel	55.00	50.86	++++	10.9	34.8	13.6	52.0	
patient	Quadratic Overdose	10.0	3.3		10.0	10.0	10.0	10.0	
	Quadratic Overdose	80.0	35.8		10.0	10.0	10.0	10.0	
	Quadratic Overdose	200.0	164.9	+	10.0	10.0	10.0	10.0	
	Maximum Dose	7200.0	6924.7		10.0	0.0	0.0	0.0	

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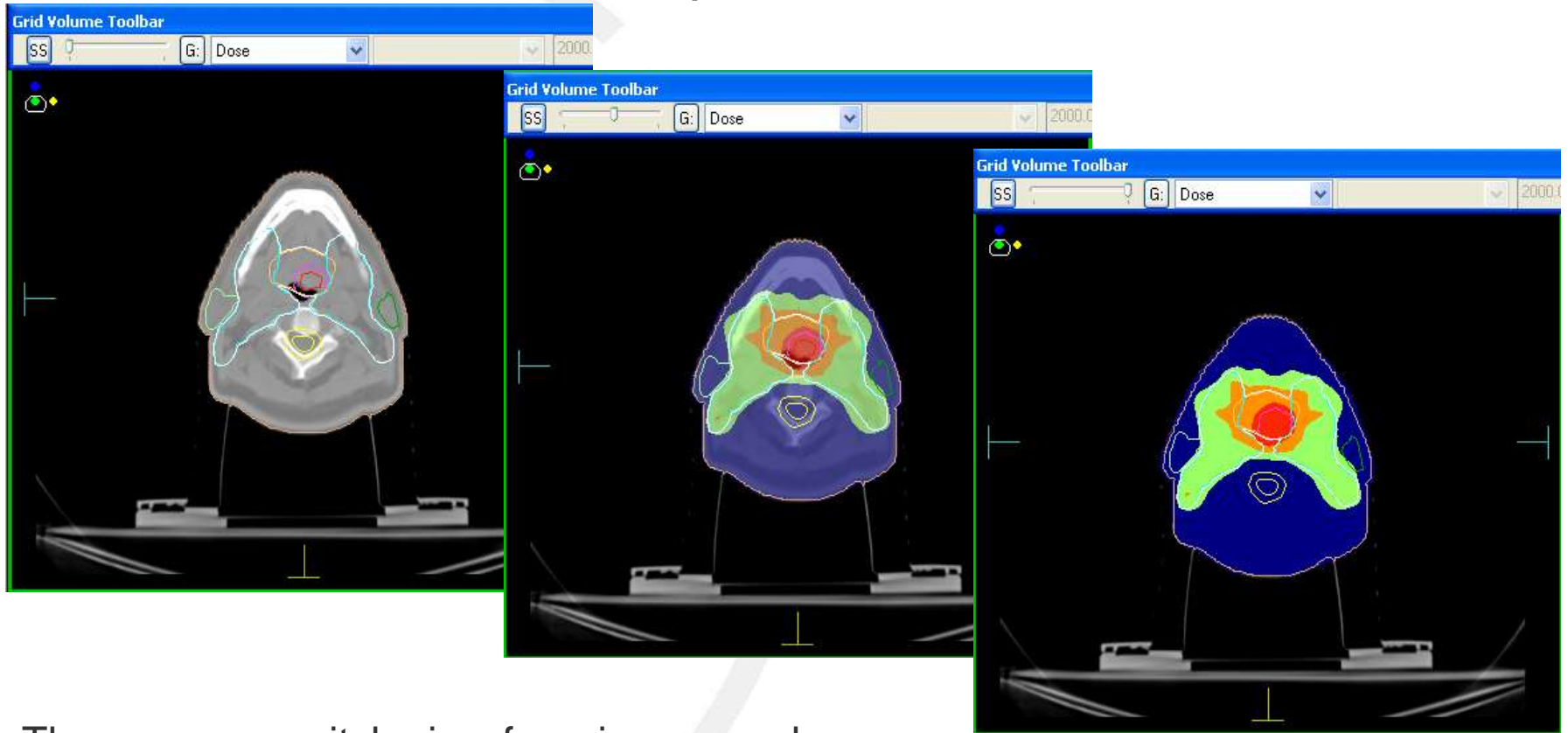
Smart Sequencing™

Monte Carlo Dose Algorithm

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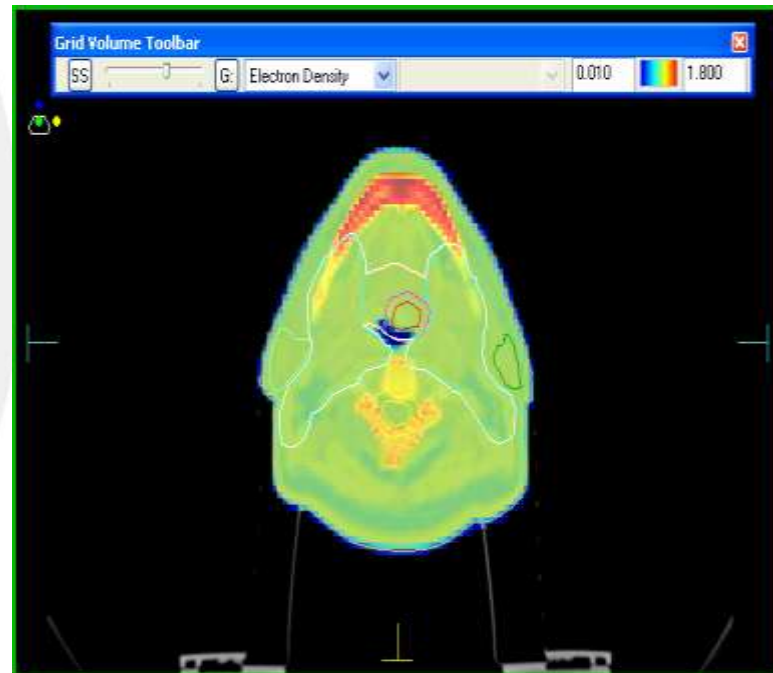
Voxel-based Structure Control: Volume ToolBar: Dose Option



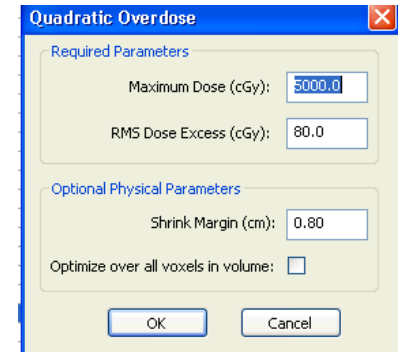
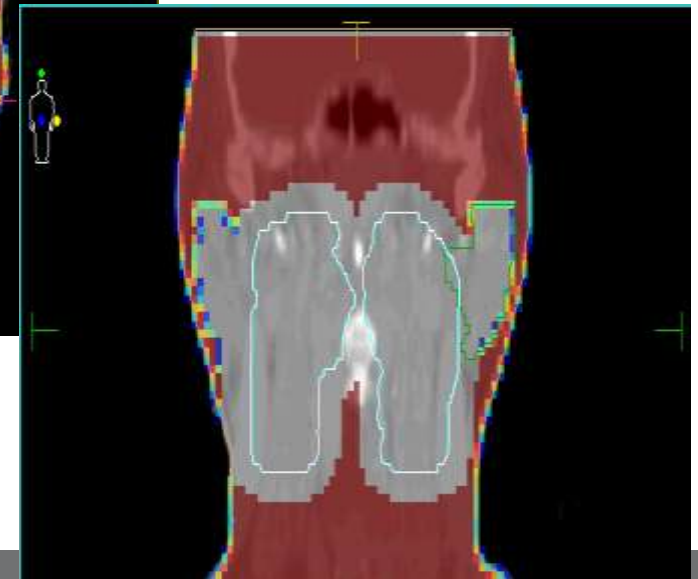
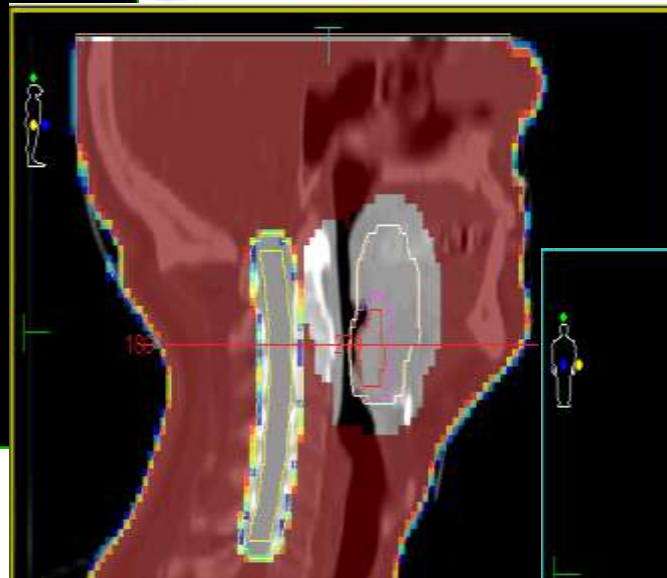
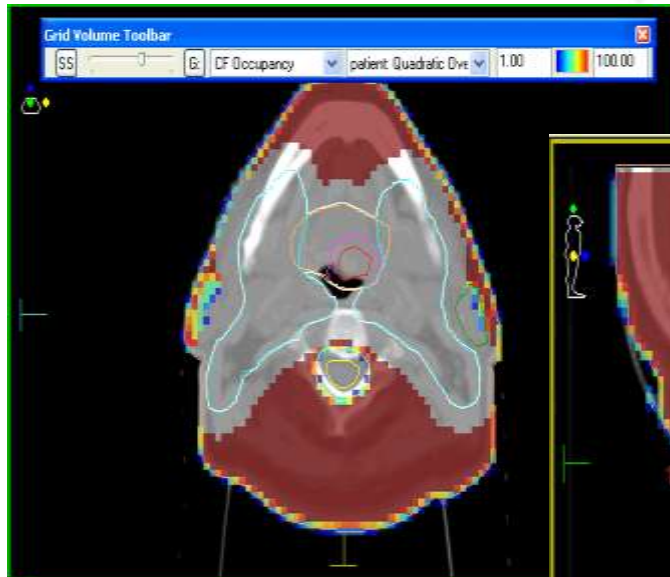
The user can switch view from images only and dose overlay with different intensities

Voxel-based Structure Control: Volume ToolBar: Dose Raw and Electron Density

The user can switch view to un-interpolated dose and full electron density according to pixel and user defined voxel



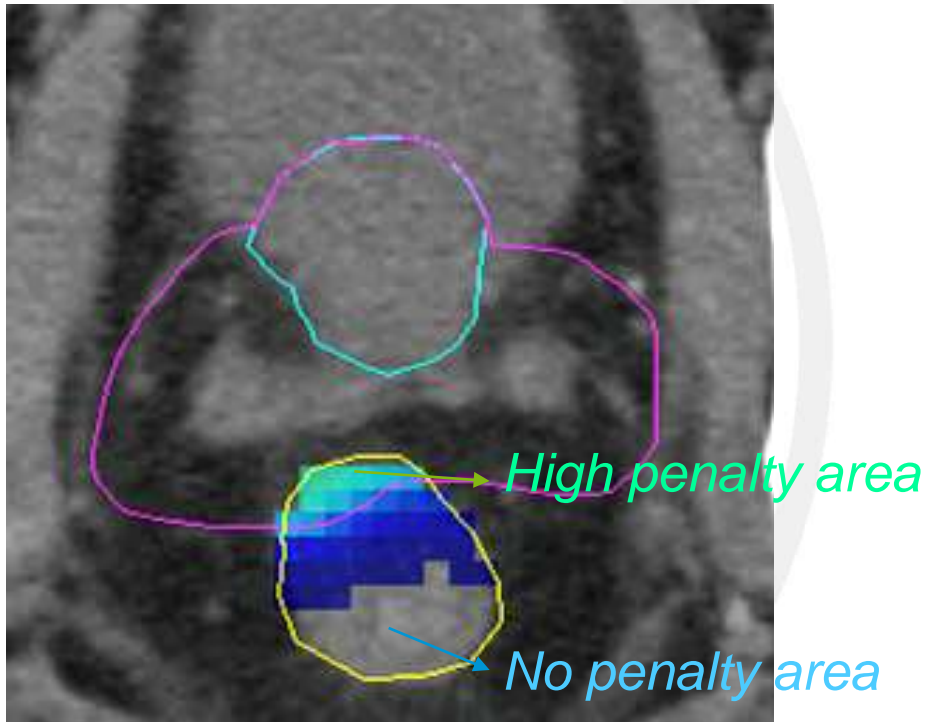
Voxel-based Structure Control: Volume ToolBar: Cost Function Occupancy



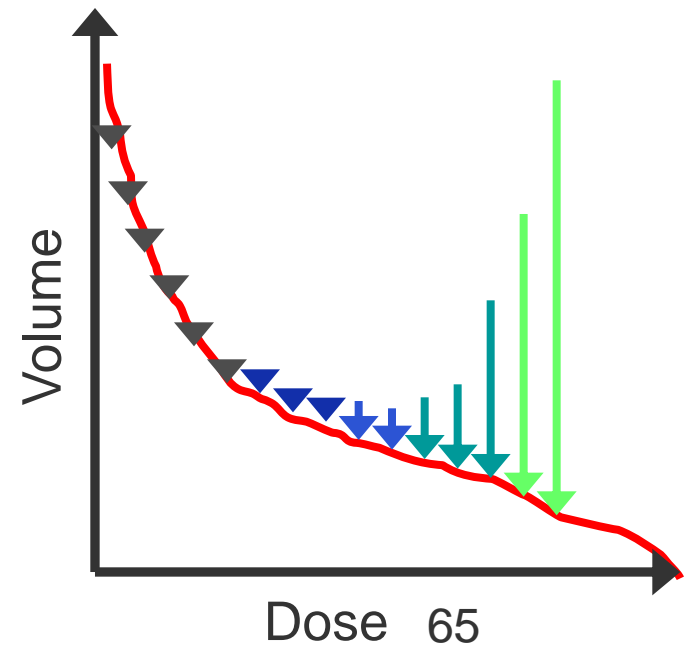
Displays which voxels are being used for a particular structure's cost function. Takes into account layering order, **shrink margin**, optimize over all voxels, clear etc

Voxel-based Structure Control: Volume ToolBar: Cost Function Variation

S: CF Variation rectum: Serial Complica

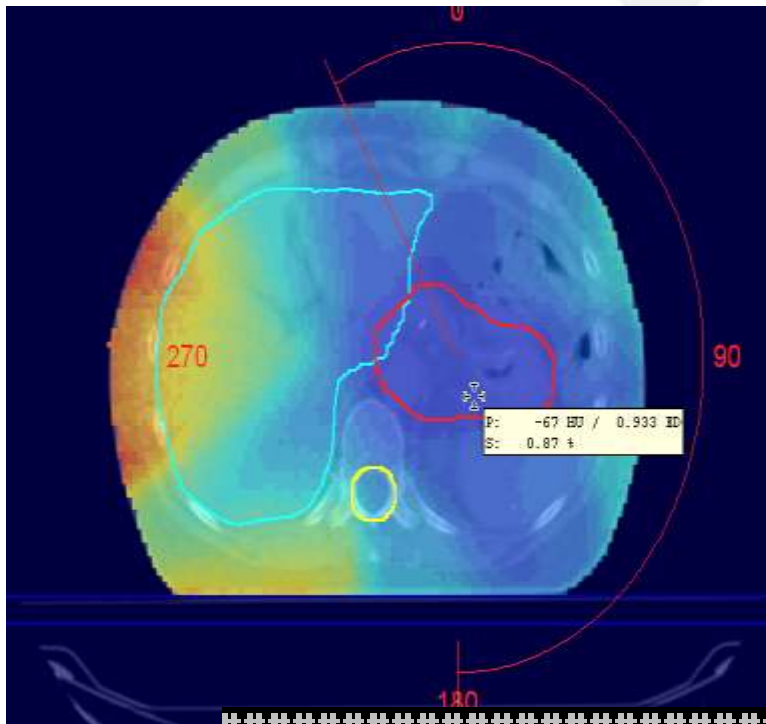
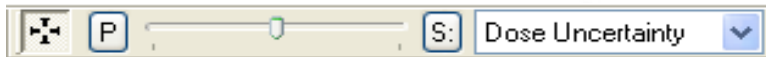


*Serial CF:
Maximum dose: 65 Gy*



Voxel-based Structure Control:

Volume ToolBar: Monte Carlo Dose Uncertainty



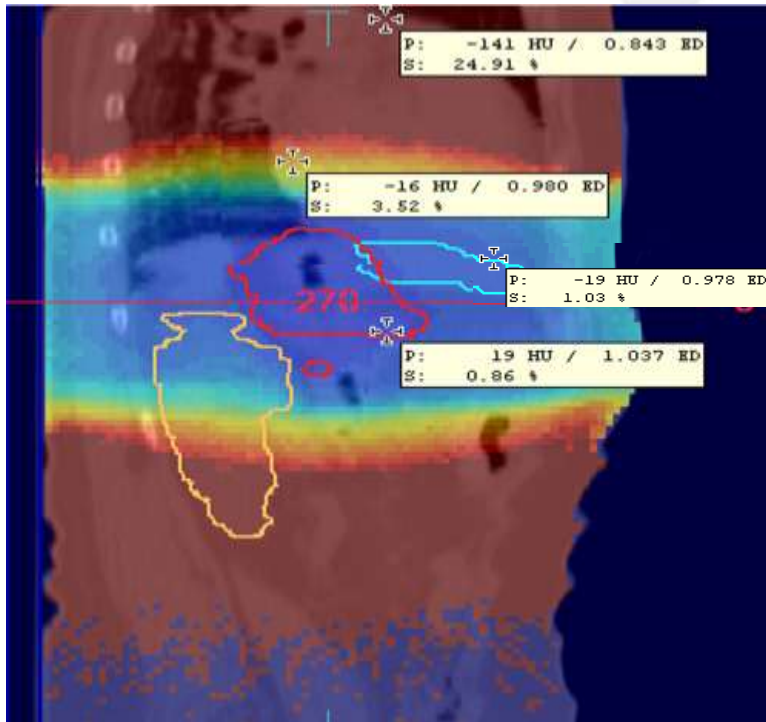
Displays the Dose uncertainty throughout the patient.

The Dose uncertainty of the target region will also be displayed in the console window during stage 2 optimization

```
#####  
# Current dose uncertainty of MC calculation: 0.9 per cent #  
#####
```

Voxel-based Structure Control:

Volume ToolBar: MC Dose Uncertainty



The Dose Uncertainty, specified by the user, is per segment. Therefore the uncertainty over the target will always be less

The peripheral uncertainty will increase as the doses become lower and more insignificant.

Voxel-based Structure Controls:

Minimum electron density fill

Automatic clearing of air voxels

Auto-flash margins

Surface Margin

Beamlet width

Target Margin

Avoidance Margin

IMRT Calculation Properties

Calculation Parameters

Grid Spacing (cm): 0.30

Monte Carlo Variance per Control Point (%): 5.00

Number of Fractions: 30

Prescription (cGy): 6600.0

Secondary Algorithm: Monte Carlo Photon

Global Parameters

Minimum Electron Density: Use with Fill option. 1.000

Minimum CT Number: Use with Clear option. -200

Auto Flash Margin (cm): 1.00

Surface Margin (cm): 0.30

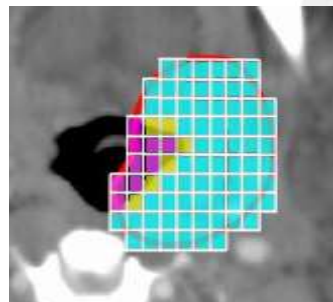
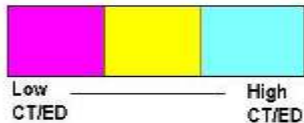
Beamlet Width (cm): 0.30

Target Margin: Normal

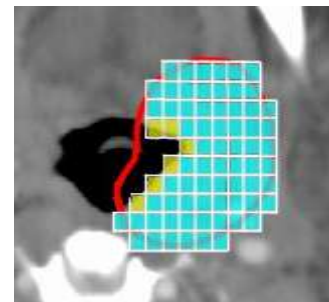
Avoidance Margin: Normal

OK Cancel

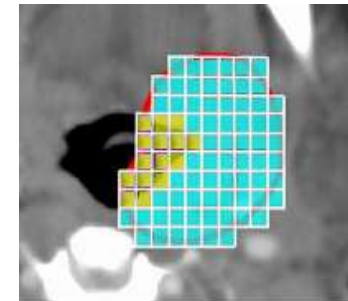
• Clear and Fill



Voxelized Structure



Application of Clear



Application of Fill

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5. Sensitivity Analysis
- 6. Smart Sequencing™**
7. Monte Carlo Dose Algorithm
8. VMAT
9. SRS Planning/Dynamic Conformal Arc

Smart Sequencing

Segmentation is integrated in the final optimization loop using XVMC Monte Carlo Dose calculations for each segment

Fluence smoothing

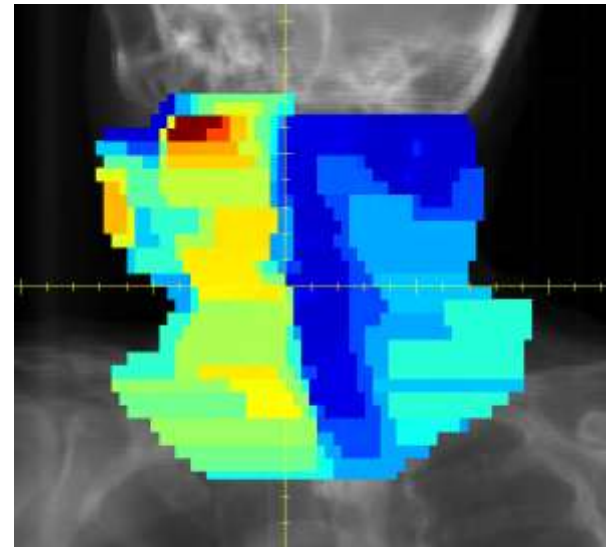
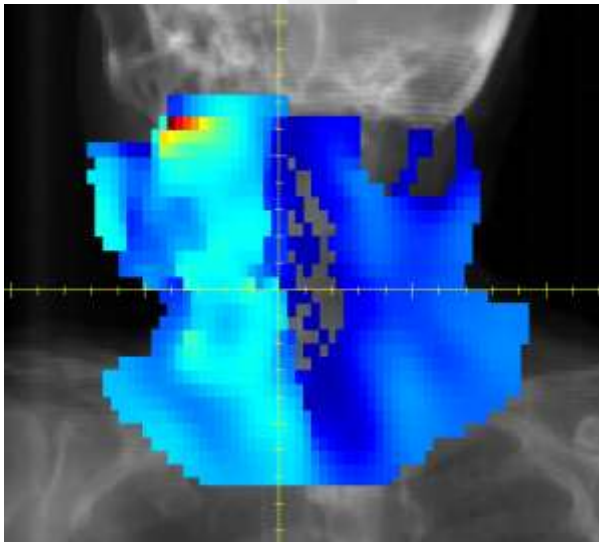
Shape optimization

Weight optimization

Minimum MU/segment

Minimum segment area (cm²)

Max. # Control Points/Arc

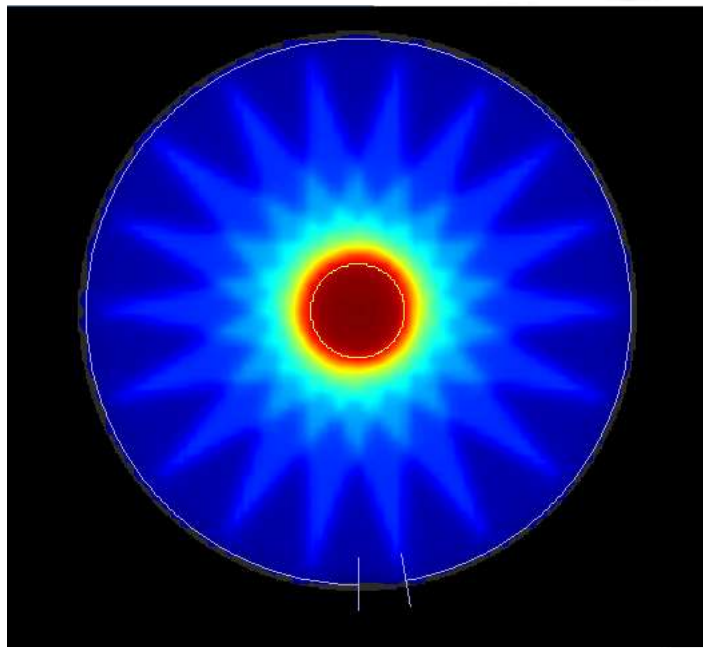


Unique Features

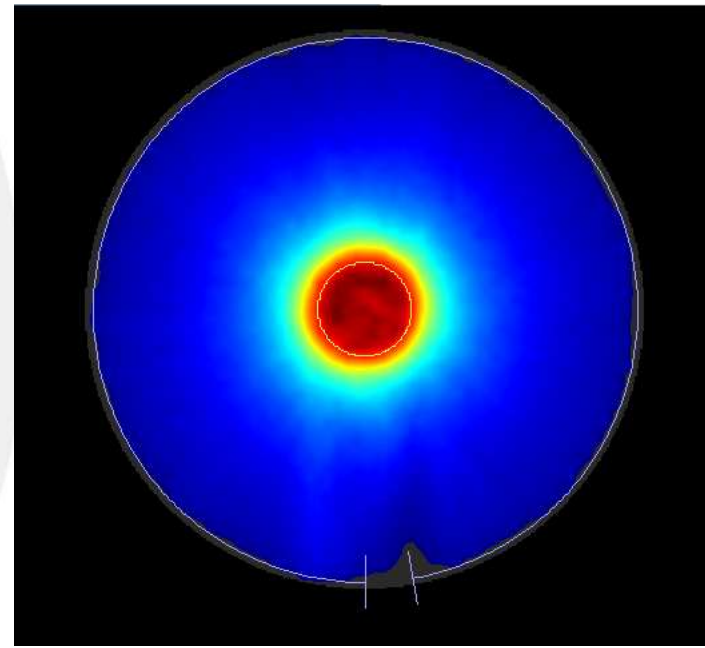
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Advantages of Monte Carlo in VMAT

No need to discretize arc into sub beams for dose calculation



Discretized Pencil Beam Arc

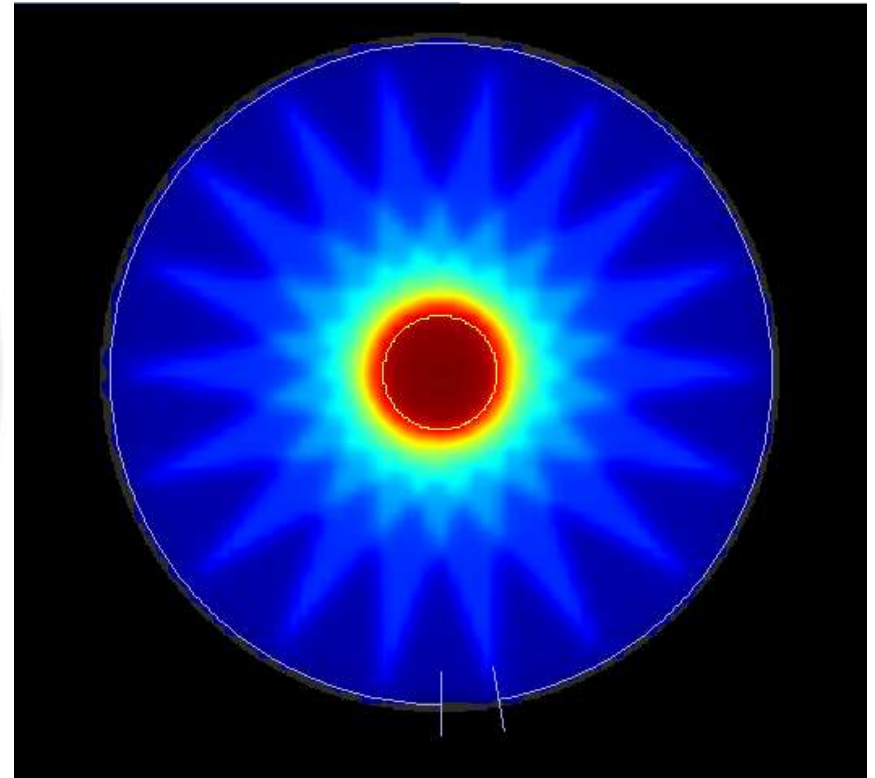


Continuous Monte Carlo Arc

Stage 2 Comparison

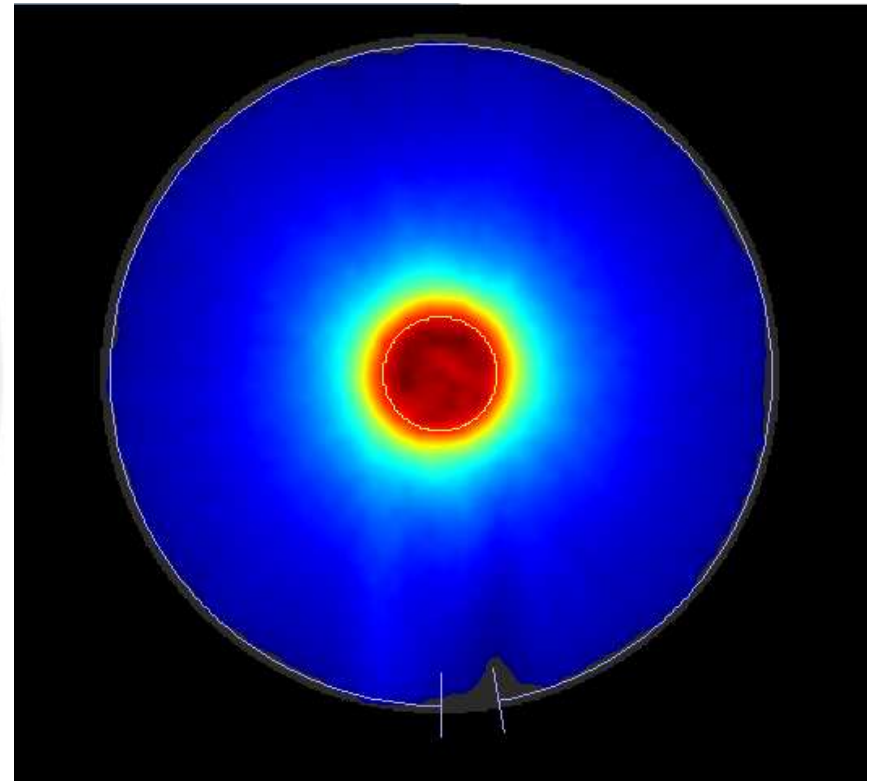
Advantages of Monte Carlo in VMAT

- Pencil Beam rays are calculated at each segment (CP) within the arc
 - Star pattern effect
 - Looks like a static gantry calculation, not reality
 - As overlap between PB rays decreases, information becomes less accurate
 - This type of calculation is similar to what other systems offer



Advantages of Monte Carlo in VMAT

- Monte Carlo calculations are done to mimic the gantry rotation around the patient
 - Every photon particle is simulated at a random gantry angle somewhere along the arc
 - Produces a smooth distribution of photon particles completely around the arc
 - Artifacts from discretized control points are smoothed out
 - MC is the only algorithm that performs the calculation in this



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VMAT Planning

- Single or Multiple Arc plans
- Specify: Collimator Angles, Gantry Start Angles, Couch Kicks, Arc Increments
- Ability to optimize multiple arcs simultaneously
- Creation of a multiple arc plan that can be treated with a single button push at the linac console
- MC dose engine allows for continuous arc calculation instead of being limited to dose approximations with discrete gantry positions

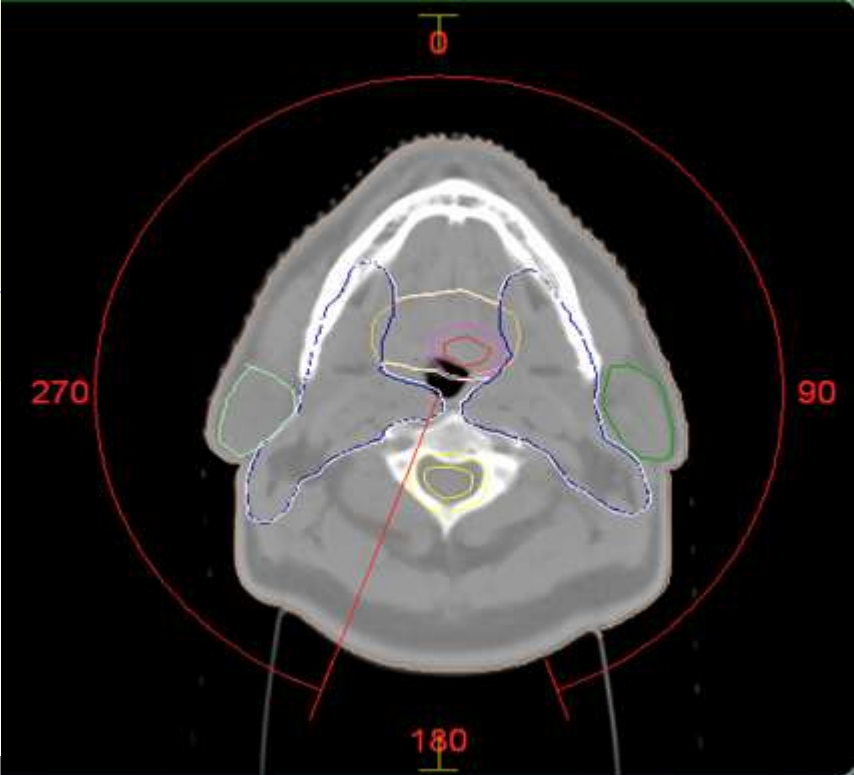
VMAT Planning: Example 2: Partial Arc 320°

Beam Setup

Delivery Mode: VMAT Machine: Elek06xMLC2wI Move All Beams With Same Isocenter

Be...	Description	Couch	Collima...	Gantry	Arc	Increment	Isocenter Location	Isocenter X (cm)	Isocenter Y (cm)	Isocenter Z (cm)
1	sequence1	0.0	0.0	200.0	320.0	20.0	Center of combo	0.34	-73.85	0.19

<click to add a new row>



OK Cancel Apply

VMAT Planning: Example 1: Single Arc Setup 360°

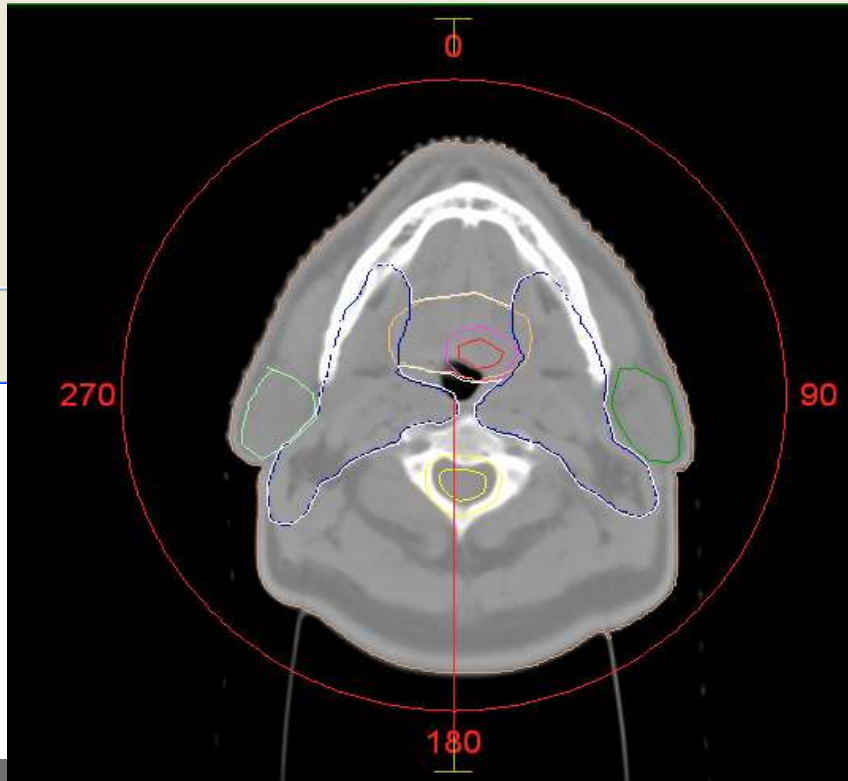
Beam Setup

Delivery Mode: **VMAT** Machine: **Elek06xMLC2wI** Move All Beams With Same Isocenter

Be...	Description	Couch	Collima...	Gantry	Arc	Increment	Isocenter Location	Isocenter X (cm)	Isocenter Y (cm)	Isocenter Z (cm)
1	sequence1	0.0	0.0	180.0	360.0	30.0	Center of combo	0.34	-73.85	0.19

<click to add a new row>

OK Cancel Apply



VMAT Planning: Example 3: Two Arcs with different Isocenters

Beam Setup

Delivery Mode: VMAT Machine: Elek06xMLC2wI Move All Beams With Same Isocenter

Be...	Description	Couch	Collima...	Gantry	Arc	Increment	Isocenter Location	Isocenter X (cm)	Isocenter Y (cm)	Isocenter Z (cm)
1	sequence1	0.0	0.0	200.0	320.0	20.0	Center of combo	0.34	-73.85	0.19
-1	sequence1	0.0	0.0	199.0	320.0	20.0	Center of ptv4	-3.13	-73.85	0.22

<click to add a new row>

OK Cancel Apply

VMAT: Sequencing

The image displays the Monaco VMAT software interface for a prostate treatment plan. The main window shows a cross-sectional view of the prostate with a color-coded dose distribution. A legend on the left lists target and organ-at-risk (OAR) structures: GTV, PTV1, BLADDER, RECTUM, FEMORAL HEAD, and URETHRA. The dose is set to 76.600 Gy. An 'Optimized DVH' graph on the right shows the volume percentage versus dose for various structures. A Windows Task Manager window is overlaid, showing system performance metrics: CPU Usage at 100%, PF Usage at 1.87 GB, and various memory statistics. The Monaco console at the bottom shows the status of the dose simulation.

Monaco - [monPROSTATE, Bond, James, CT, DEMOvmat0:2]

File Activities View Dose Calculation Tools DVH Reports Help

Norm: Absolute 76.600 Gy 100.0 %

Sequence 1 Angle 180 Segment End MU 0.00 0.00 7.57

Legend:

- GTV
- PTV1
- BLADDER
- RECTUM
- FEMORAL HEAD
- URETHRA

All Off

1 SEQ1

All On All Off

Dose (Gy):

Dose (Gy)	2D	3D
76.600	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
68.940	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
61.280	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
53.620	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
45.960	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
38.300	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
30.640	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
22.980	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
15.320	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
7.660	<input type="checkbox"/>	<input type="checkbox"/>

All 2D On All 3D On

Windows Task Manager

Applications Processes Performance Networking

CPU Usage: 100 %

PF Usage: 1.87 GB

Totals:

Handles	11994	Physical Memory (K)	Total	16774828
Threads	751	Available	15499528	
Processes	47	System Cache	2528900	

Commit Charge (K):

Total	1969440	Kernel Memory (K)	Total	145244
Limit	32928536	Paged	81180	
Peak	2252628	Nonpaged	64064	

Processes: 47 CPU Usage: 100% Commit Charge: 1923M / 32156M

Monaco - [monPROSTATE, Bond, James, CT, DEMOvmat0]

Dose simulation with a total of 3540000 histories in 8 threads.
Dose simulation with a total of 3540000 histories in 8 threads.
Dose simulation with a total of 3600000 histories in 8 threads.
Dose simulation with a total of 3660000 histories in 8 threads.

Monaco 3.0 – Varian VMAT

Varian VMAT Arc Info

- User can decrease the total number of arcs by increasing the Target Dose Rate (up to maximum) prior to stage 2 optimization.
- At the beginning of stage 2, the console will indicate the number of arcs used.
- Varian arcs are automatically sorted and split upon DICOM export.
- User should reduce the parameter **Max # Control Points / Arc** accordingly for Varian VMAT plans.

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SRS Planning/Dynamic Conformal Arc



- Stereotactic planning with dynamic conformal arcs and Apex mMLC
- Support for multiple isocenters
- Frame based stereotactic localization using Ergo++ Localizer module

Monaco: The Next Generation in IMRT Planning

- Monaco as **dedicated IMRT/VMAT** system
- Meaningful way of prescribing using **Biological cost functions**
- **Optimization**
 - Changes applicable during optimization
 - Constrained optimization
 - Evaluation tools (impact factor, sensitivity analysis)
- **No final “Recalculation”**
 - optimization of segment shape and weight
 - Monte Carlo Simulations during optimization



Muchas gracias!