Volumetric Modulated Arc Therapy (VMAT): The future of IMRT?

Daliang Cao

Swedish Cancer Institute, Seattle, Washington, USA

SWEDISH

Acknowledgements

- David M. Shepard
- Matthew Earl
- Timothy Holmes
- Muhammad Afghan
- Cedric Yu
- Shuang Luan

SWEDISH

History of VMAT

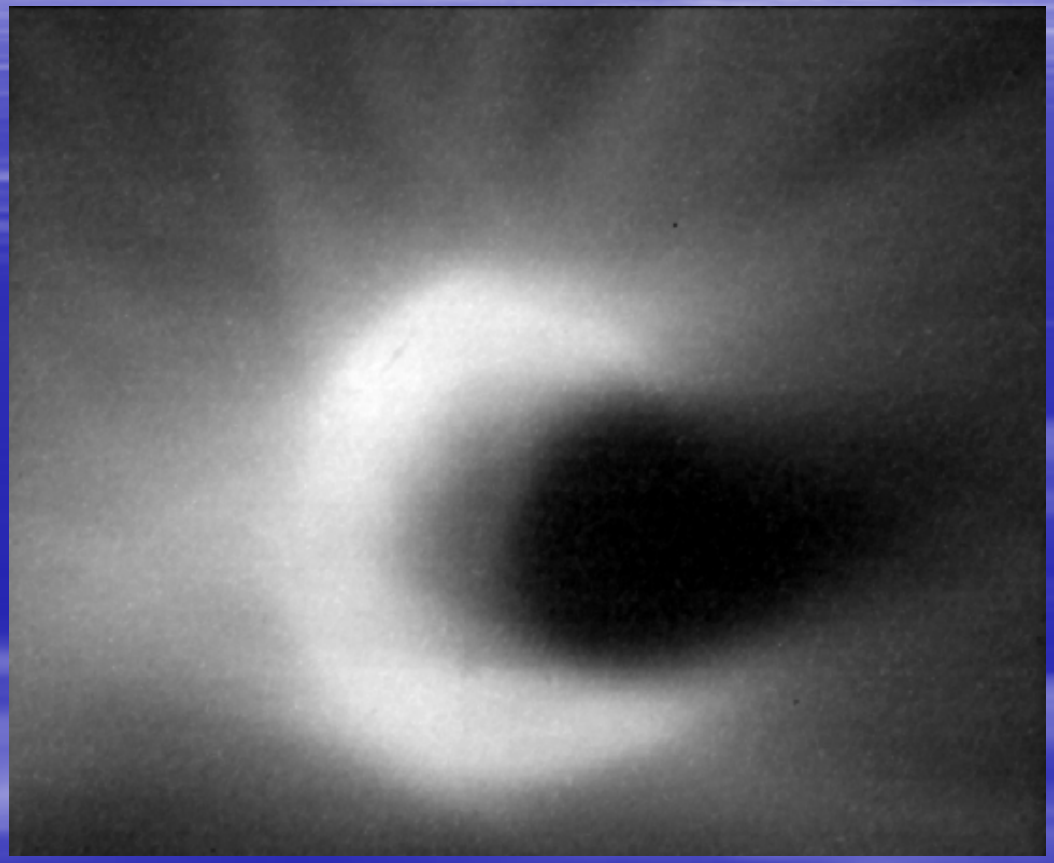
Intensity-modulated arc therapy with dynamic multileaf collimation: an alternative to tomotherapy

C X Yu 1995 *Phys. Med. Biol.* **40** 1435-1449 doi:10.1088/0031-9155/40/9/004

- VMAT, formally known as Intensity Modulated Arc Therapy (IMAT), was first brought up by Dr. Cedric Yu in 1995.

SWEDISH

IMAT (1)



- 1995- Initial paper described the delivery technique and demonstrated feasibility.

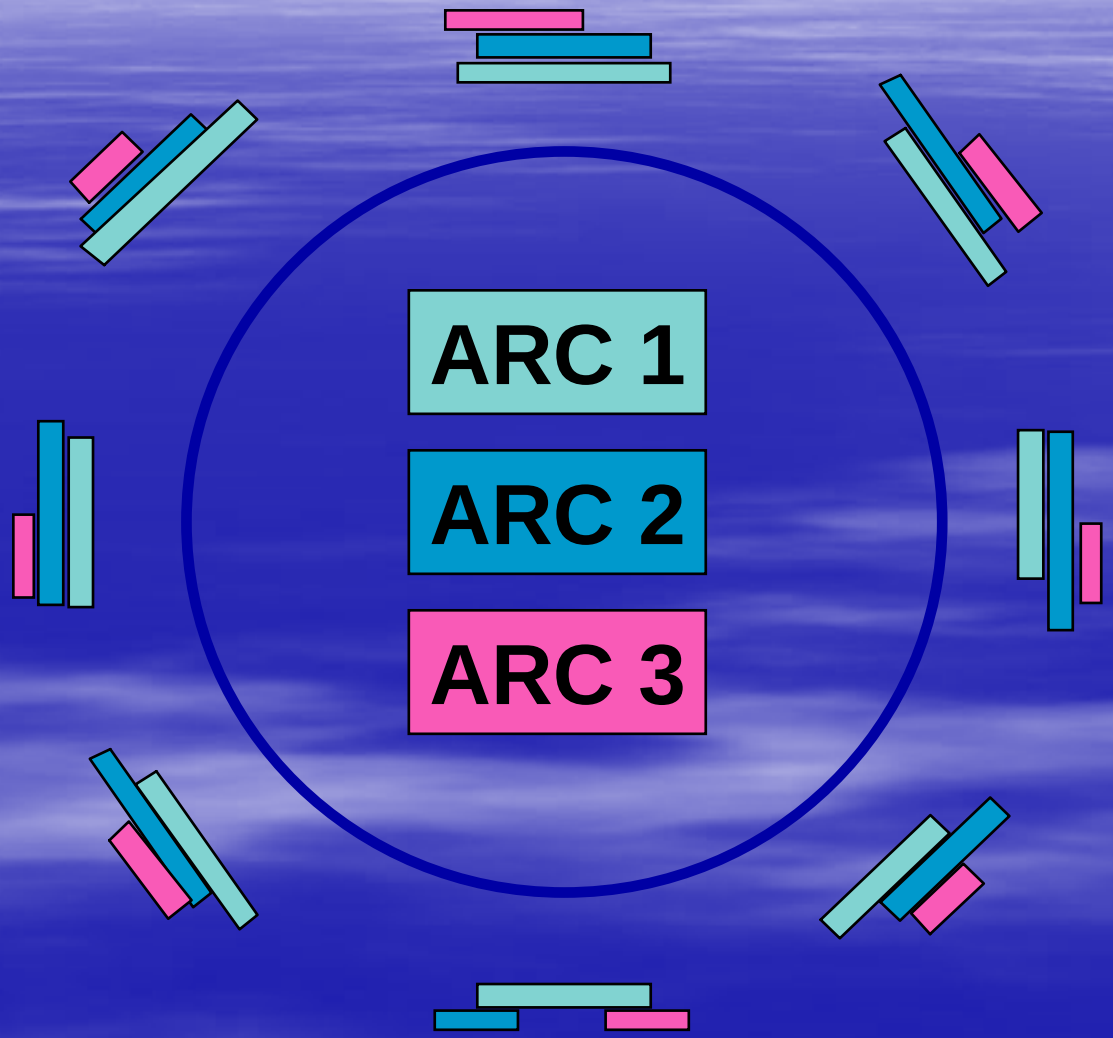
SWEDISH

Basics of IMAT

- IMAT is a rotational IMRT that can delivered using conventional linear accelerators with conventional MLC.
- Radiation is on while gantry is rotating with MLC leaves moving continuously.
- Intensity modulation is created by overlapping arcs.

SWEDISH

IMAT Delivery



SWEDISH

From Cedric Yu

Benefit of Rotational IMRT

Number of Beam Directions	Objective Function Value	Standard Deviation In The Target Dose	Minimum Dose Covering 90% of the Target (1.0 = Max)	Mean Dose To the Region At Risk	Total Integral Dose
3	0.665	0.124	0.747	0.488	2733
5	0.318	0.090	0.814	0.215	2564
7	0.242	0.064	0.867	0.206	2597
9	0.222	0.064	0.855	0.192	2599
11	0.202	0.058	0.879	0.186	2570
15	0.187	0.053	0.908	0.180	2542
21	0.176	0.049	0.912	0.171	2545
33	0.151	0.038	0.933	0.155	2544

Improvement found by increasing the number of beam angles

Independent of the number of beam angles

SWEDISH

D.M. Shepard, et al, *Medical Physics*, 26 pp. 1212 (1999); T.R. Mackie, et al, *Intensity Modulated Radiation Therapy – The State of the Art*, pp. 247 (2003)

IMAT – Dynamic Conformal Arcs

Clinical Trial

- In 2000, a Phase I clinical trial was conducted at the University of Maryland.
- Plans were created using forward planning.
- Arcs were approximated as multiple shaped fields spaced every 5 to 10º.
- Both coplanar and non-coplanar arcs were considered and wedge filters were incorporated in selected plans.

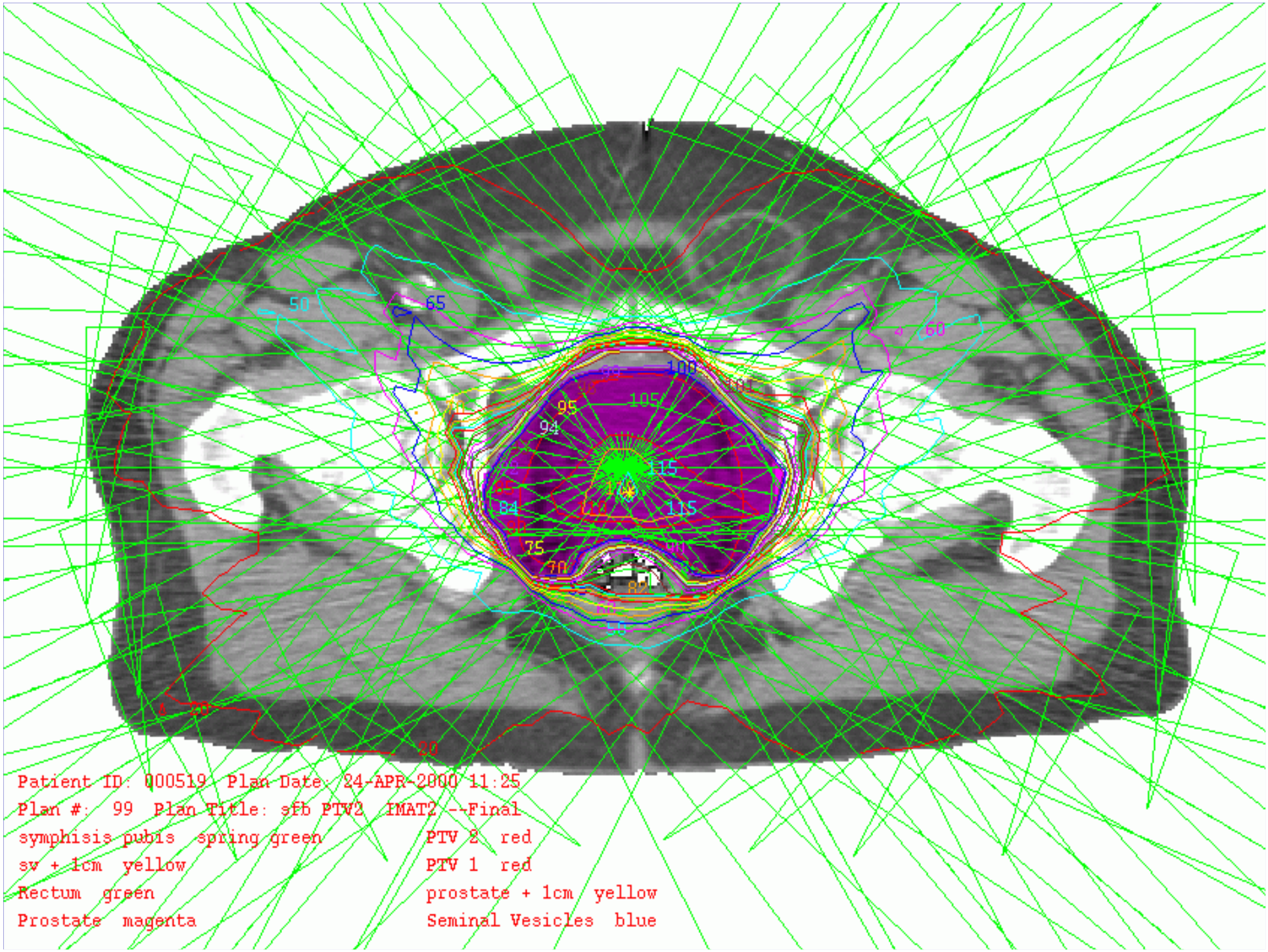
SWEDISH

IMAT – Dynamic Conformal Arcs

Example 1: Prostate

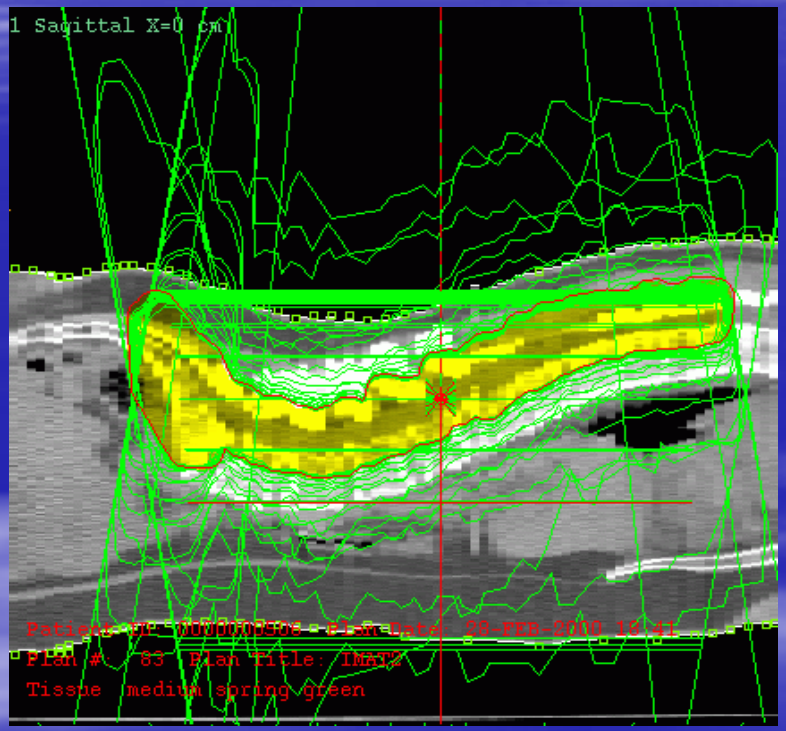
- Two sets of bilateral arcs.
- 1 set of arcs matches BEV of PTV.
- 1 matches BEV of PTV minus rectum.
- The weights of the arcs are optimized.

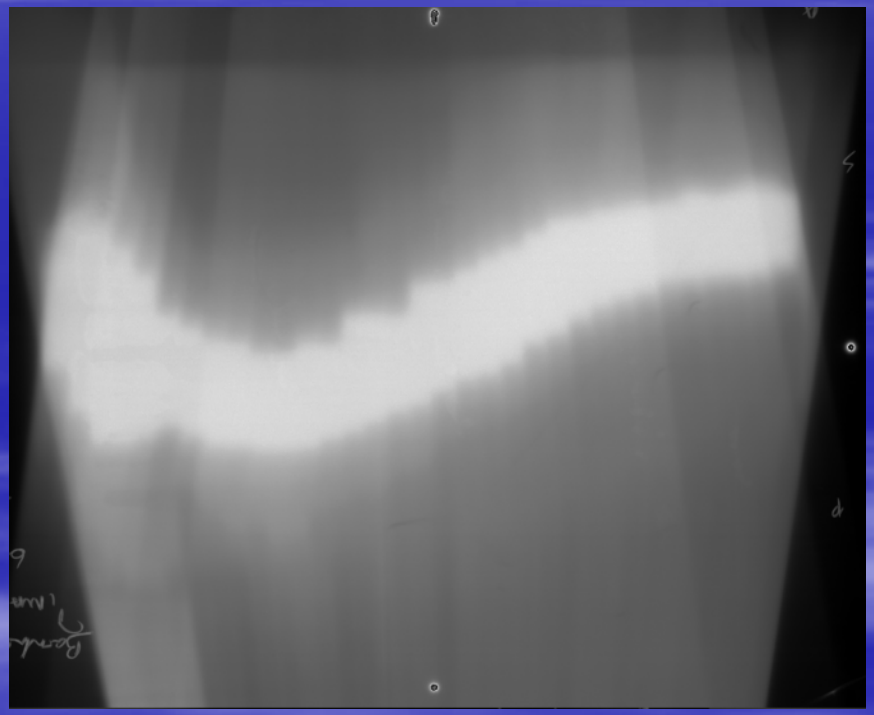
SWEDISH


50
65
60
100
105
95
94
115
115
84
75
70
80
20
20
Patient ID: 000519 Plan Date: 24-APR-2000 11:25
Plan #: 99 Plan Title: stb PTV2 IMAT2 --Final
symphisis pubis spring green
sv + 1cm yellow
Rectum green
Prostate magenta
PTV 2 red
PTV 1 red
prostate + 1cm yellow
Seminal Vesicles blue

IMAT – Dynamic Conformal Arcs

Example 2: Spinal Ependymoma





SWEDISH

5-arc treatment

IMAT – Dynamic Conformal Arcs

Initial Experience

- 50 patients were treated in this trial: central nervous system (17 patients), head and neck (25 patients) and prostate (8 patients).
- Results demonstrate that IMAT can be delivered safely and efficiently on a general-purpose linear accelerator.
- Average treatment time was 7.5 minutes.

SWEDISH

IMAT-Dynamic Conformal Arcs

Commercial Solutions

- Multiple vendors offer solutions for planning and delivering dynamic conformal arcs.
- Elekta offers this capability with the 3DLine mMLC and Ergo++ treatment planning.

SWEDISH

IMAT – Current Status

- IMAT has largely withered on the vine due to a lack of appropriate delivery control systems and a lack of robust inverse planning tools.

- Good News: Linear accelerator and treatment planning vendors are currently addressing these needs and we will soon be able to realize the full potential of IMAT.

SWEDISH

New Developments in IMAT

SWEDISH

IMAT to VMAT – New Developments

Delivery Control Systems

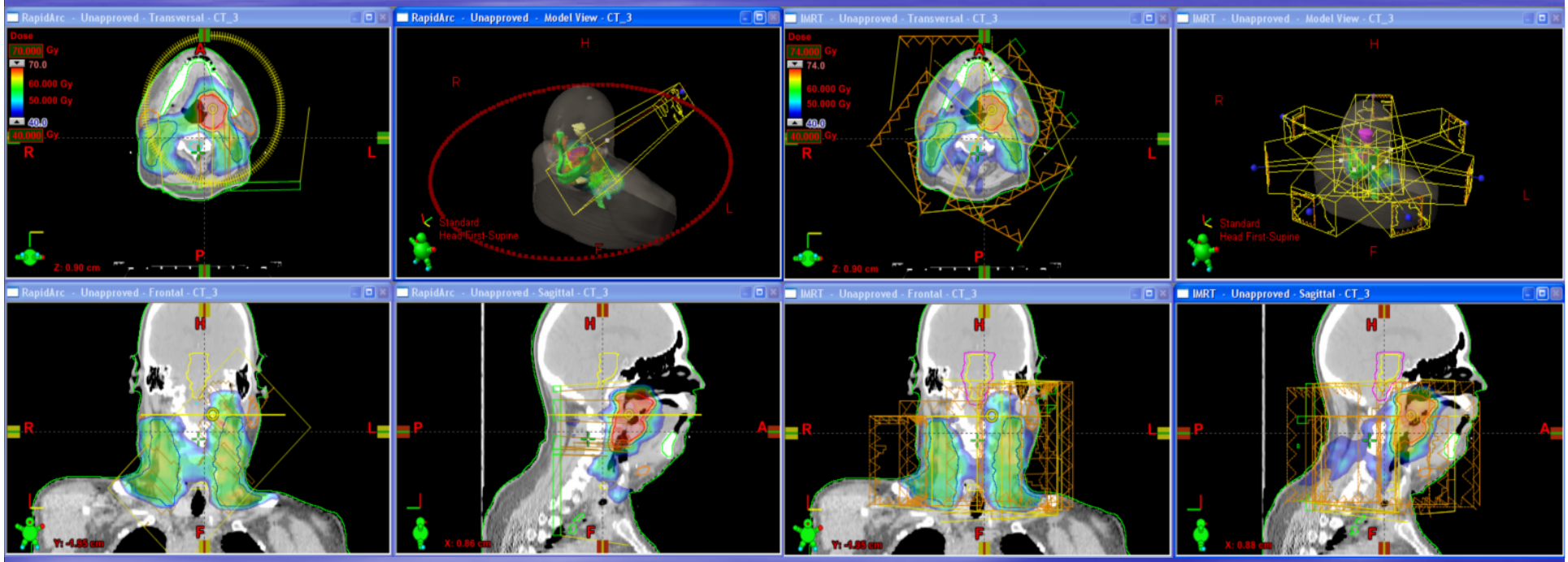
- Elekta and Varian have introduced new linac control systems that will be able to change the MLC leaf positions and dose rate while the gantry is rotating.
- Elekta → PreciseBeam Infinity®
- Varian → RapidArc®
- Both are using the term Volumetric Modulated Arc Therapy (VMAT).

SWEDISH

RapidArc always uses single arc to deliver treatment

SWEDISH

RapidArc™ vs. "Conventional" IMRT



RapidArc
Single-Arc plan

496 MU

Conventional
7-field IMRT

1685 MU

SWEDISH

Courtesy of Dave Mellenberg

Elekta announces Elekta Infinity – a new System for Faster, more precise Treatment of Cancer Tumors

Stockholm, Sweden, October 29, 2007

Elekta, a global leader in radiation oncology and non-invasive neurosurgery solutions, announced Elekta Infinity*, the definitive new digital linear accelerator optimized for delivering Volumetric Intensity Modulated Arc Therapy* (VMAT), a very fast Intensity Modulated Radiation Therapy (IMRT) treatment delivered in single or multiple arcs, at the 49th Annual Meeting of The American Society for Therapeutic Radiology and Oncology (ASTRO). The meeting is being held October 28-November 1, at the Los Angeles Convention Center.

In the Elekta booth, Jay Hoey, Executive Vice President Product Creation at Elekta and CEO of IMPAC Medical Systems, announced the new Elekta Infinity, which more precisely targets tumors and protects surrounding healthy tissue, while drastically reducing radiation therapy treatment times.

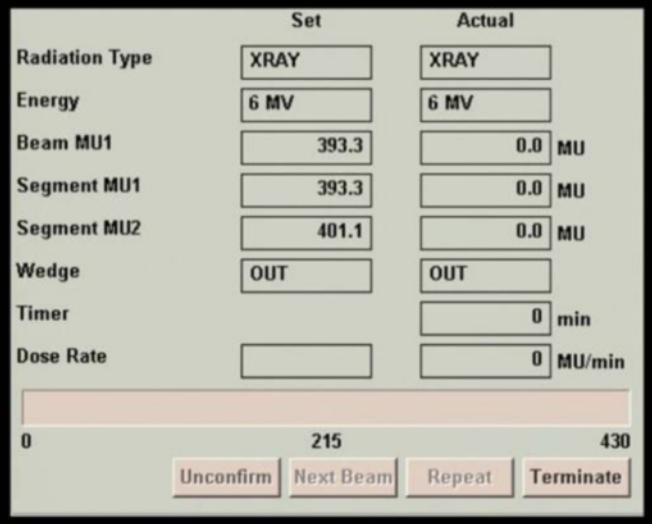
The foundations of infinite possibility

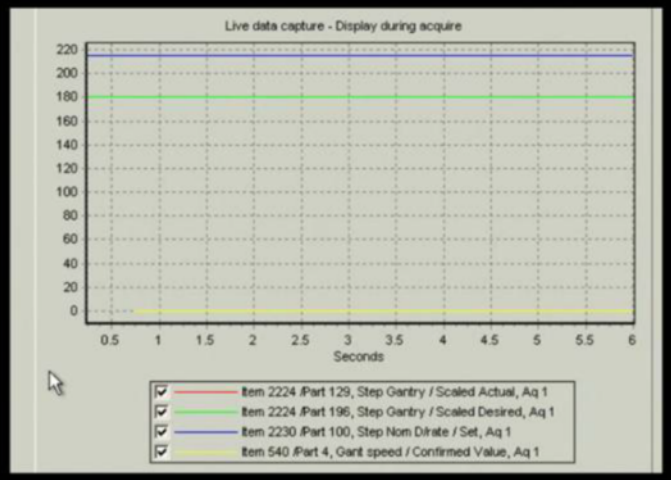
ELEKTA

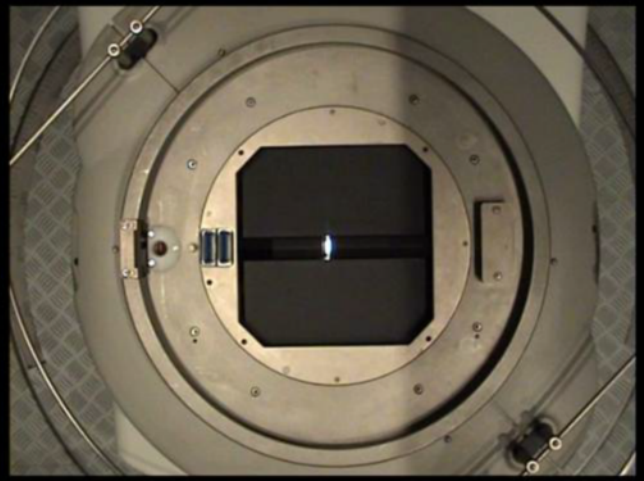
SWEDISH

Elekta VMAT can be delivered using single or multiple arcs

Elekta: VMAT







SWEDISH

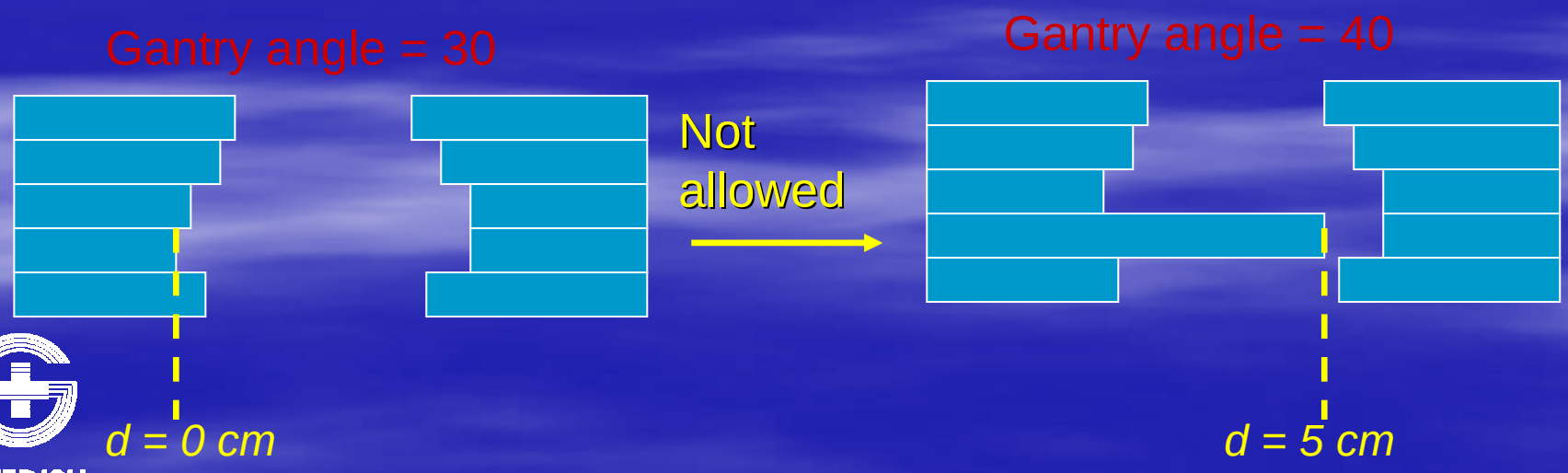
VMAT – Inverse Planning

- The complex nature of VMAT treatment planning has been a primary barrier to routine clinical implementation.
- From one angle to the next in each VMAT arc, one must account for the interconnectedness of the beam shapes.

SWEDISH

Interconnectedness of Adjacent Beam Shapes

- Leaf motion between adjacent angles is limited by leaf travel speed and gantry rotation speed.
- For example, if the gantry speed is 10 degree/sec and the leaf travel speed is 3 cm/sec, then the maximum leaf travel distance between two adjacent angles is 3 cm.



SWEDISH

VMAT – Arc Sequencing

- We have developed an “arc-sequencing” algorithm that translates optimized intensity maps into deliverable VMAT arcs.
- The key feature is that the VMAT delivery constraints are included in the arc-sequencing.
- Highly conformal dose distributions can be achieved with limited number of arcs.

SWEDISH

How do we create VMAT plans?

- A step-and-shoot treatment plan is created is created in the Pinnacle^3 treatment planning system with beams separated by 10 degrees.
- The optimized intensity maps are extracted and sent to our arc-sequencing algorithm.
- The sequencer produces a VMAT plan that is read back into Pinnacle^3 for a final convolution/superposition dose calculation.

SWEDISH

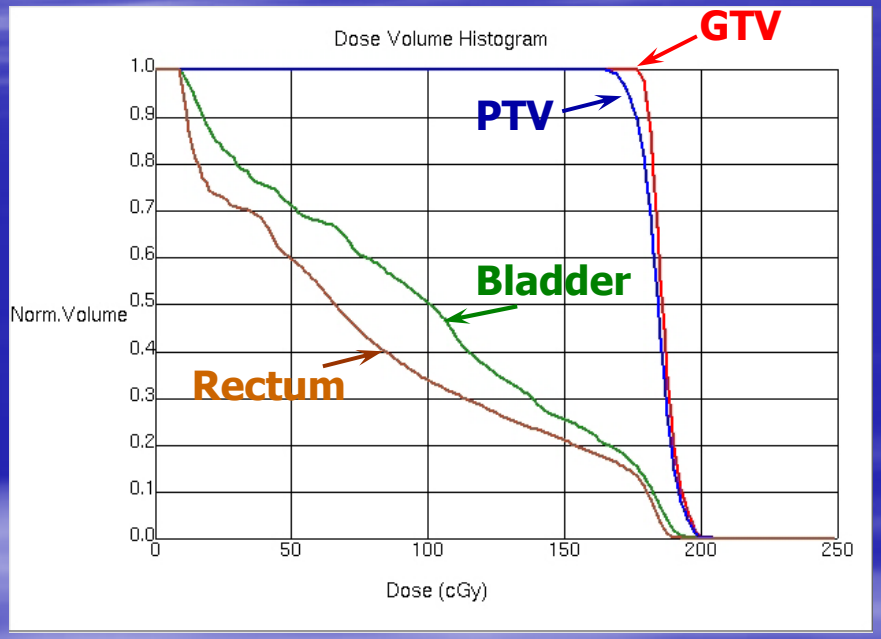
Arc Sequencer – Details

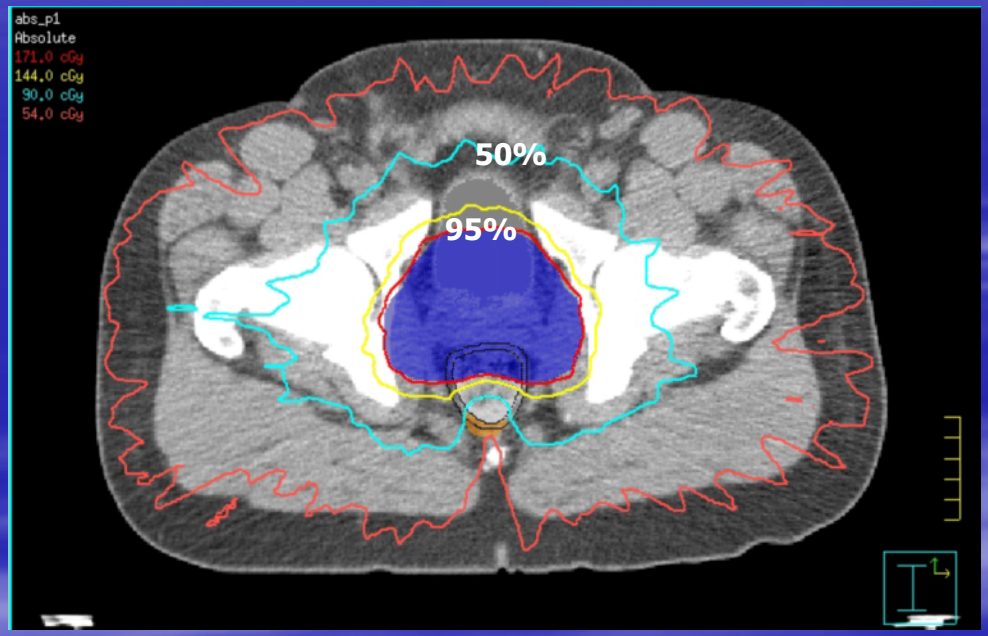
- The algorithm uses a simulated annealing based optimization and minimizes the discrepancy between the optimized and sequenced intensity maps.

- The algorithm iteratively changes the leaf positions and aperture weights and rejects any change that violates an VMAT delivery constraint.

SWEDISH

A prostate case

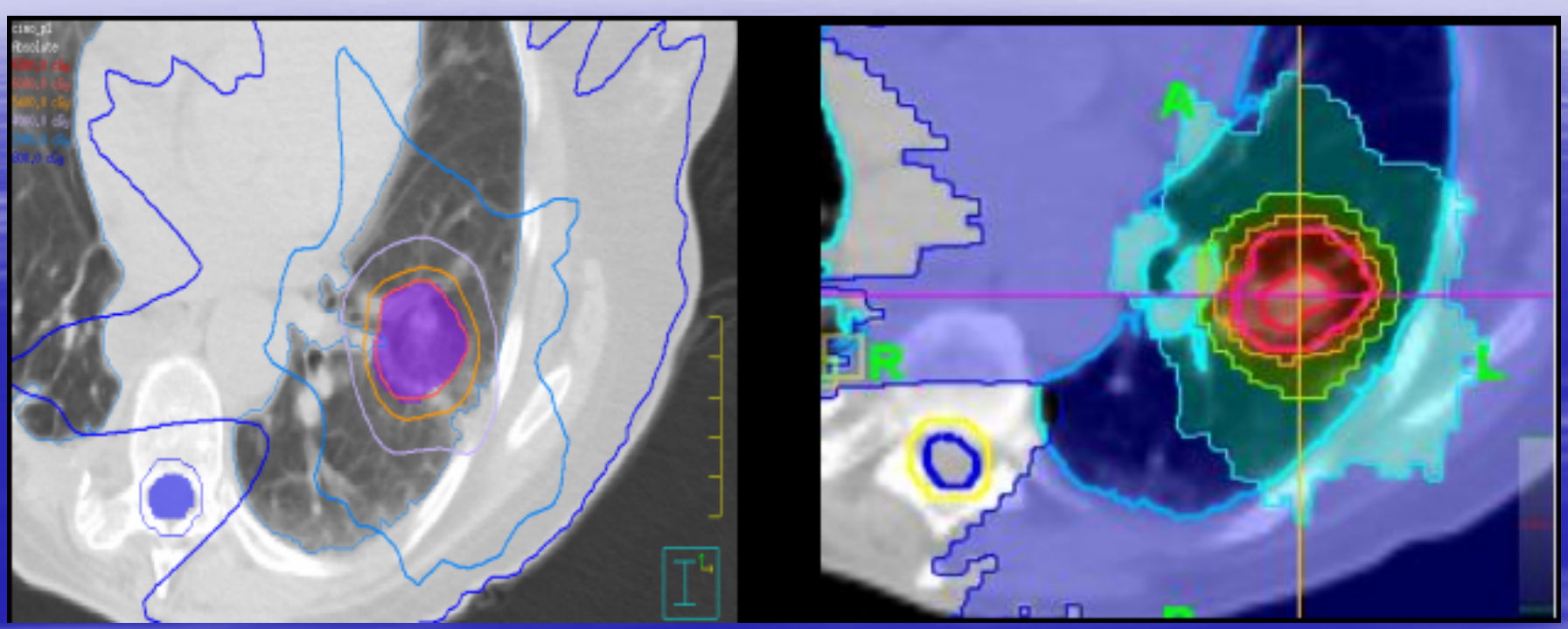




A 4-arc VMAT plan

SWEDISH

A lung case

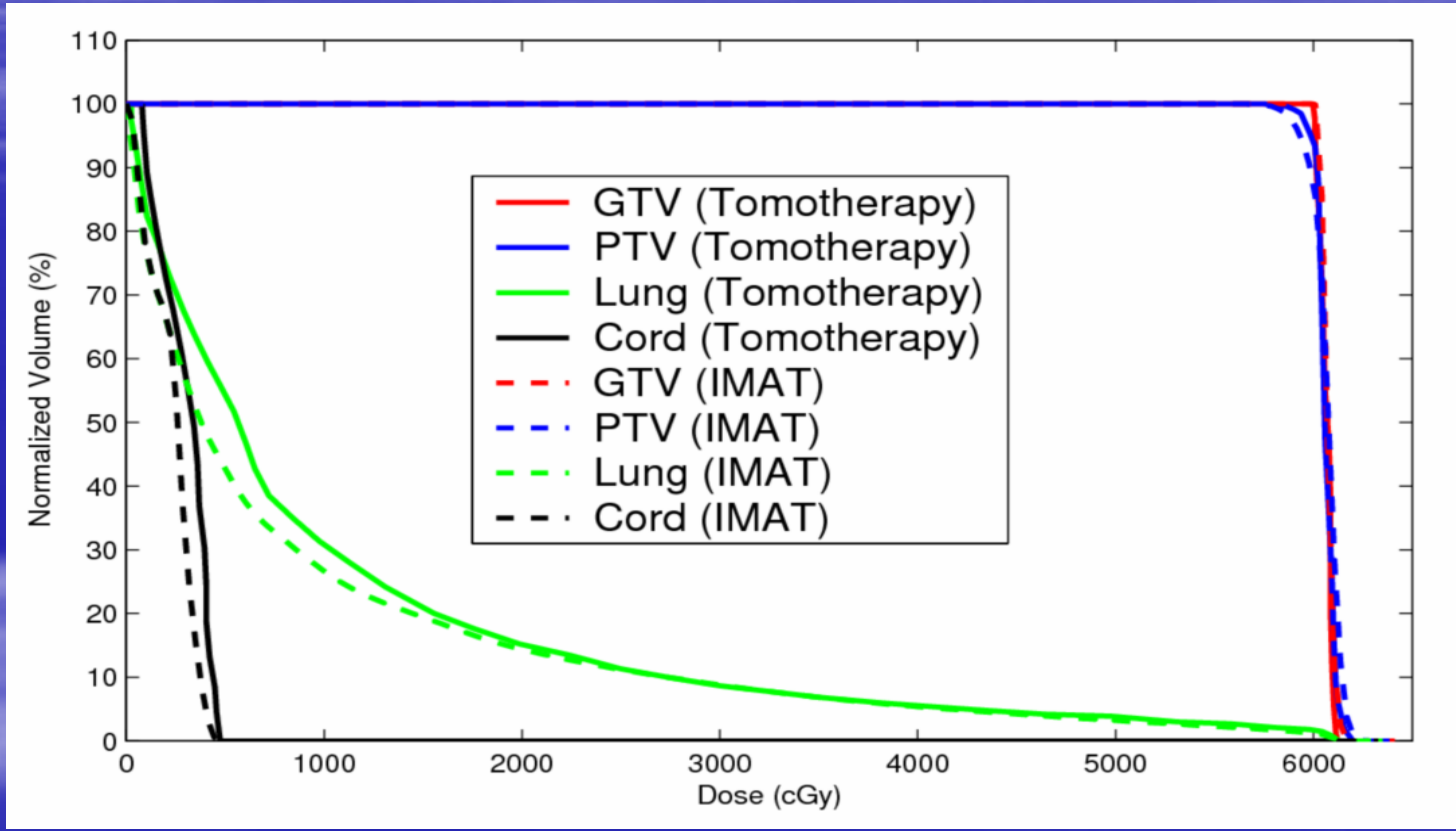


4-arc IMAT plan **Helical tomotherapy plan**

The isodose plot on a same axial slice suggests very similar dose distributions for both VMAT and tomotherapy plans.

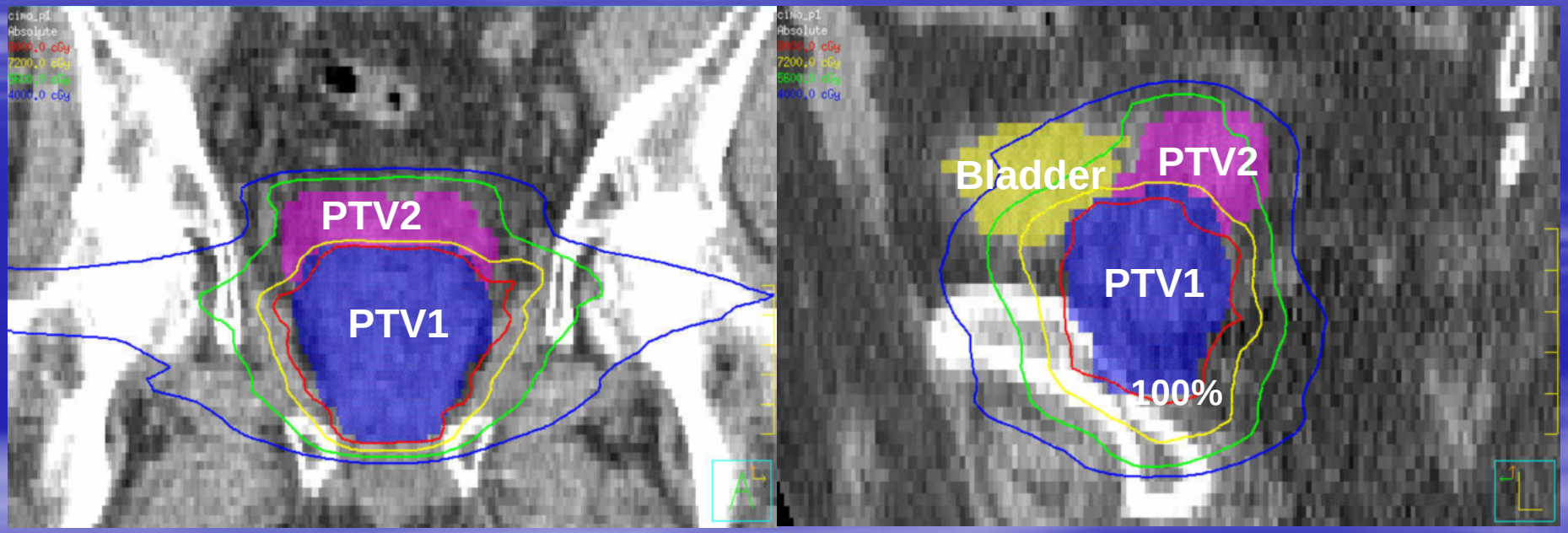
SWEDISH

DVH comparisons for the lung case



SWEDISH

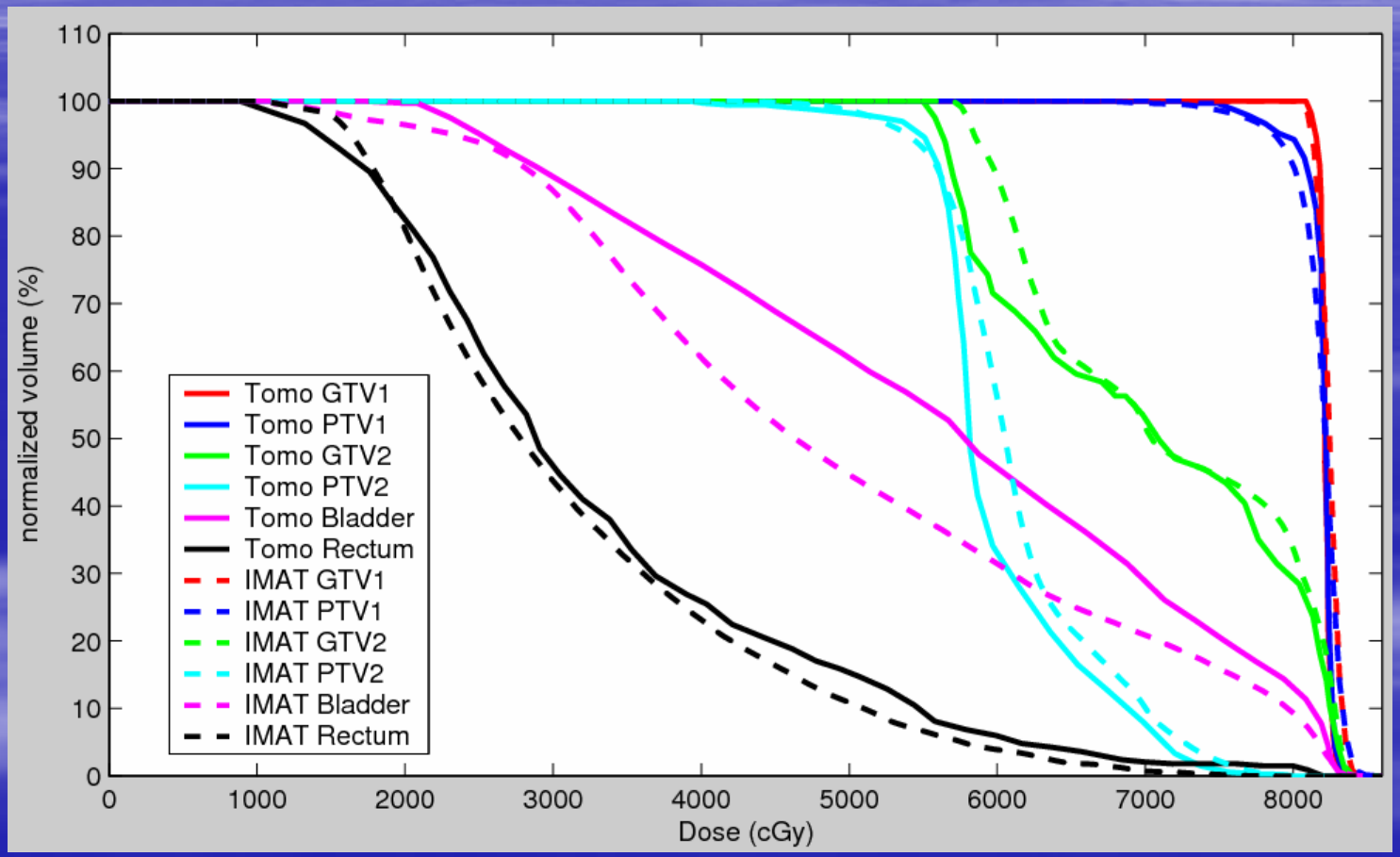
Another prostate case



5 Arc VMAT plan

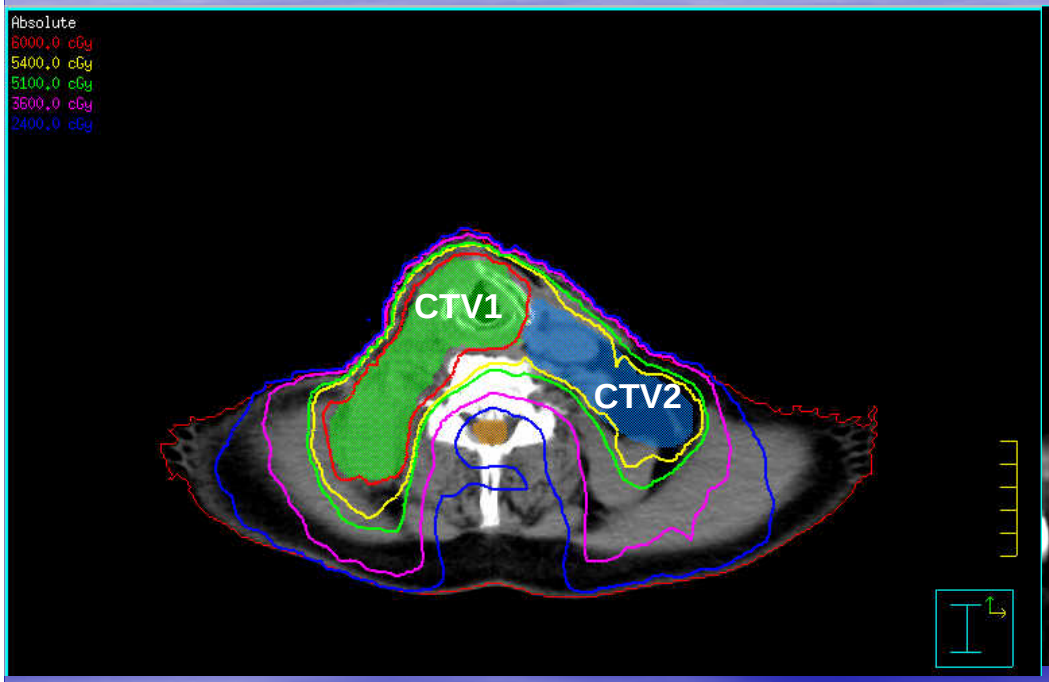
SWEDISH

Another Prostate Case (II)

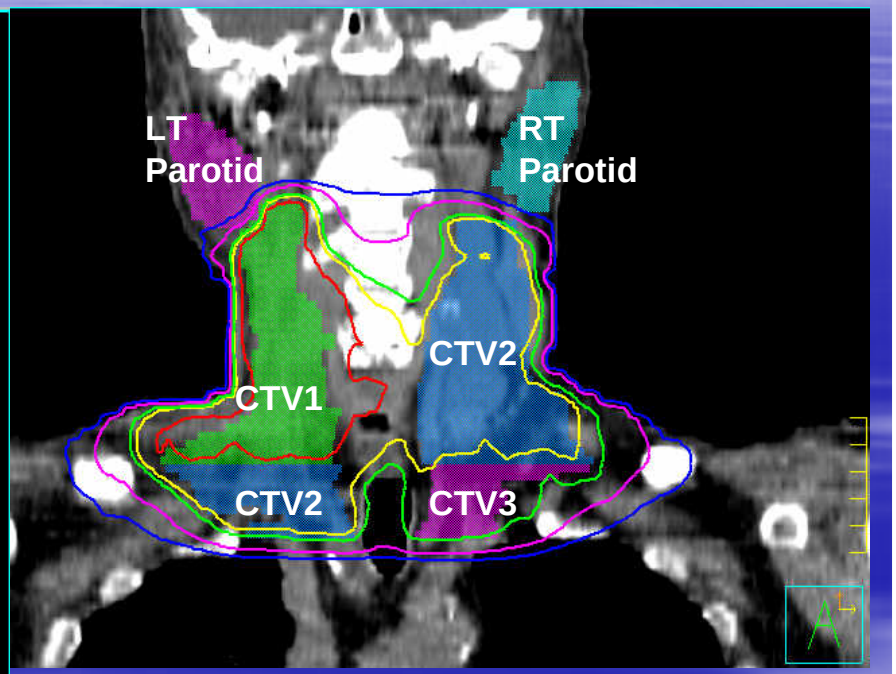


SWEDISH

A head-&-neck case with three prescription levels



axial

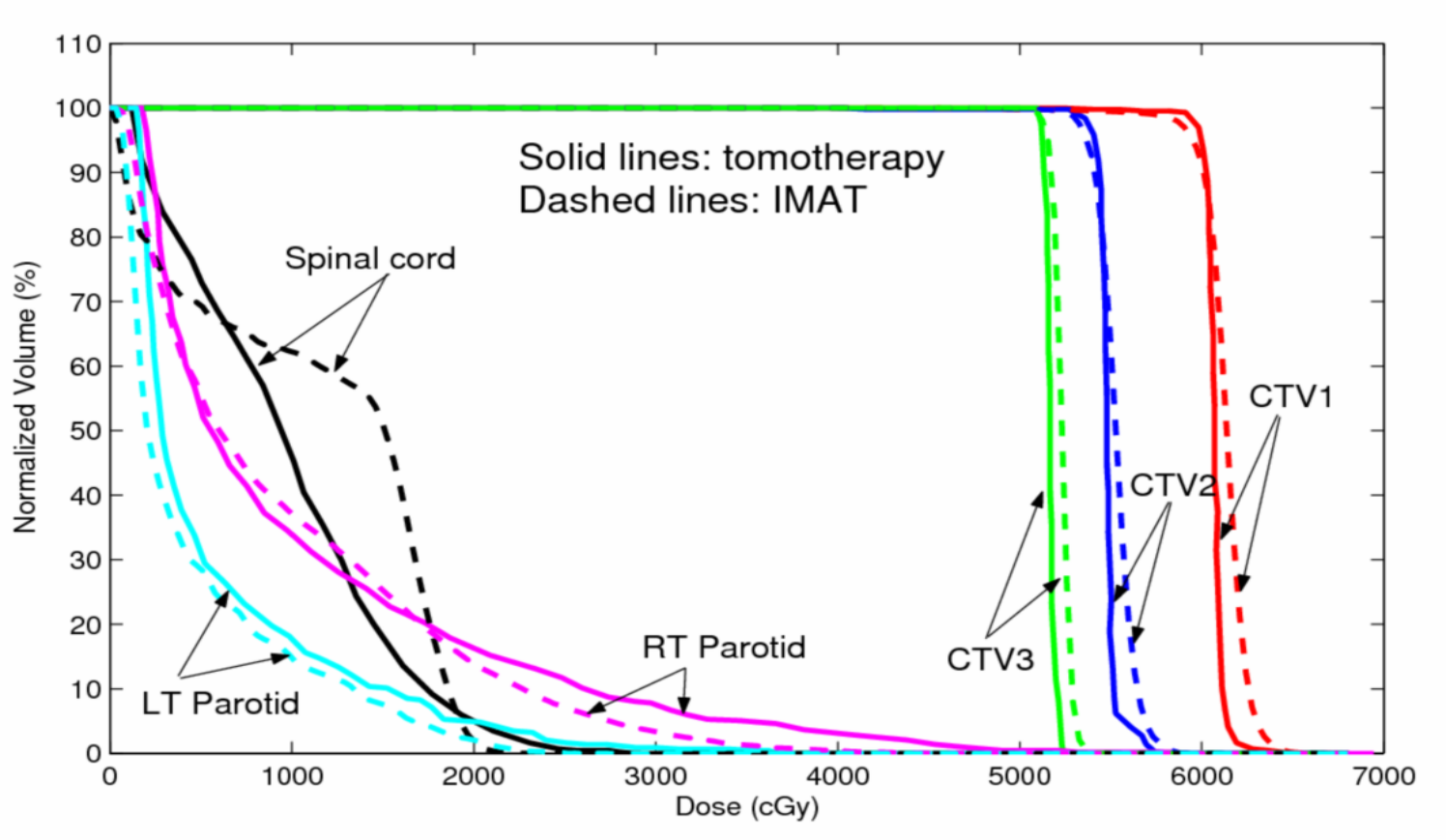


coronal

- Three targets with prescription levels of 60, 54, and 51 Gy
- A VMAT plan with 9 350º axial coplanar arcs was generated
- The five isodose levels in the above figures are 60, 54, 51, 35, and 24 Gy.

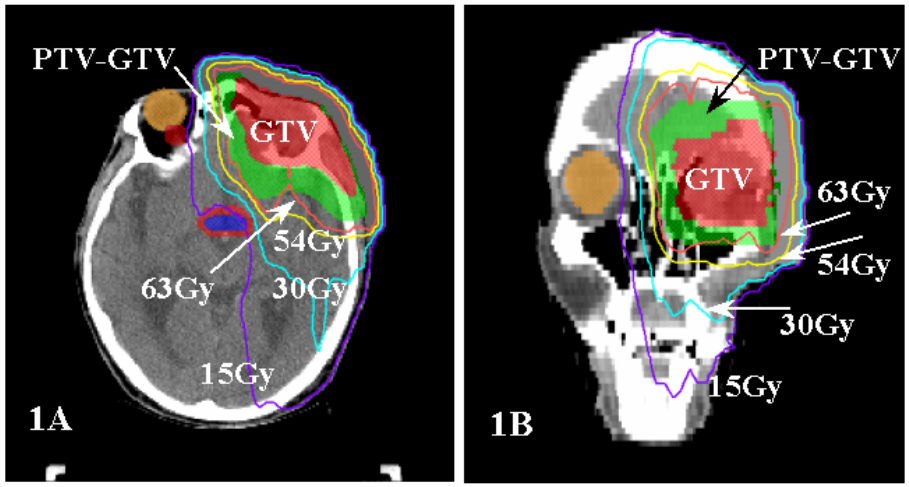
SWEDISH

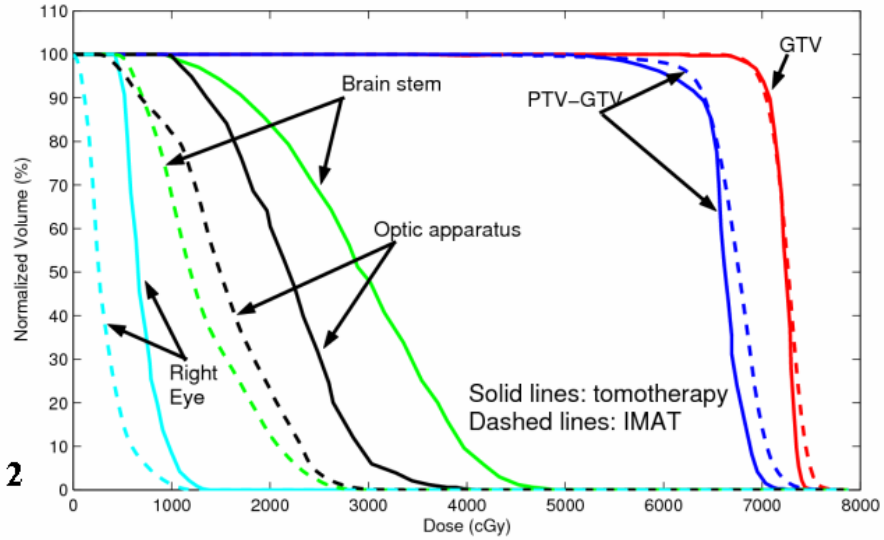
DVH comparisons for this H&N case



SWEDISH

An orbit case using sagittal arc

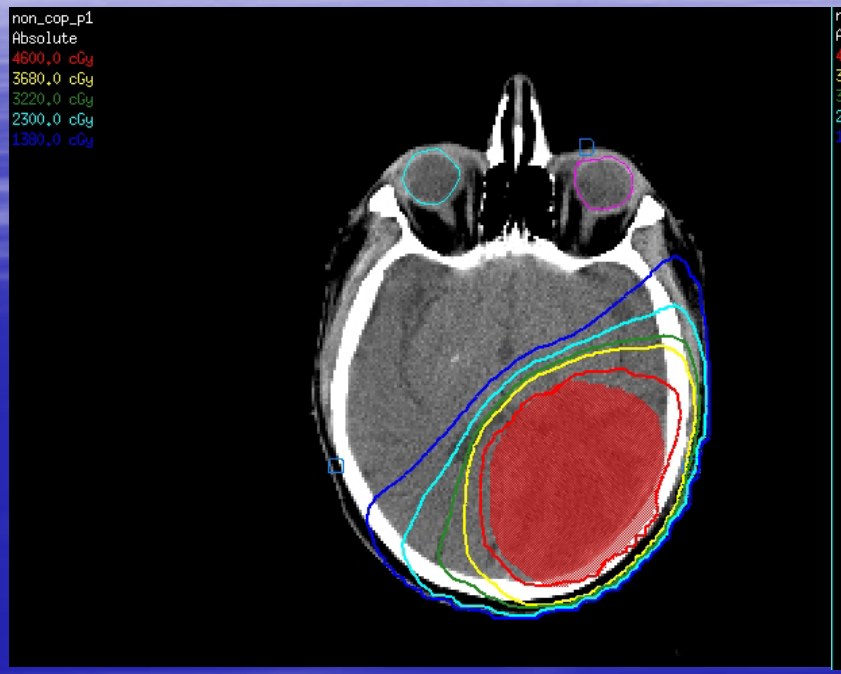




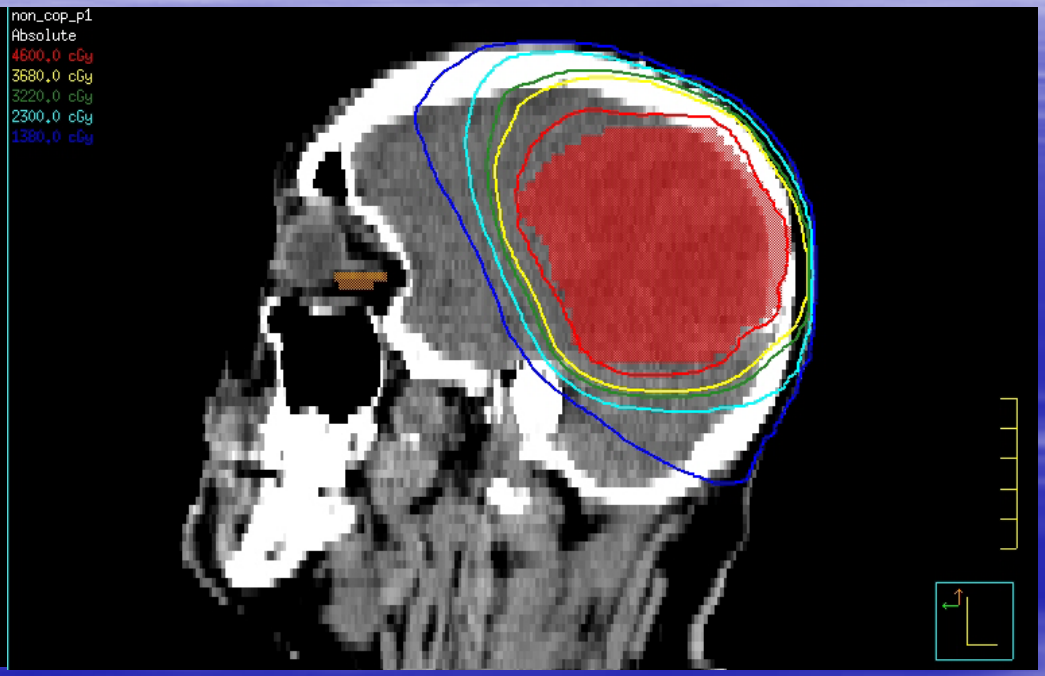
- The prescriptions to GTV and PTV-GTV are 70 and 63 Gy, respectively.
- A VMAT plan with four 210º sagittal arcs were created for this case.

SWEDISH

A Brain GBM case



axial

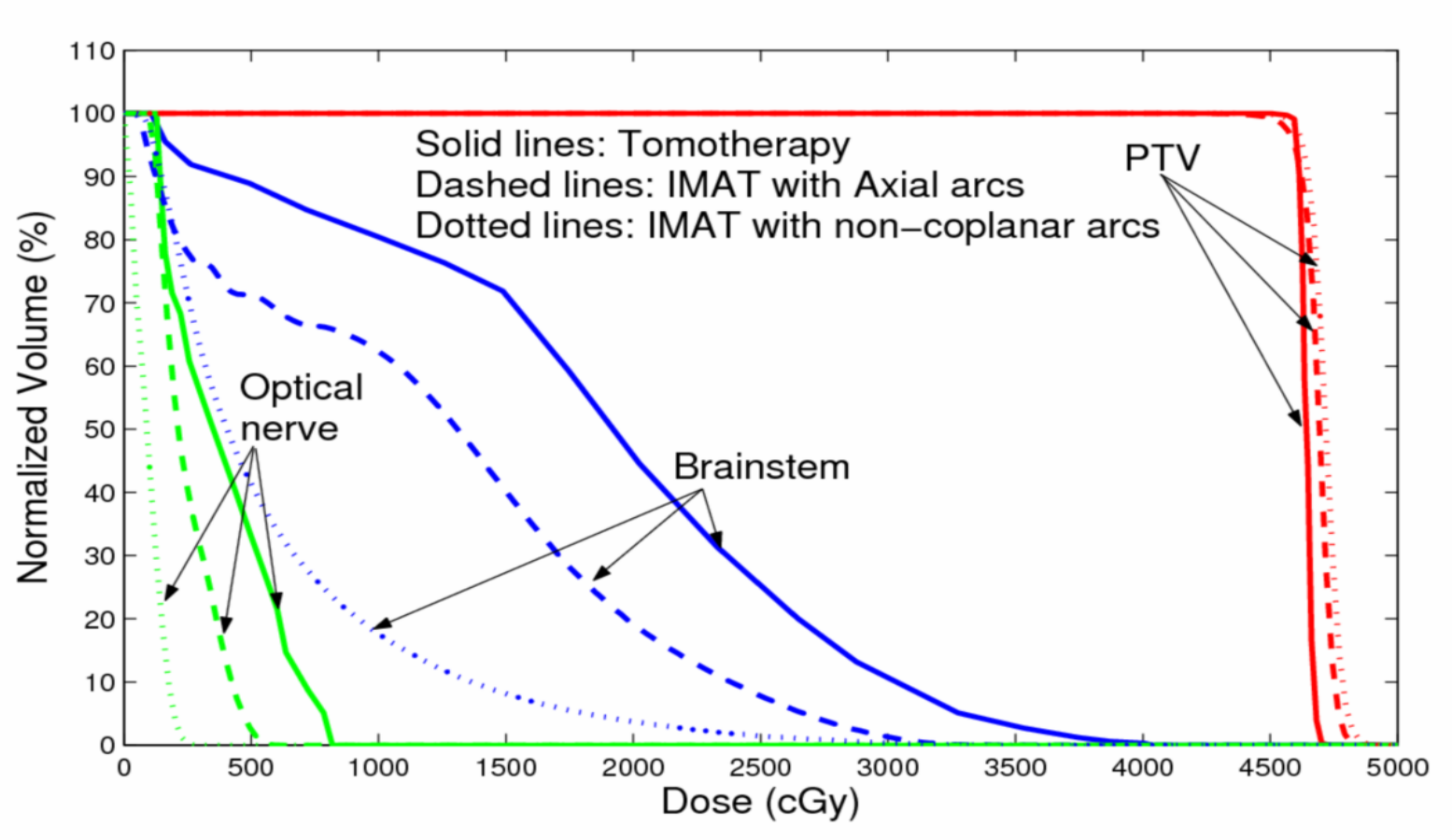


sagittal

- Both coplanar and non-coplanar VMAT plans were generated for this case.
- The above isodose plots are from the non-coplanar VMAT plan. Five isodose levels are plotted: 100%, 80%, 70%, 50%, and 30%.

SWEDISH

DVH comparisons for this brain case



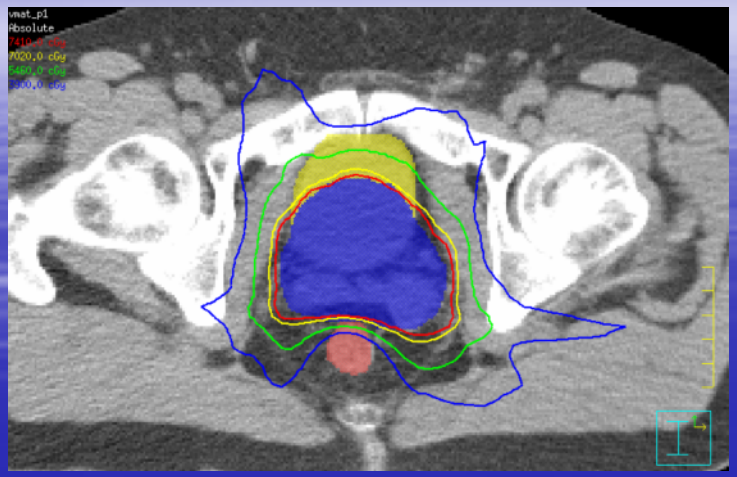
SWEDISH

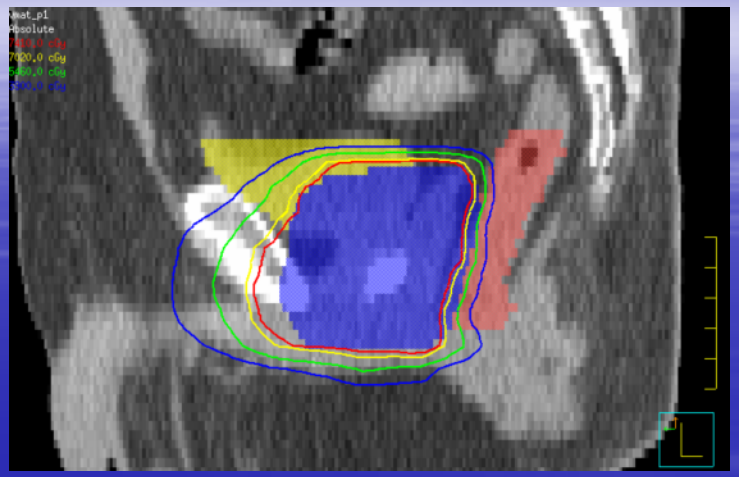
New development of the Arc Sequencer

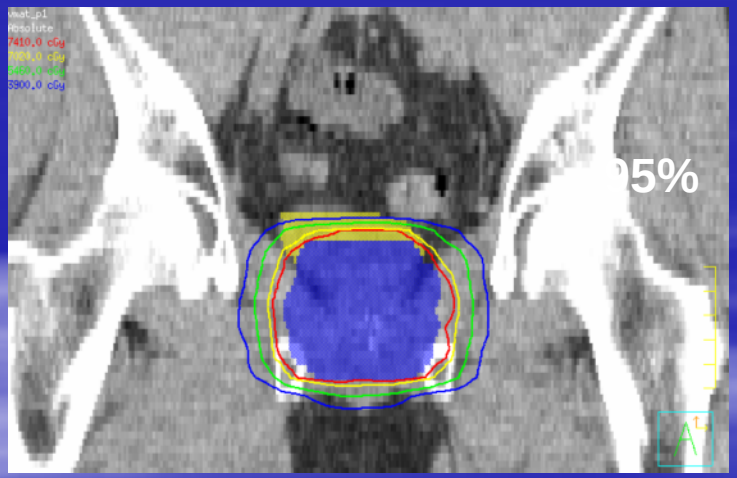
- **Capable of generating both Single-Arc & Multiple-Arc VMAT plans**

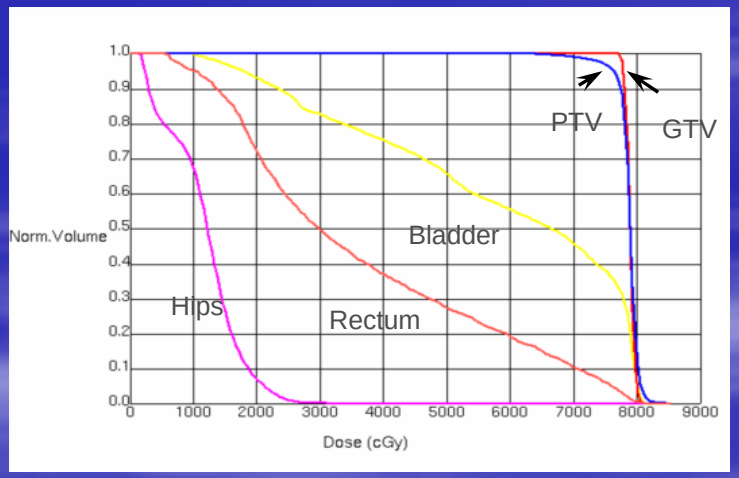
SWEDISH

Single Arc: A Prostate Case





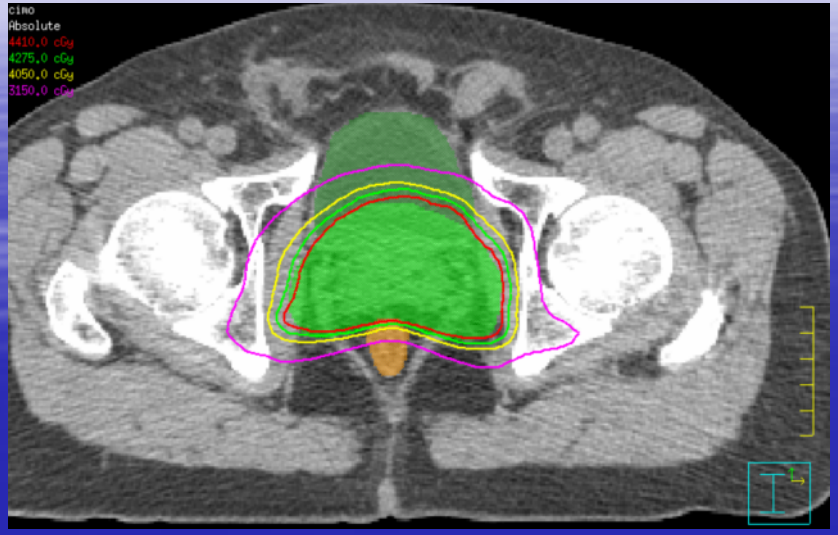


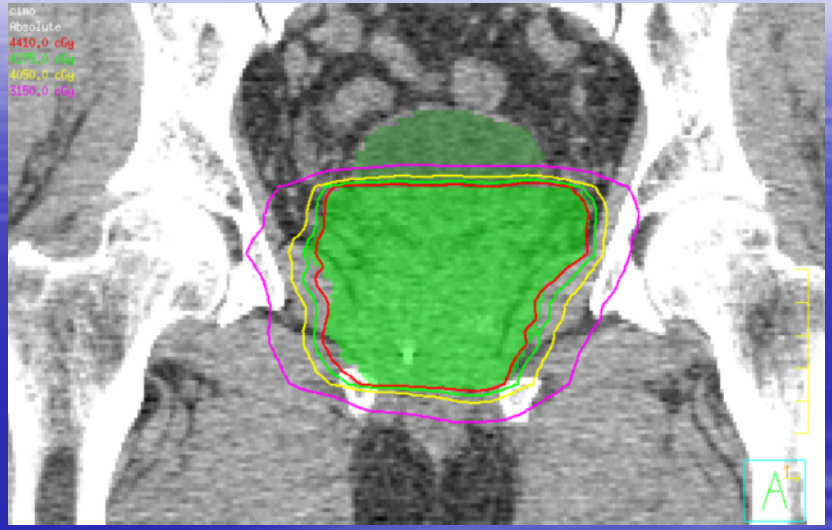


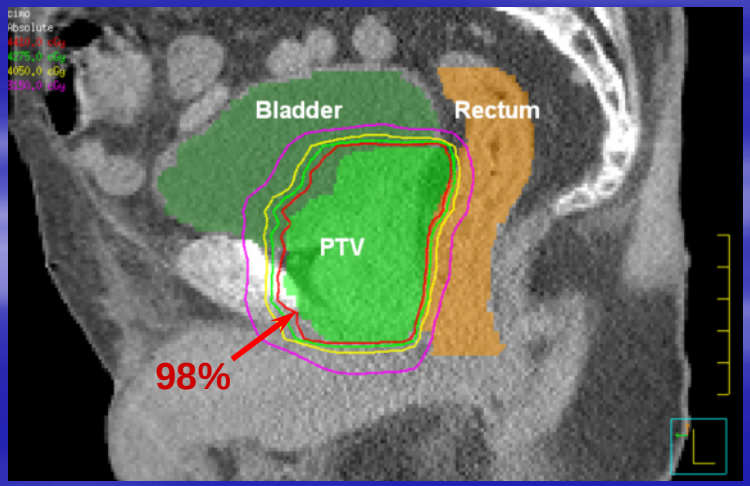
- MU for this case is 702 per fraction with 200cGy per fraction.
- Delivery time is about 2 minutes.

SWEDISH

Single Arc: Another Prostate Case

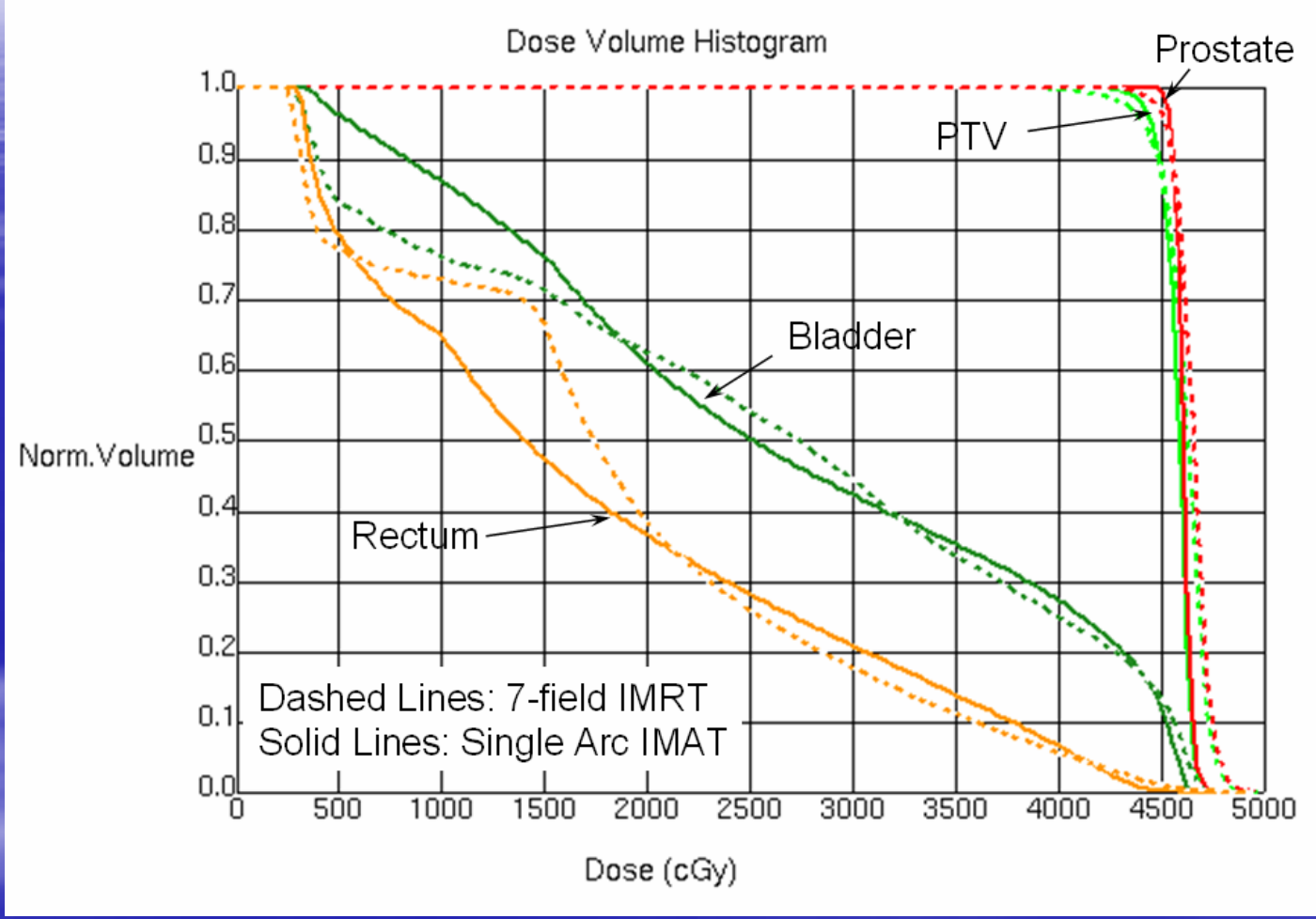






SWEDISH

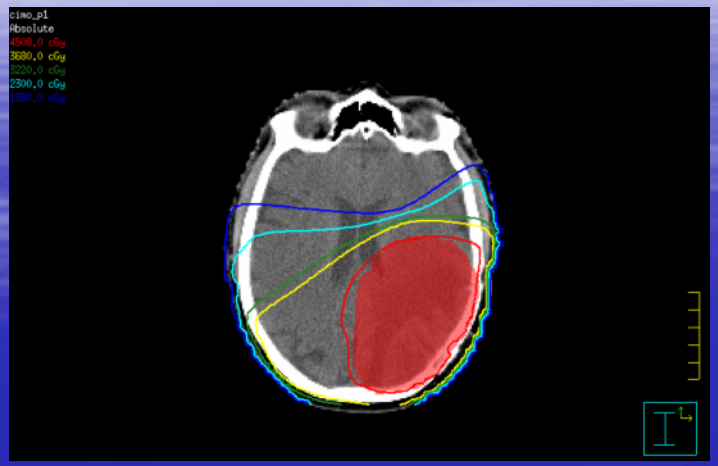
Single Arc: Another Prostate Case (II)

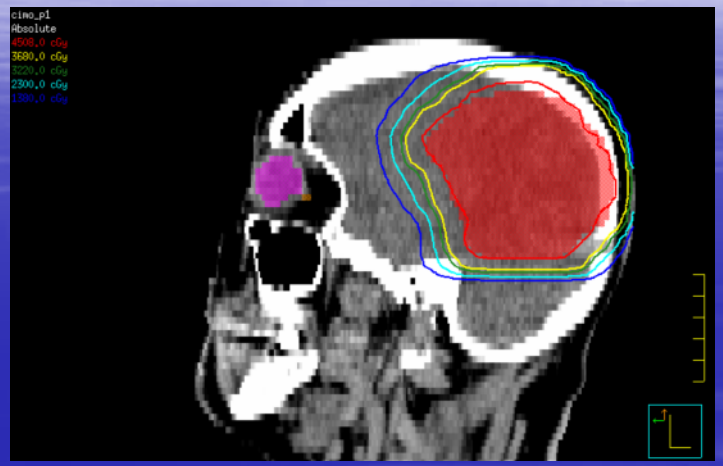


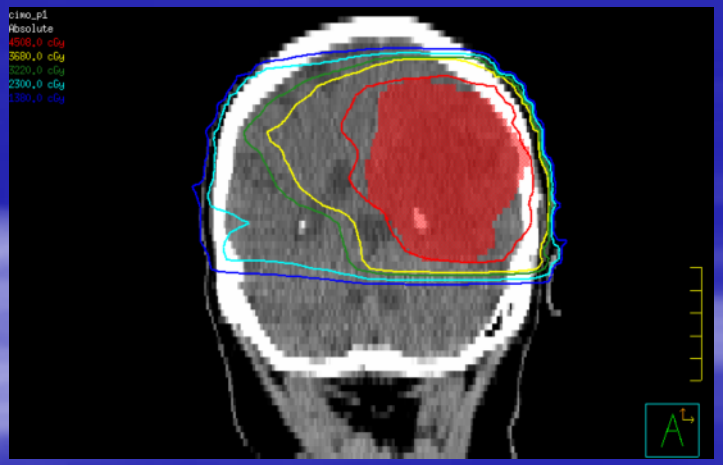
- 554 MUs to deliver 180 cGy; Delivery time ≈ 2 minutes
- 7 fields IMRT - 626 MUs, 6 to 8 minute delivery

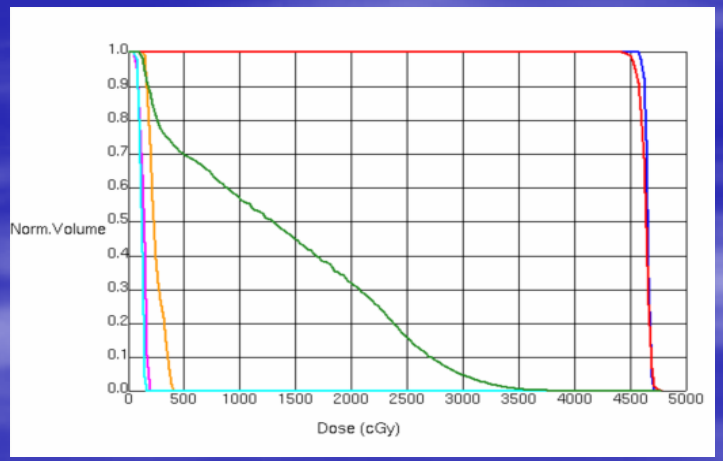
SWEDISH

Single Arc: A Brain Case





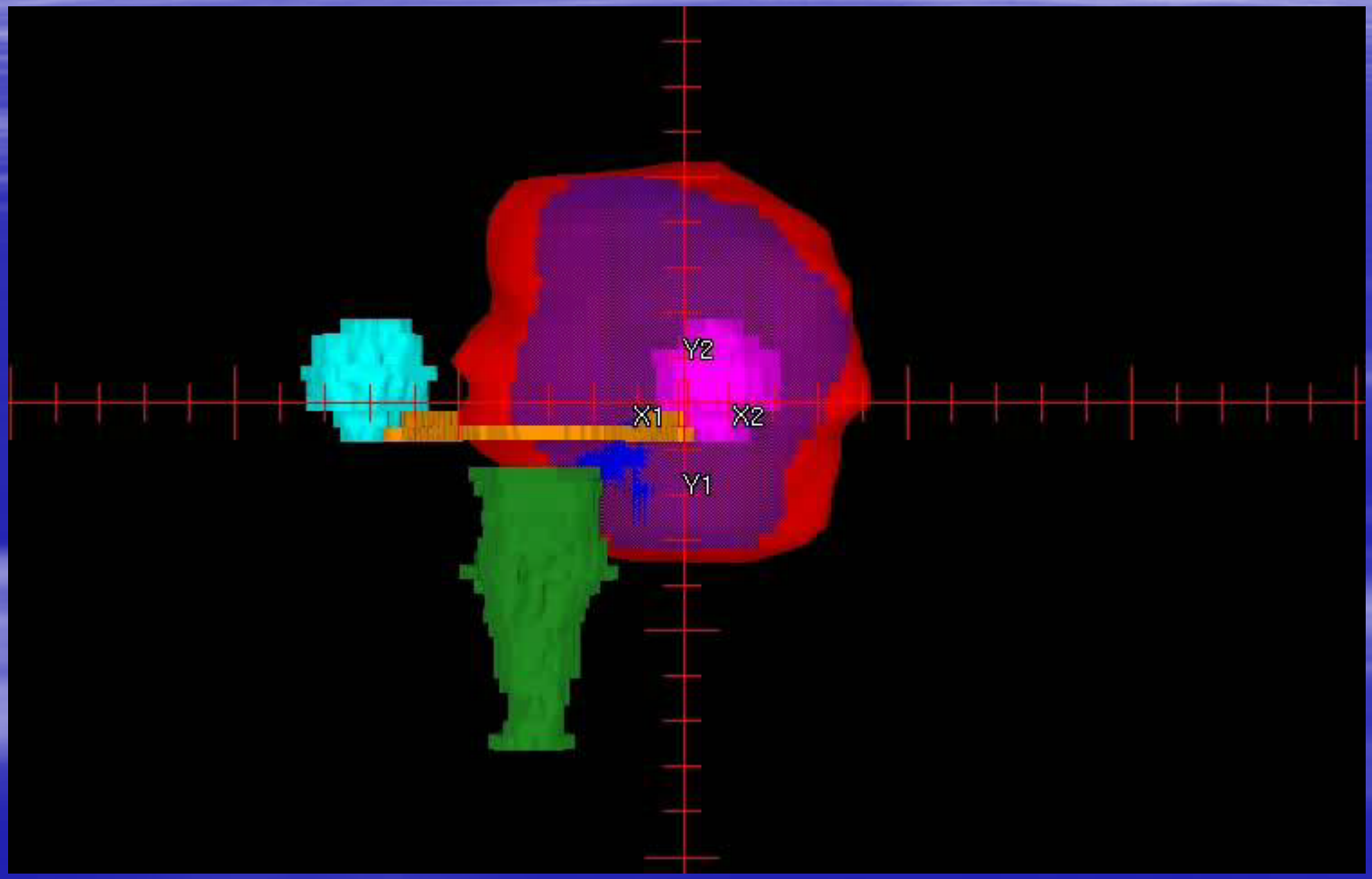




- MU: 267 per fraction with 200 cGy per fraction
- Delivery time about 2 minutes

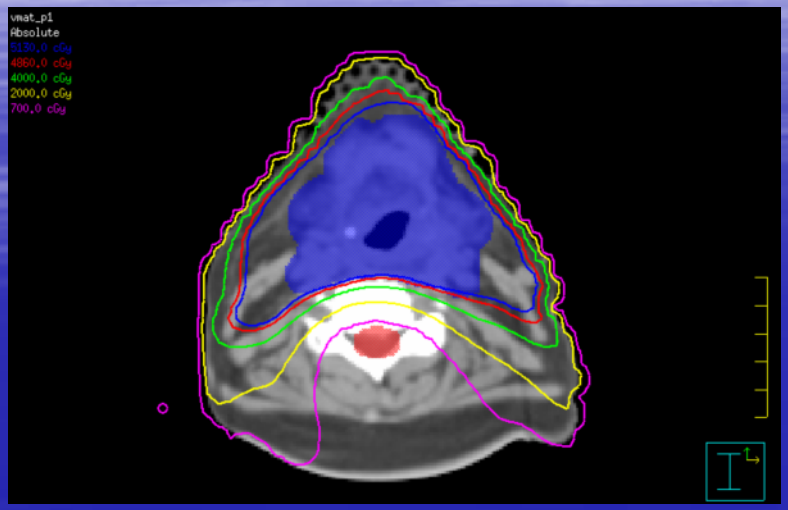
SWEDISH

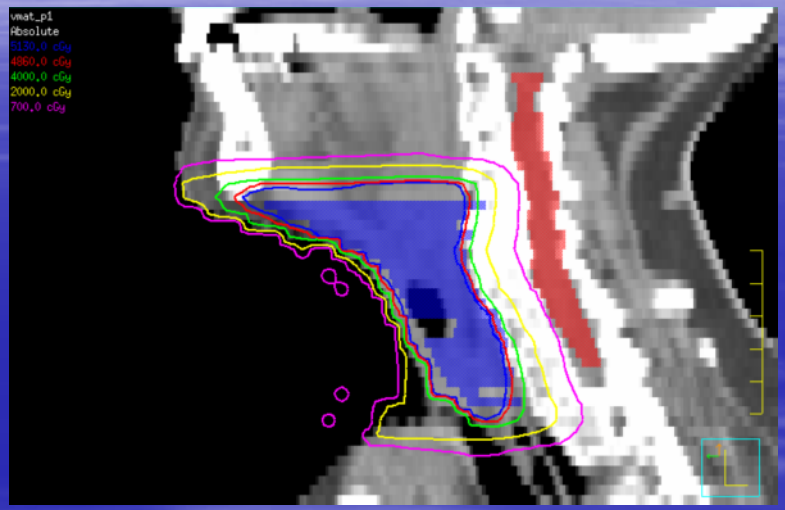
Single Arc: A Brain Case (II)

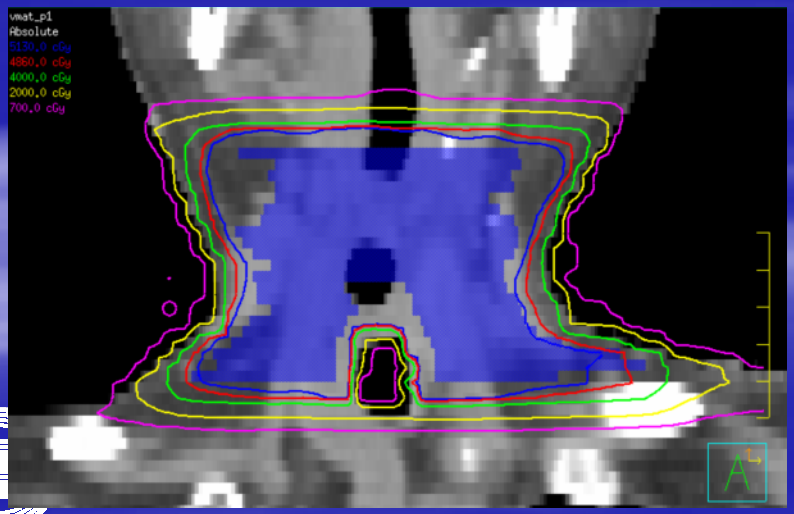


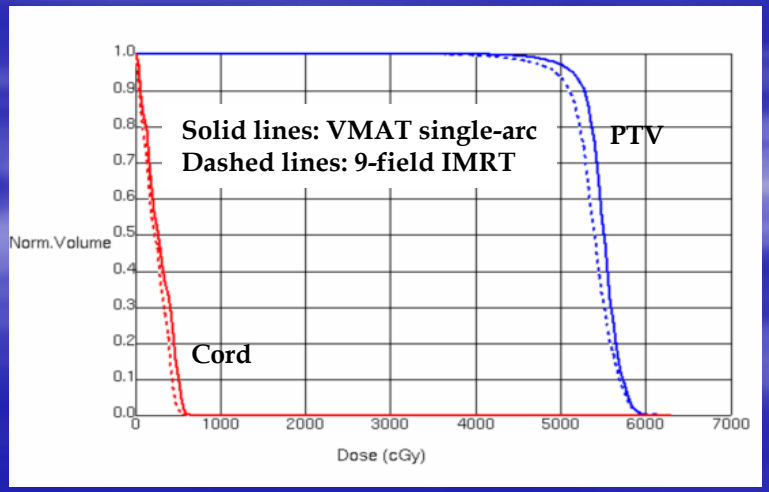
SWEDISH

Single Arc: Head-&-Neck Case (I)





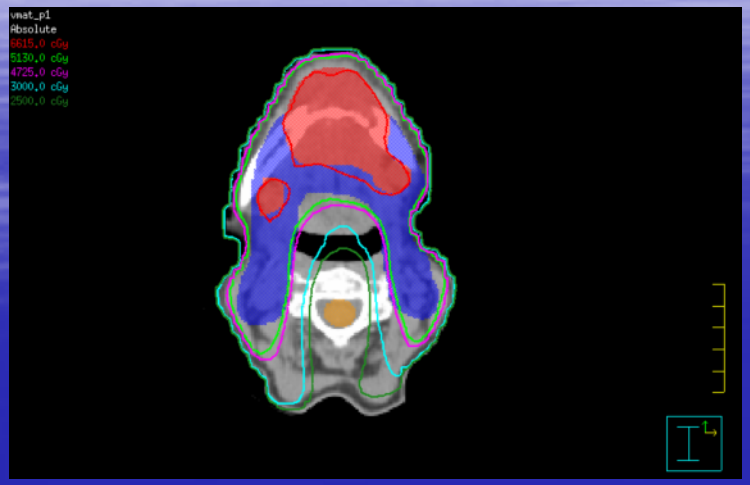


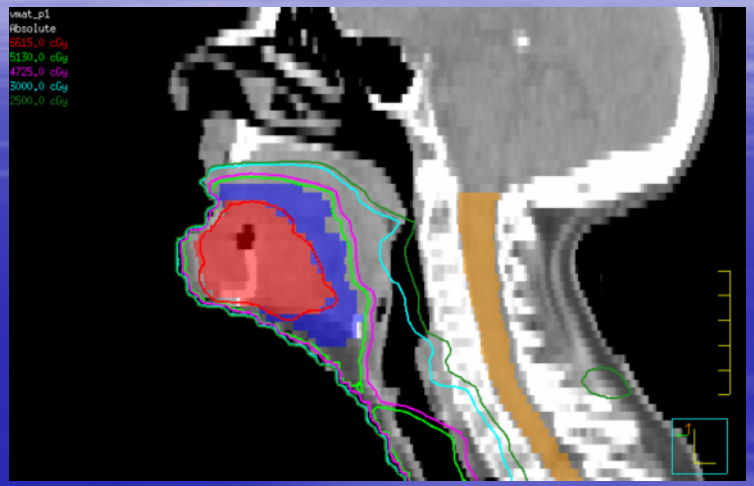


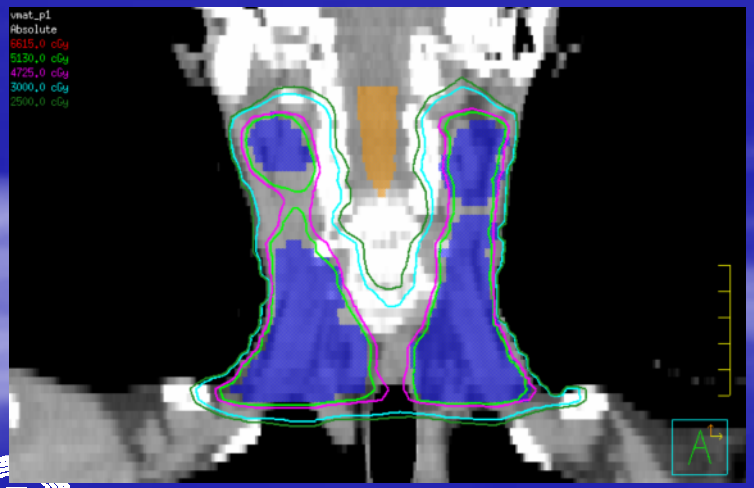
SWEDISH

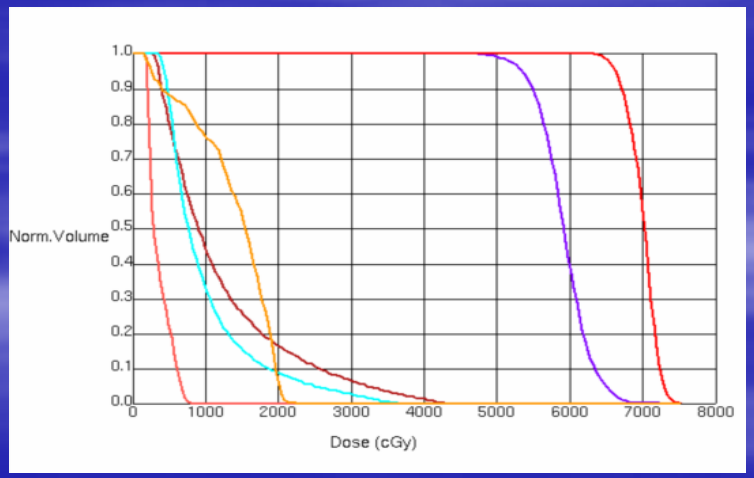
VMAT: single-arc, 532 MU; IMRT: 89 segments, 728 MU

Single Arc: Head-&-Neck Case (II)





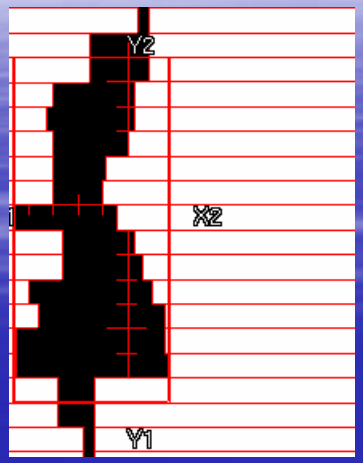




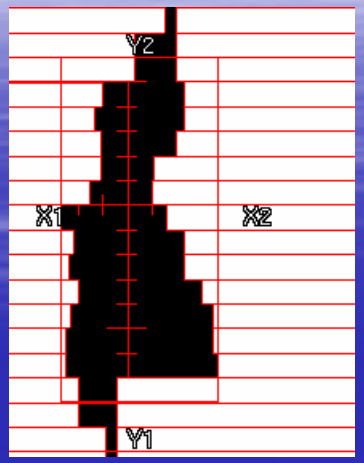
- 566 MU to deliver 180 cGy per fraction; ~2 minutes to deliver

SWEDISH

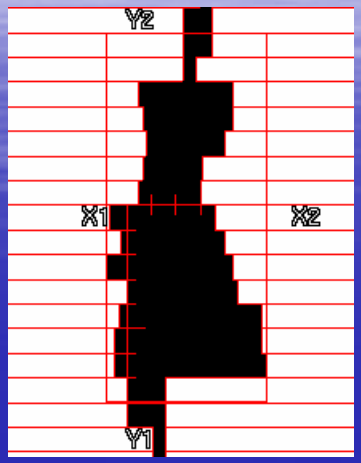
Single Arc: Head-&-Neck Case (II)



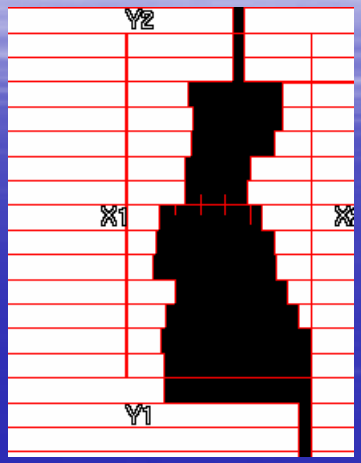
172°



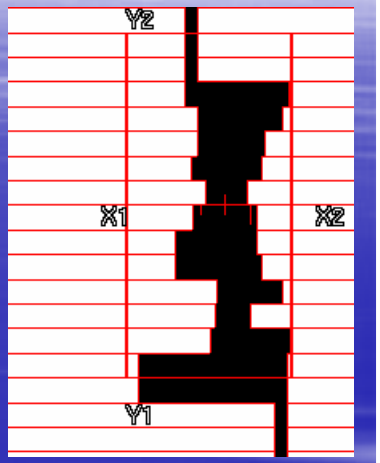
170°



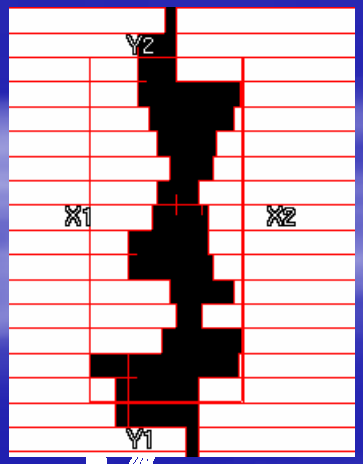
168°



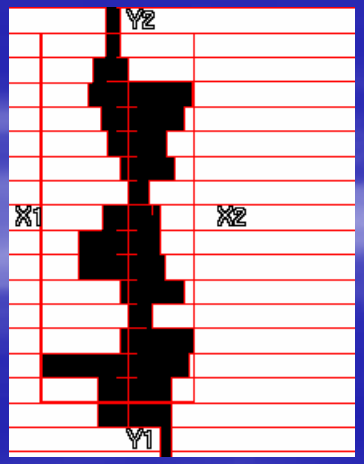
166°



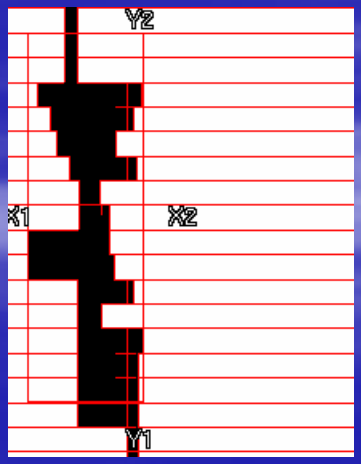
164°



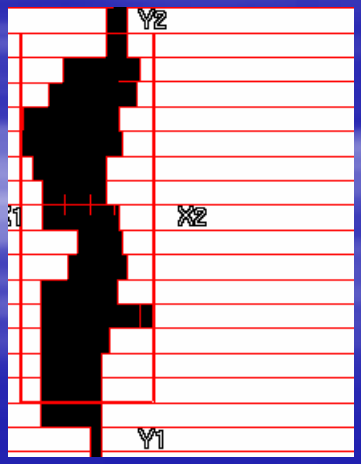
162°



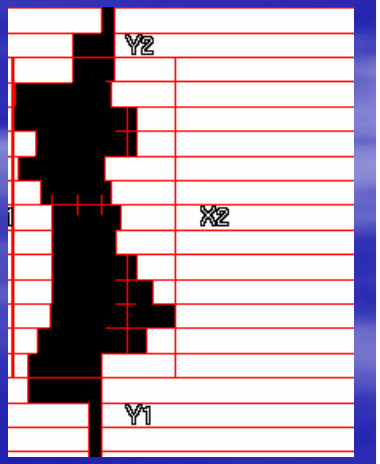
160°



158°



156°



154°

SWEDISH

Max leaf motion is 2cm per 2 degree

VMAT vs. Step-&-Shoot IMRT

	number of Arcs/Segments		number of MU		Estimated Delivery time (minutes)	
	VMAT	IMRT	VMAT	IMRT	VMAT	IMRT
Prostate	1	69 (7flds)	554	626	2	6-8
Lung	1	80 (7flds)	422	668	2	7-9
Brain	1	57 (7flds)	267	418	2	6-8
H&N (1)	1	172 (9flds)	566	1120	2	15-20
H&N (2)	2	127 (9flds)	452	1010	2	10-15
H&N (3)	1	89 (9flds)	532	728	2	8-10
H&N (4)	1	169 (9flds)	424	1045	2	15-20

SWEDISH

Summary

- VMAT is a rotational approach to IMRT that can be delivered using conventional linear accelerators with conventional MLC.
- VMAT can provide highly conformal dose distribution and improve the IMRT delivery efficiency significantly.
- Both Elekta and Varian will be offering VMAT delivery capability.

SWEDISH

Thank you!

SWEDISH