VMAT Treatment Planning

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Acknowledgments

- Vivek Mehta
- Daliang Cao
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- Ke Sheng

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Disclaimer

- Our IMAT work is sponsored in part through a grant from Elekta.

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Objectives

1) To provide an overview of VMAT capable treatment planning systems.
2) To review VMAT planning techniques and tools for creating optimal VMAT plans
3) To examine the quality of plans that can be obtained using VMAT

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VMAT Treatment Planning

IMAT Inverse Planning Solutions

- Varian → Eclipse RapidArc
- Philips → Pinnacle SmartArc
- Elekta → ERGO++
- Elekta → Monaco VMAT
- Nucletron → Oncentra MasterPlan VMAT
- Siemens/Prowess → Prowess Panther

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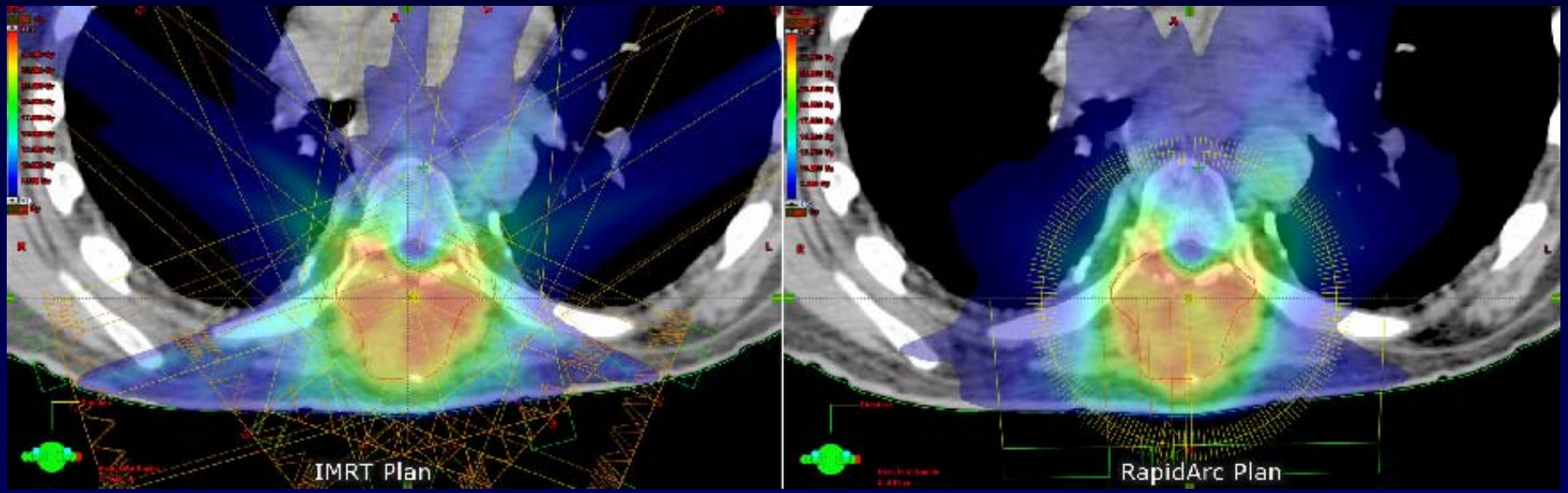
Varian Eclipse



- Planning is performed using Direct Aperture Optimization.
- Typical plan uses 1 arc with 177 control points.
- For some cases, multiple arcs are use to improve the plan quality or provide adequate coverage of large targets.

Direct aperture optimization: A turnkey solution for step-and-shoot IMRT

D. M. Shepard, M. A. Earl, X. A. Li, S. Naqvi, and C. Yu
University of Maryland School of Medicine, Department of Radiation Oncology, 22 South Greene St., Baltimore, Maryland 21201-1595

(Received 26 September 2001; accepted for publication 12 March 2002; published 13 May 2002)

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Phys. Med. Biol. **48** (2003) 1–15 — PII: S0031-9155(03)57398-5

Inverse planning for intensity modulated arc therapy using direct aperture optimization

M A Earl, D M Shepard, S Naqvi, X A Li and C X Yu

Department of Radiation Oncology, University of Maryland School of Medicine, Baltimore, MD 21201, USA

DAO Optimization (1)

- A simulated annealing algorithm is used to optimize the MLC leaf positions and aperture weights.
- After each change in an MLC leaf position, the algorithm checks to see if any of the delivery constraints are violated. If so, the change is rejected.
- Otherwise, the change is accepted based on the rules of simulated annealing.

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DAO Optimization (2)

- The key feature of DAO is that all of the delivery constraints are included directly into the IMAT optimization.

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Volumetric modulated arc therapy: IMRT in a single gantry arc

Karl Otto[a)]
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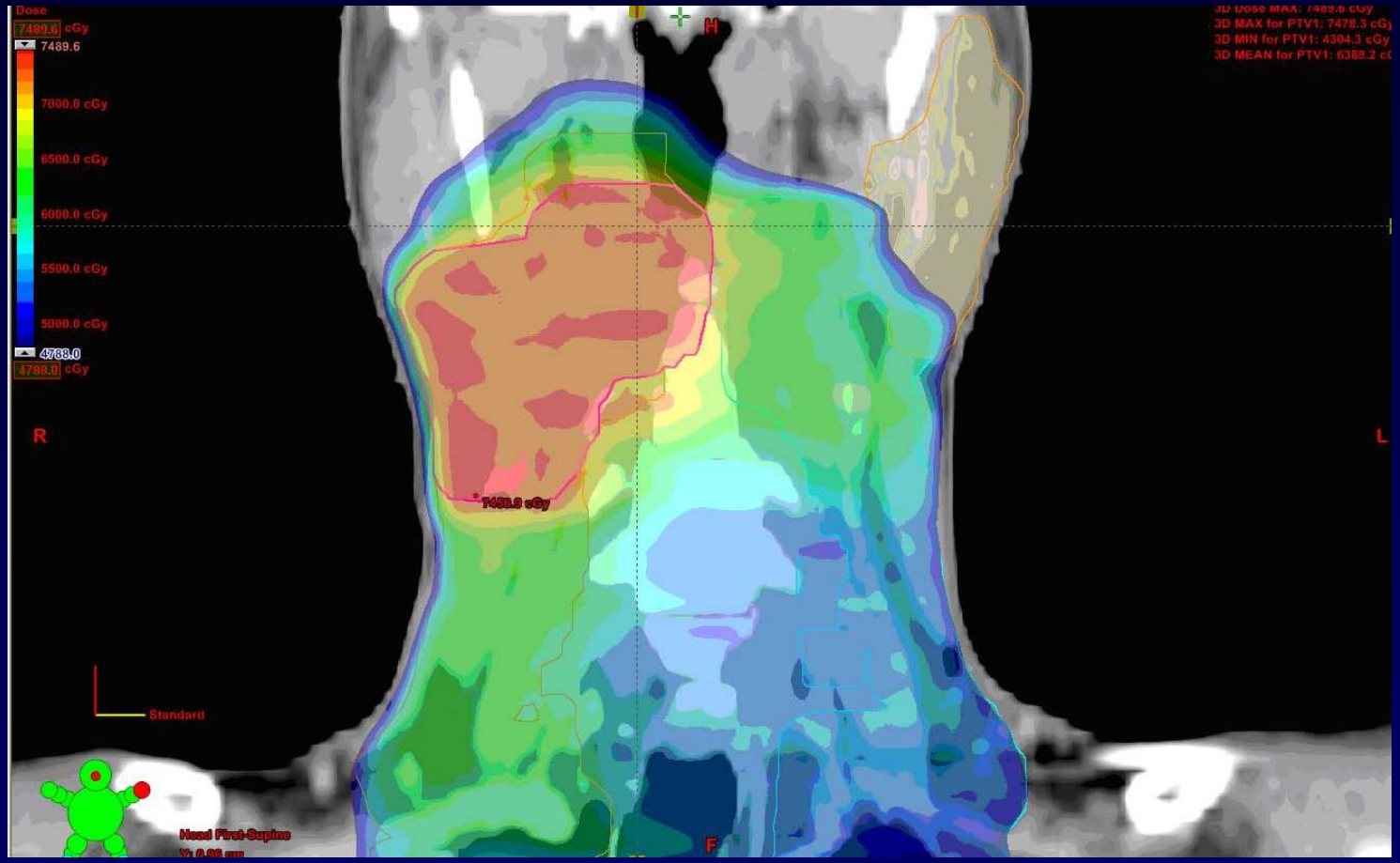
(Received 25 June 2007; revised 21 September 2007; accepted for publication 5 November 2007; published 26 December 2007)

In this work a novel plan optimization platform is presented where treatment is delivered efficiently and accurately in a single dynamically modulated arc. Improvements in patient care achieved through image-guided positioning and plan adaptation have resulted in an increase in overall treatment times. Intensity-modulated radiation therapy (IMRT) has also increased treatment time by requiring a larger number of beam directions, increased monitor units (MU), and, in the case of tomotherapy, a slice-by-slice delivery. In order to maintain a similar level of patient throughput it will be necessary to increase the efficiency of treatment delivery. The solution proposed here is a novel aperture-based algorithm for treatment plan optimization where dose is delivered during a single gantry arc of up to 360 deg. The technique is similar to tomotherapy in that a full 360 deg of beam directions are available for optimization but is fundamentally different in that the entire dose volume is delivered in a single source rotation. The new technique is referred to as volumetric modulated arc therapy (VMAT). Multileaf collimator (MLC) leaf motion and number of MU per

Eclipse VMAT

- In Otto's paper, he used DAO to produced IMAT plans.
- Key innovations:
  1. Focused on a single arc approach with more control points in the single arc. Termed "VMAT".
  2. Progressive sampling was used to improve the speed of the algorithm.
- This is the approach utilized in Eclipse

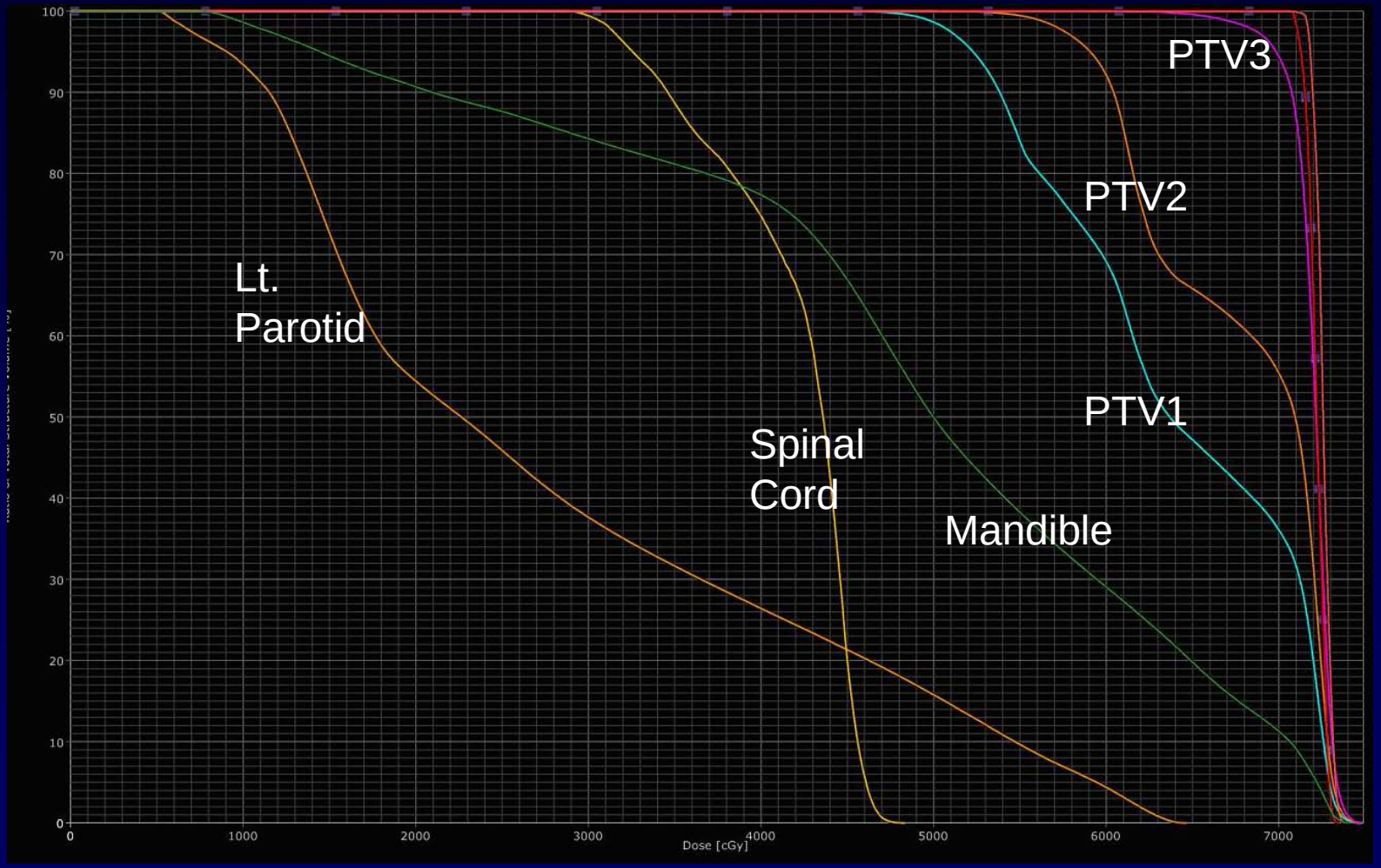
Varian Eclipse



- Composite dose for H&N patient treated at UMMS.
- Initial = 50.4 Gy, SFB1 = 9Gy, SFB2=10.8Gy

Courtesy of Warren D'Souza

Varian Eclipse



- Initial plan and SFB1 used 2 arcs, SFB2 used 1 arc
- Delivery time = 1.5 minutes per arc

Courtesy of Warren D'Souza

Philips Pinnacle^3 SmartArc

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Philips Pinnacle - SmartArc

- SmartArc is an extension of the DMPO planning functionality in Pinnacle.
- The SmartArc planning tools were developed by RaySearch (Stockholm).

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Development and evaluation of an efficient approach to volumetric arc therapy planning

Karl Bzdusek[a)]
Philips Healthcare, Fitchburg, Wisconsin 53711

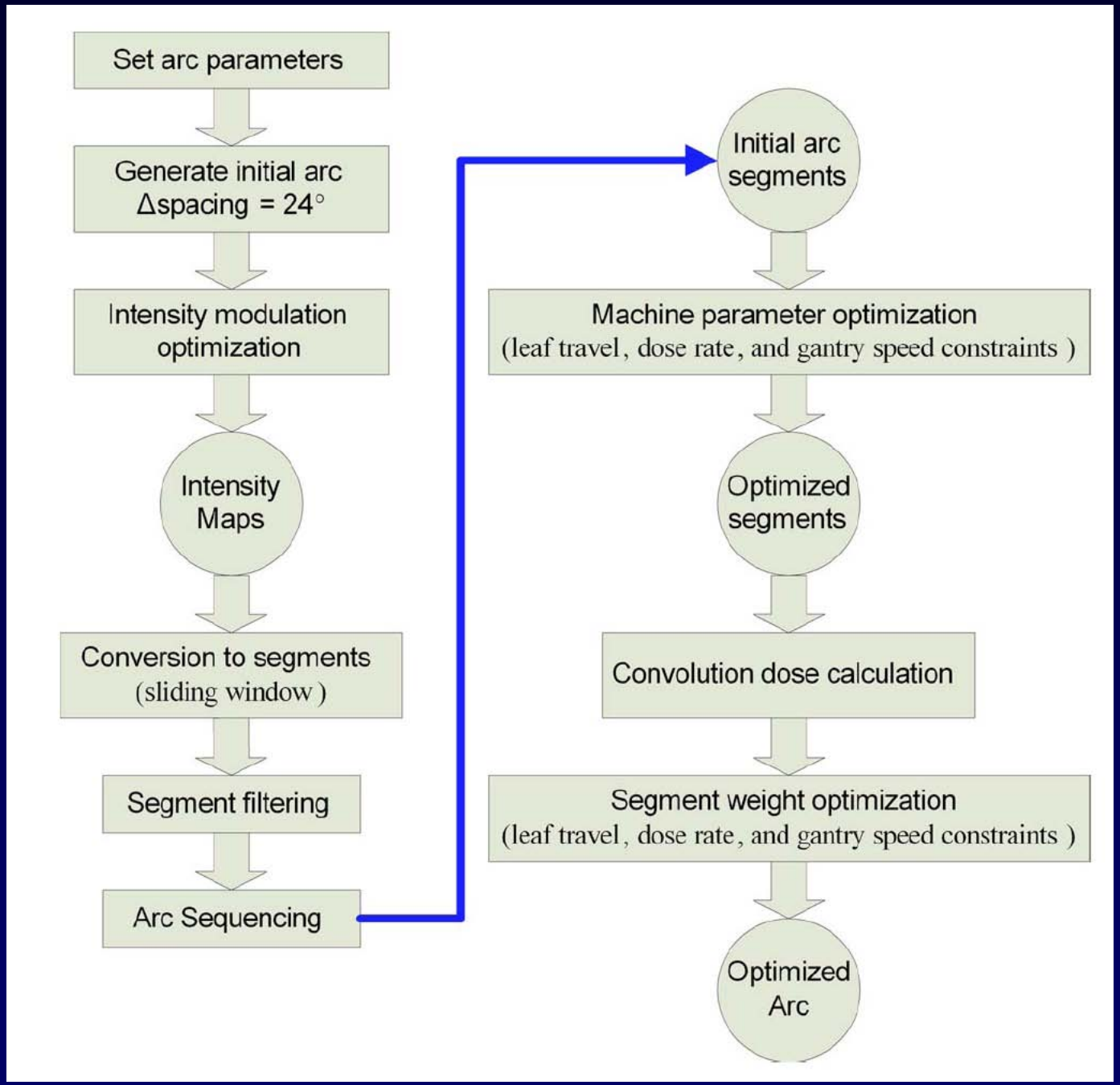
Henrik Friberger, Kjell Eriksson, and Björn Hårdemark
Raysearch Laboratories, Stockholm 11134, Sweden

David Robinson and Michael Kaus
Philips Healthcare, Fitchburg, Wisconsin 53711

(Received 29 November 2008; revised 3 March 2009; accepted for publication 20 April 2009; published 27 May 2009)

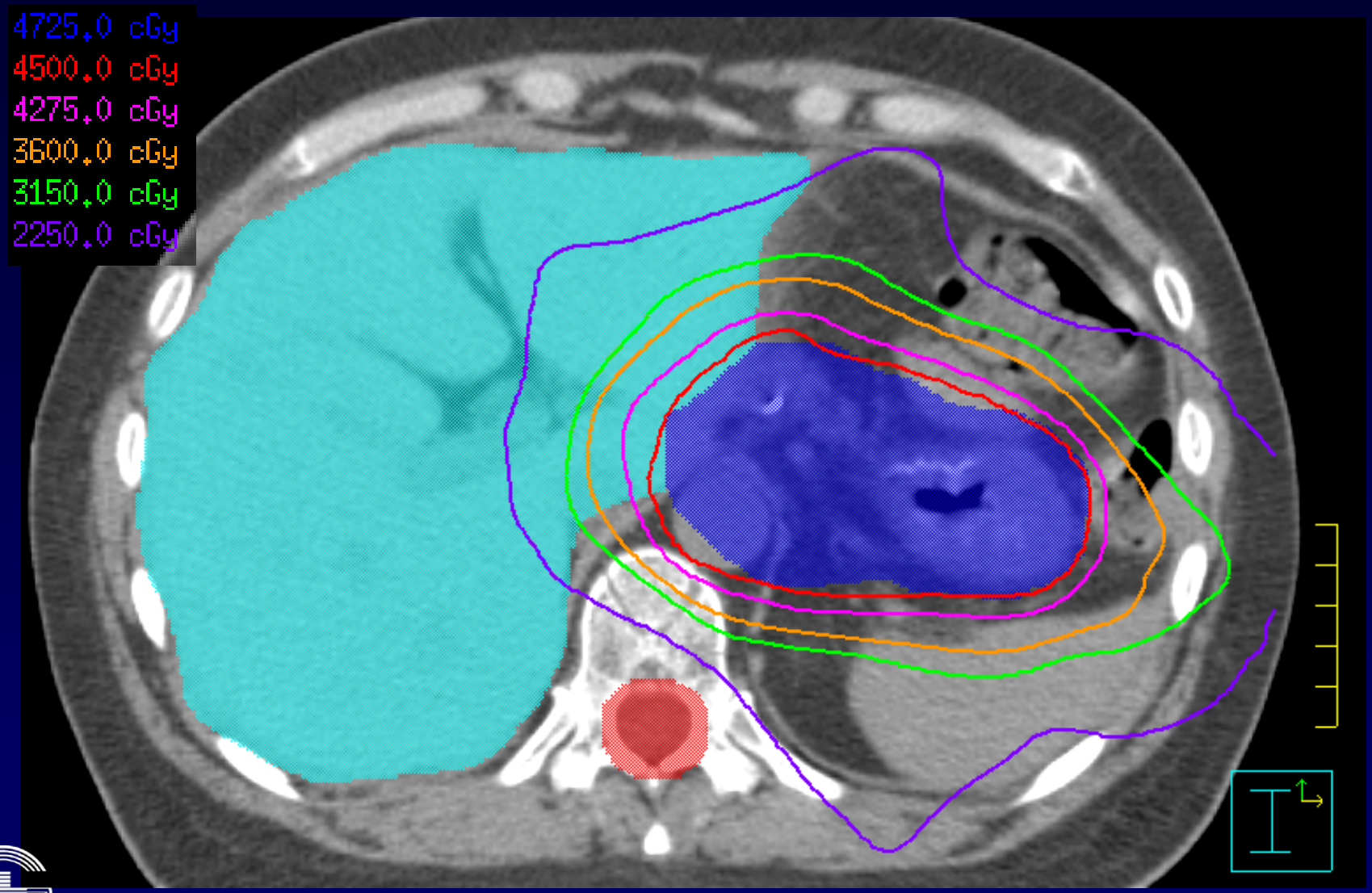
An efficient method for volumetric intensity modulated arc therapy (VMAT) planning was developed, where a single arc (360° or less) is delivered under continuous variation of multileaf collimator (MLC) segments, dose rate, and gantry speed. Plans can be generated for any current linear accelerator that supports these degrees of freedom. MLC segments are derived from fluence maps at relatively coarsely sampled angular positions. The beam segments, dose rate, and gantry speed are then optimized using direct machine parameter optimization based on dose volume objectives and leaf motion constraints to minimize arc delivery time. The method can vary both dose rate and gantry speed or alternatively determine the optimal plan at constant dose rate and gantry speed. The method was used to retrospectively generate variable dose rate VMAT plans to ten patients (head and neck, prostate, brain, lung, and tonsil). In comparison to step-and-shoot intensity modulated radiation therapy, dosimetric plan quality was comparable or improved, estimated delivery times ranged from 70 to 160 s, and monitor units were consistently reduced in nine out of the ten cases by an average of ~6%. Optimization and final dose calculation took between 5 and 35 min depending on plan complexity. © *2009 American Association of Physicists in Medicine.*
[DOI: 10.1118/1.3132234]

Key words: volumetric modulated arc therapy, arc therapy, treatment planning, direct machine parameter optimization



Courtesy of Philips Medical

Pancreas Case – Treated with SmartArc



- 4500 cGy delivered in 25 fractions
- 1 arc, 338 MUs, Delivery time = 1.6 minutes

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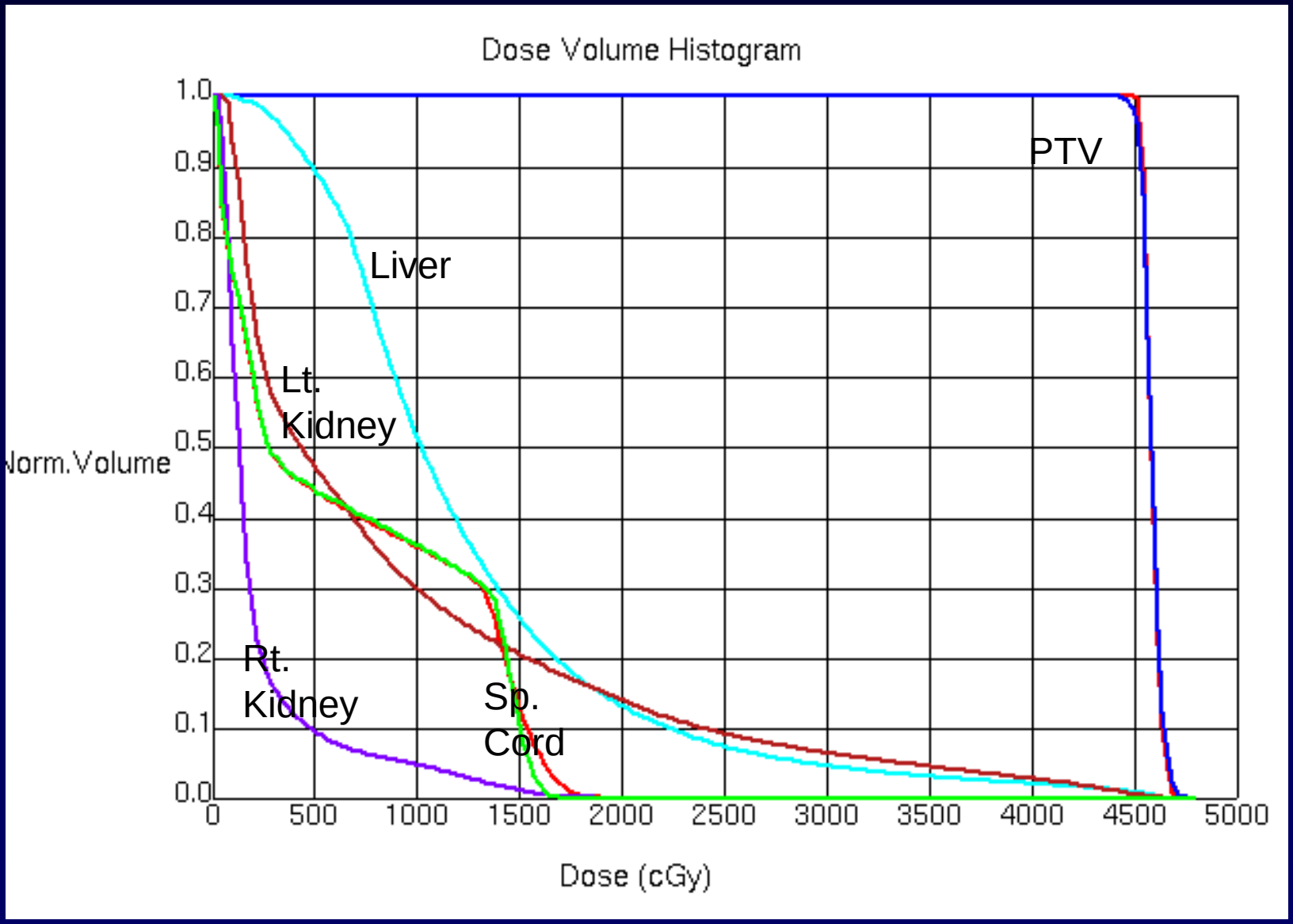
Pancreas Case – Treated with SmartArc



Summary From Initial Cases @ SCI

- 80 cases treated including lung, HN, liver, pancreas, esophagus, brain, and chest wall.
- 1 arc used in 60% of cases
- 2 arcs used in 40% of cases.
- Average delivery time (Elekta Linac):
  - 1 arc cases = 1.9 minutes
  - 2 arc cases = 3.9 minutes

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Elekta VMAT

- Anatomy based inverse (Ergo++).
- Full inverse planning solution (Monaco)

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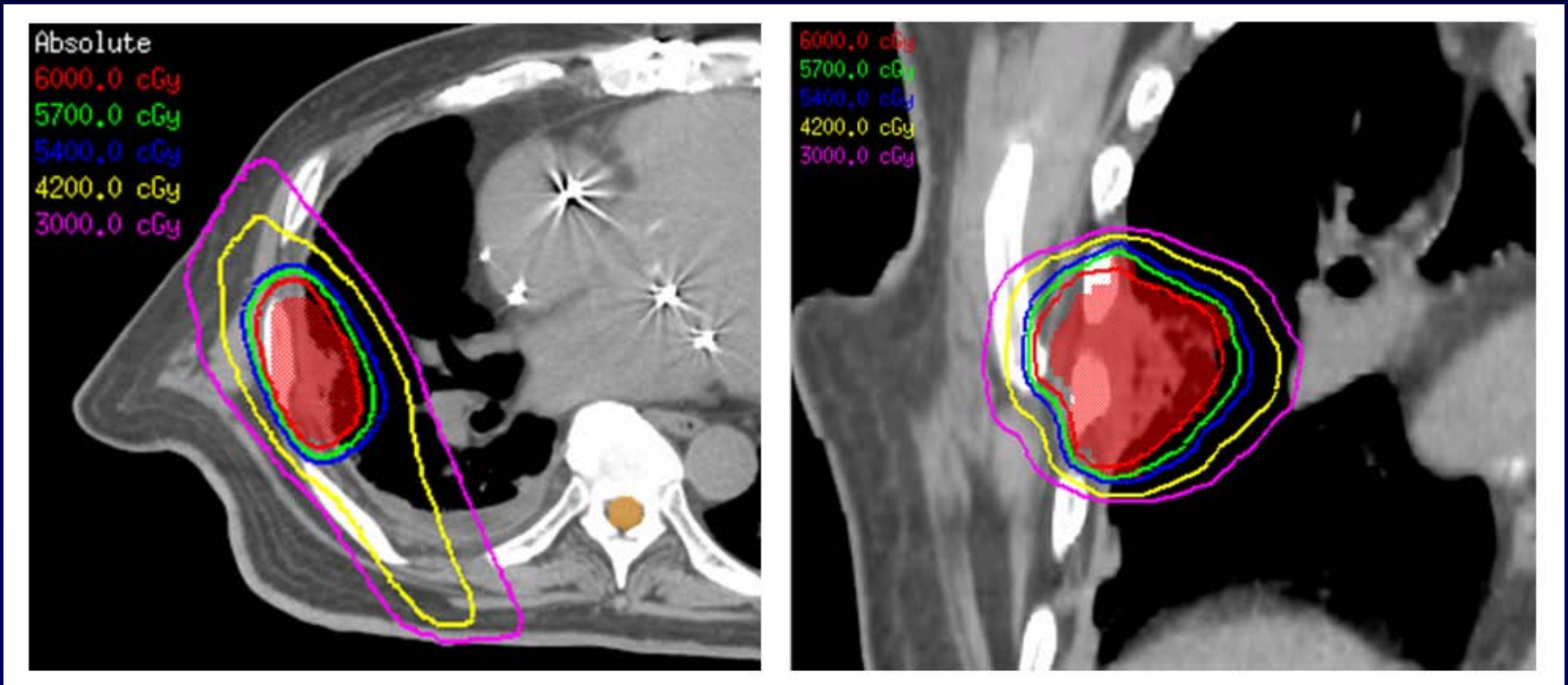
Ergo++

- TPS originally designed for stereotactic radiosurgery with dynamic arc capabilities.
- For VMAT, Ergo++ designs the beam shapes based simply on the patient's anatomy.
- The beam weights within a given arc are then optimized.

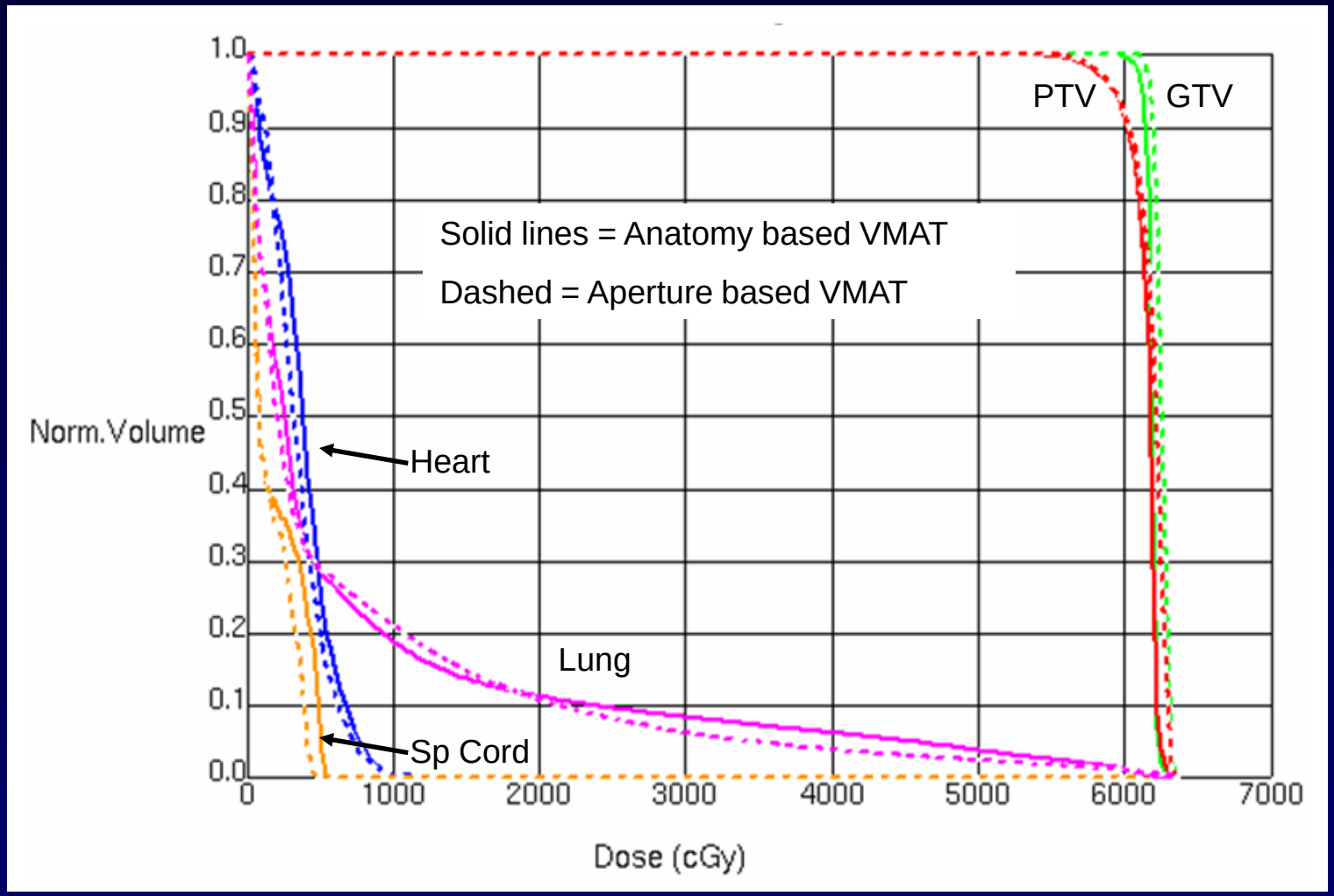
Anatomy Based Inverse Planning

Plan Quality



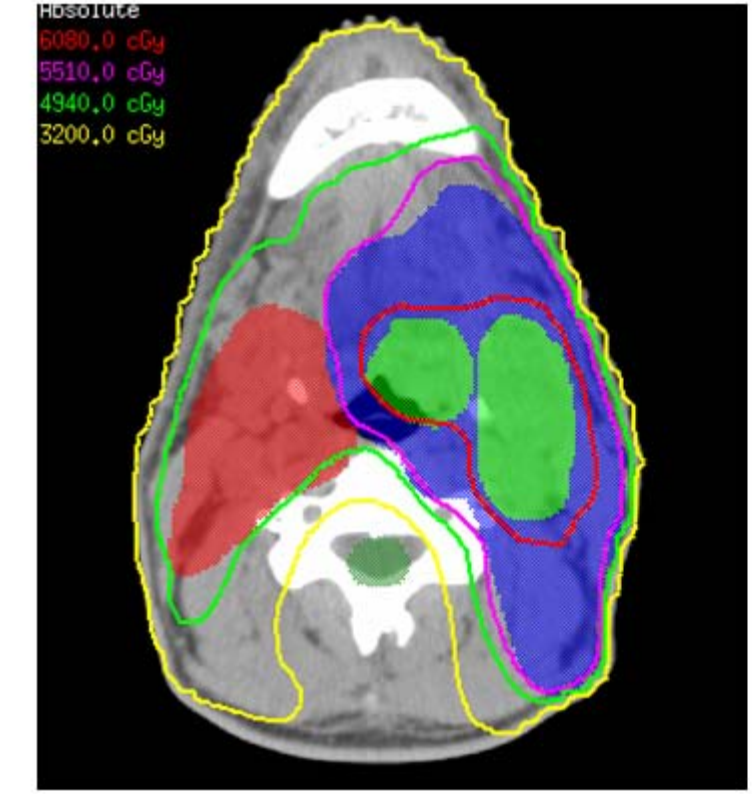
Anatomy Based Inverse Planning

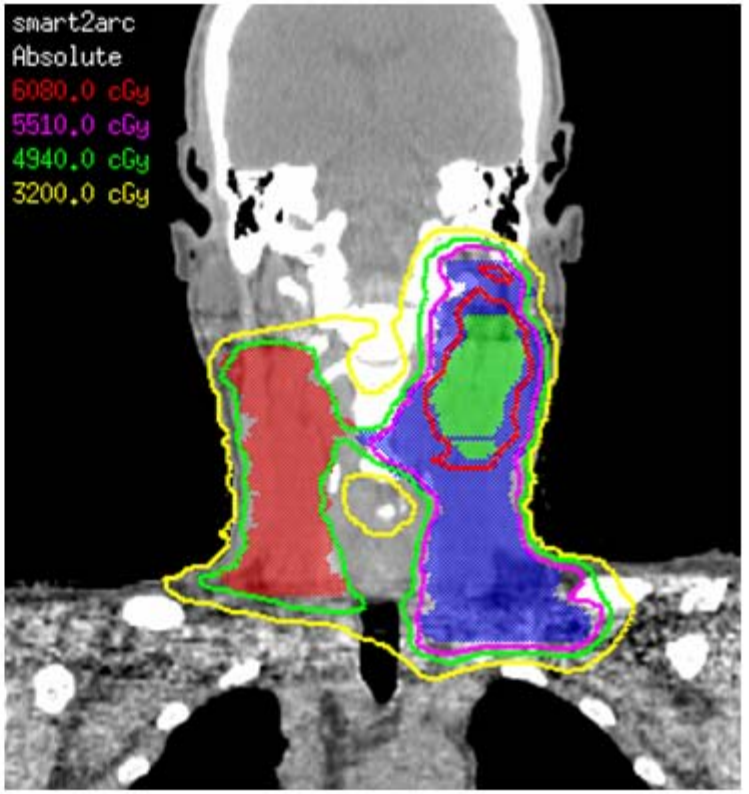
Plan Quality



Aperture Based Inverse Planning

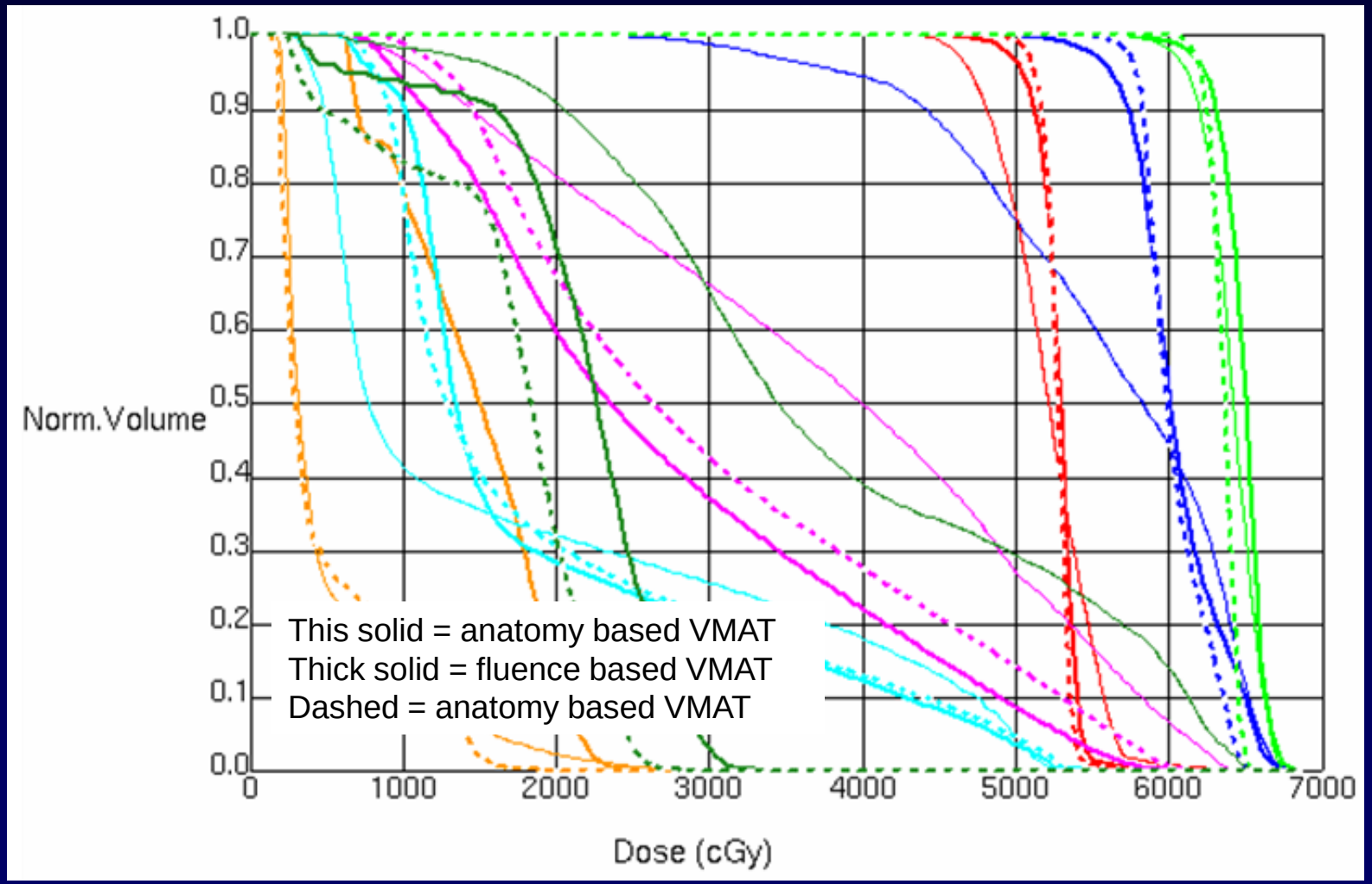
Plan Quality





Anatomy Based Inverse Planning

Plan Quality



Anatomy based inverse planning for IMAT:

20%	1. Directly optimizes the MLC leaf positions
20%	2. Sequences fluence maps into IMAT arcs.
20%	3. May fail to produce uniform target doses for highly complex targets.
20%	4. Requires progressive sampling
20%	5. Utilizes a sweeping window delivery technique.

Answer:

- Anatomy based inverse planning may fail to produce uniform target doses for complex cases.

References:

1. “A Comparison of Treatment Planning and Delivery of VMAT Using Anatomy Based and Fluence Based Inverse Planning with Step and Shoot IMRT”, Med. Phys. 36, 2556 (2009);
2. “Aperture Based Inverse Planning”, Intensity Modulated Radiation Therapy ¬– The State of the Art, Edited by Jatinder R. Palta and T. Rockwell Mackie, D.M Shepard, M.A. Earl, C.X. Yu, and Y. Xiao, Medical Physics Publishing, Madison, WI, 2003.

Monaco VMAT

Monaco Background

- Monaco is an IMRT-only TPS.
- 3 key features: (1) Monte Carlo dose calculation; (2) Biology based IMRT optimization; (3) VMAT inverse planning.

Monaco VMAT Algorithm

- Optimized fluence maps are produced at a series of discrete beam angles.
- These optimized fluence are then converted into deliverable VMAT arcs.

Monaco – Sweeping Window

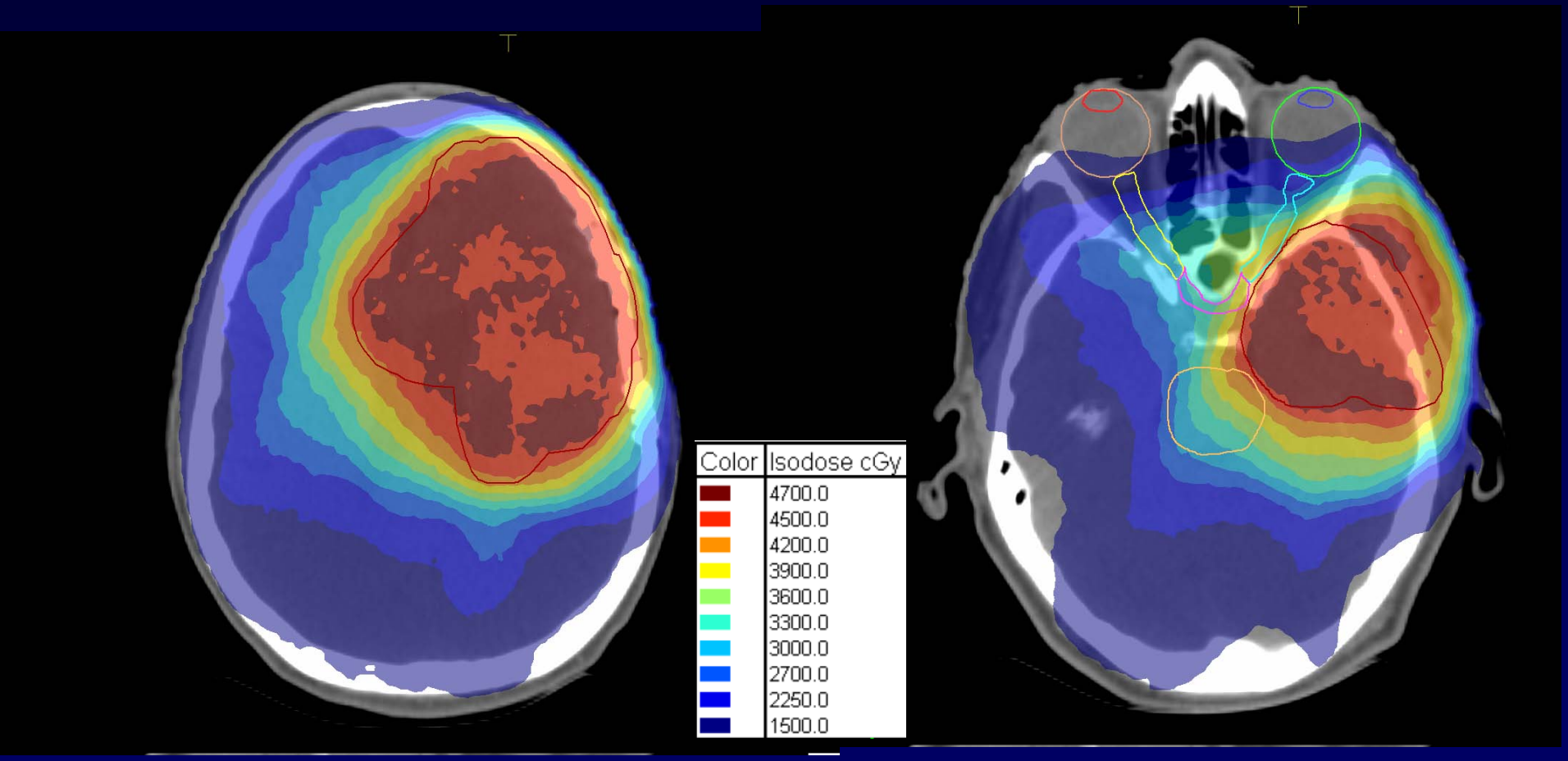
- Monaco produces plans using a “sweeping leaf sequencer” where the leaves move unidirectionally across the field.
- The leaf movement continues to alternate between sectors of the arc.

Sweeping-window arc therapy: an implementation of rotational IMRT with automatic beam-weight calculation

C Cameron 2005 *Phys. Med. Biol.* **50** 4317-4336 doi: 10.1088/0031-9155/50/18/006 Help

Monaco VMAT

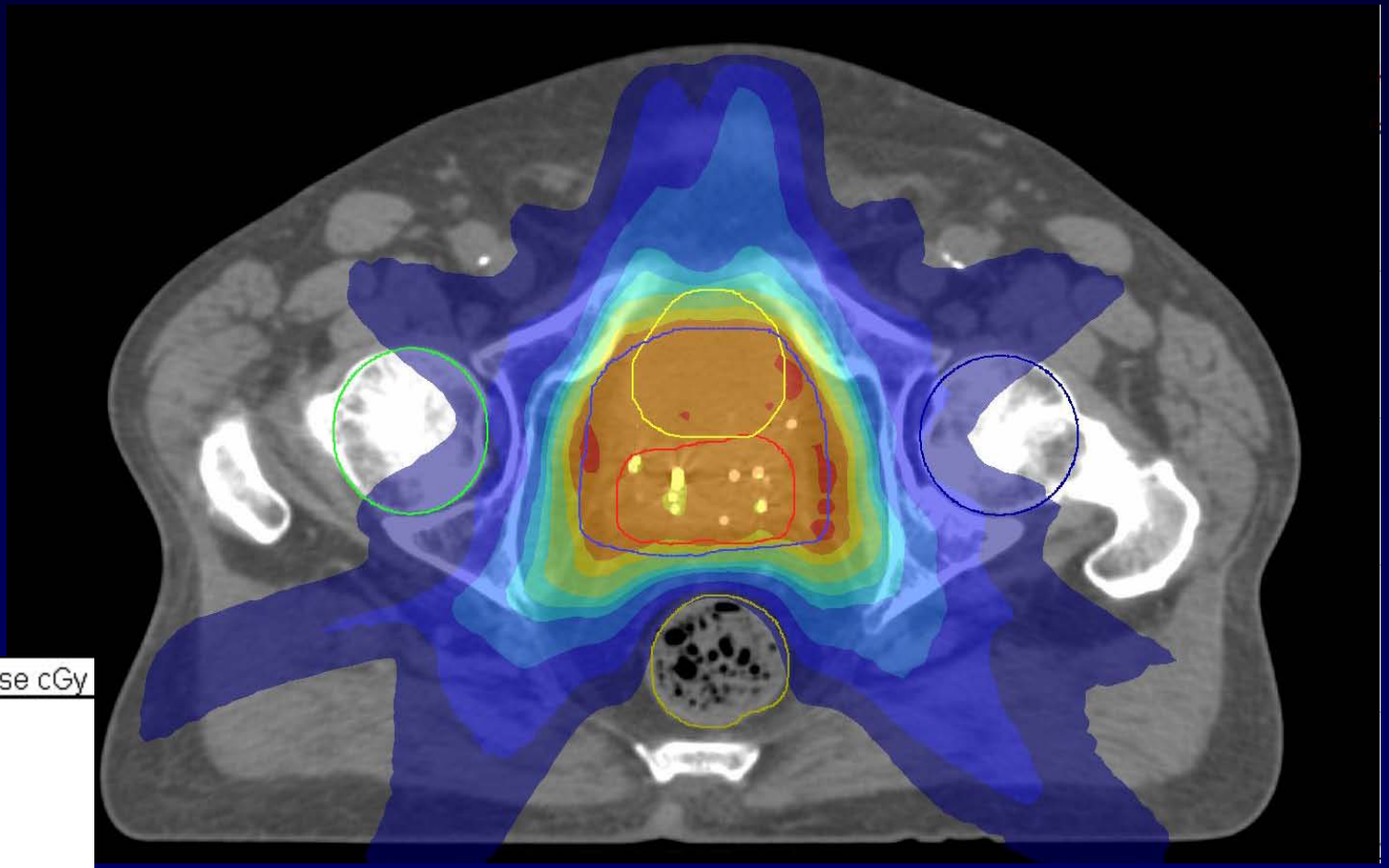
Case #1 - Brain



- 180 cGy/fraction, 320 MU
- Delivery time = 4 min. 40 sec.

Monaco VMAT

Case #2 - Prostate



Color	Isodose cGy
	4800.0
	4700.0
	4500.0
	4275.0
	3800.0
	3500.0
	3200.0
	2550.0
	2000.0
	1500.0

- 180 cGy/fraction, 678 MU
- Delivery time = 3 min 54 sec

Verification of Monaco VMAT: Matrixx and Ion Chamber

	Coronal 3mm/3%	Sagittal 3mm/3%	Ion Chamber *	Delivery time
Pelvis	99.7%	99.9%	-1.8%	3'30"
Esophagus	99.6%	97.3%	0.9%	4'14"
Pancreas	99.8%	99.7%	-1.7%	4'04"
Brain	98.6%	98.0%	-2.0%	4'03"
Prostate	99.6%	99.1%	-2.3%	3'49"
HN	96.4%	96.0%	-3.3%	8' 48"

* Ion chamber data= (Measured – Planned)/Planned

Nucletron – Oncentra VMAT

- Oncentra VMAT module was developed by RaySearch Laboratories.
- RaySearch also developed the SmartArc module for Pinnacle.
- Underlying VMAT planning engine is very similar.

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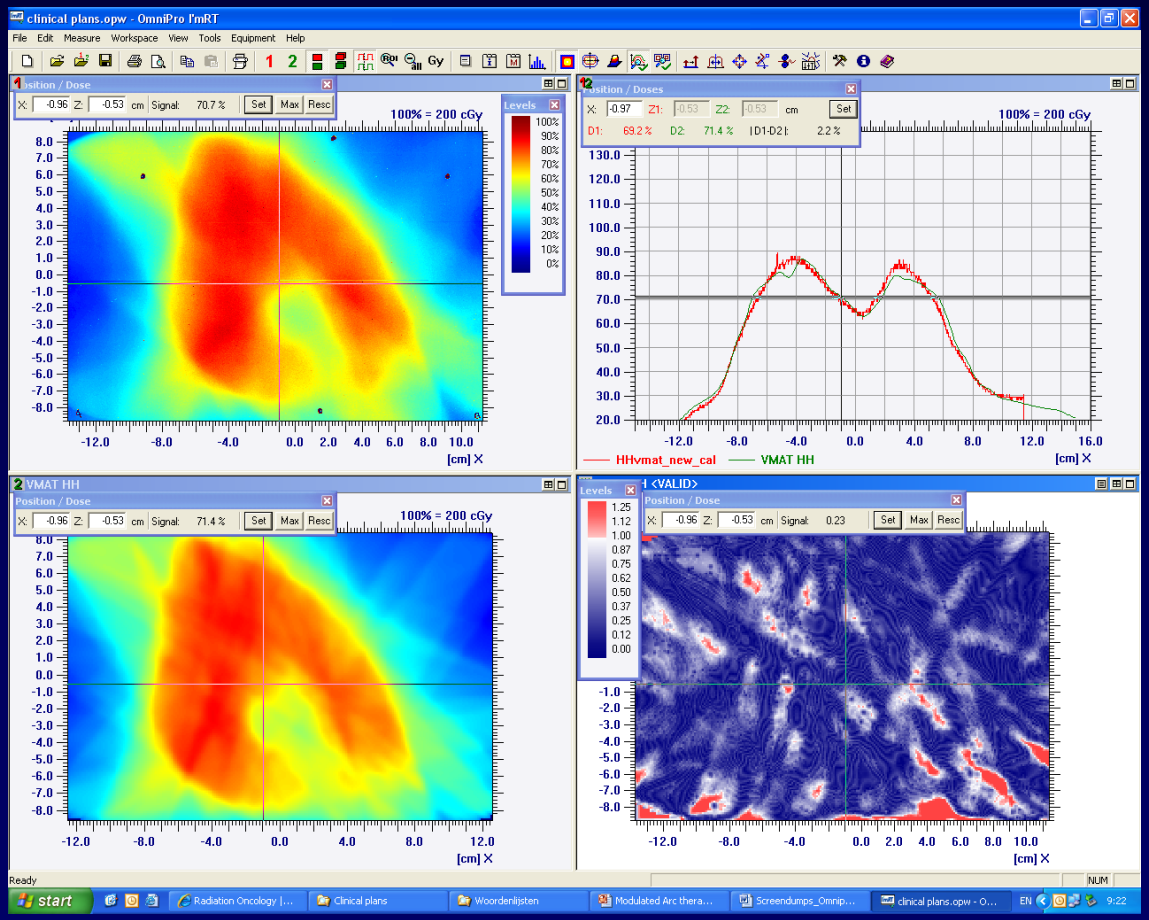
H&N Verification

VMAT

γ(3%,3mm)

planned

measured



Siemens/Prowess CBT

- Prowess' Direct Aperture Optimization algorithm is used to develop VMAT plans for delivery on Siemens linacs using Siemens' cone beam therapy (CBT) technique.

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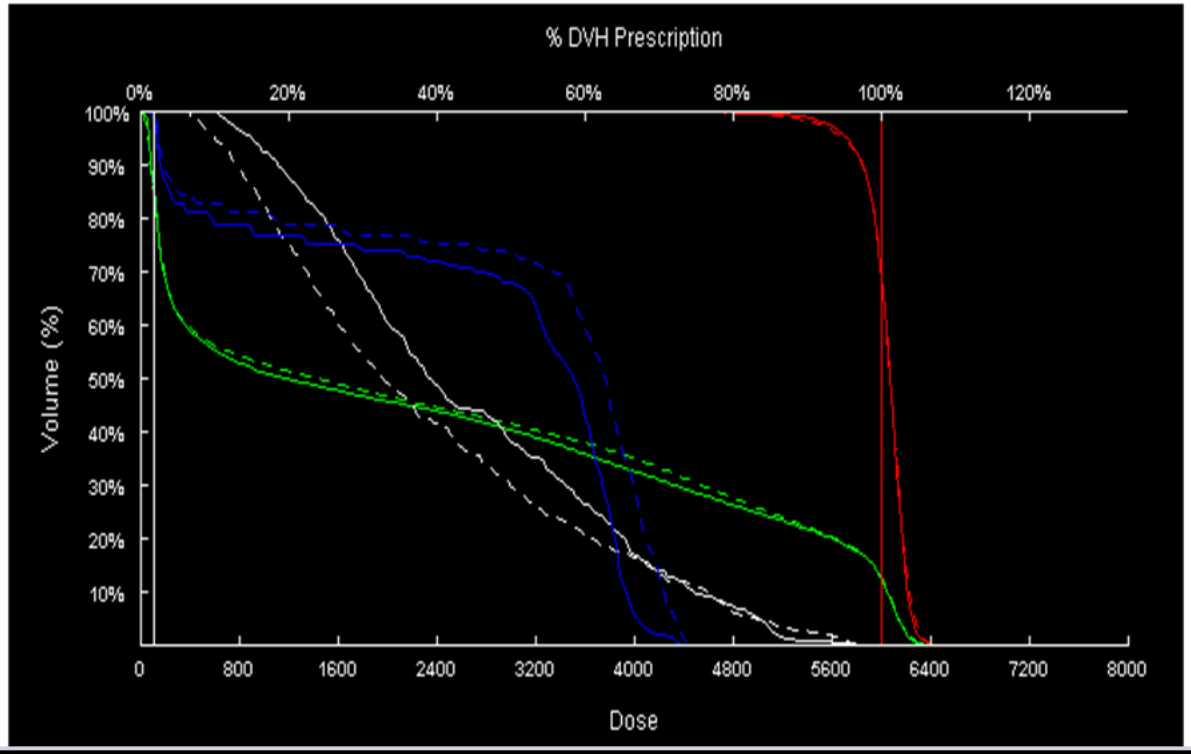
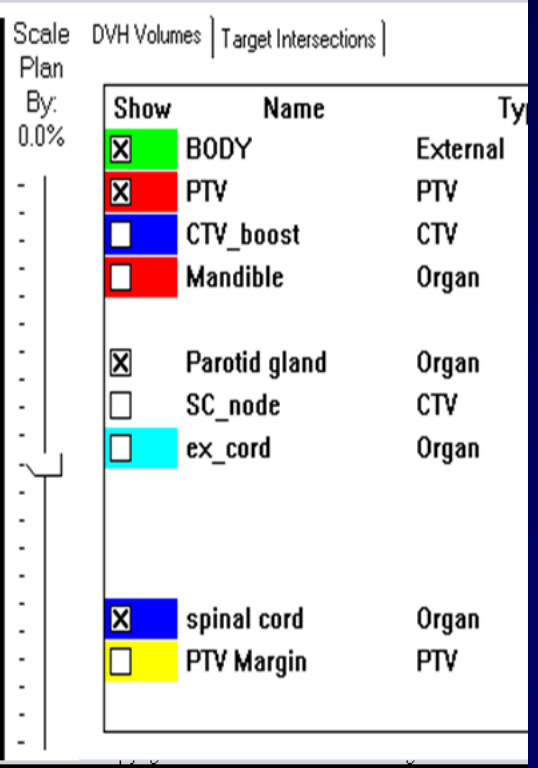
SIEMENS

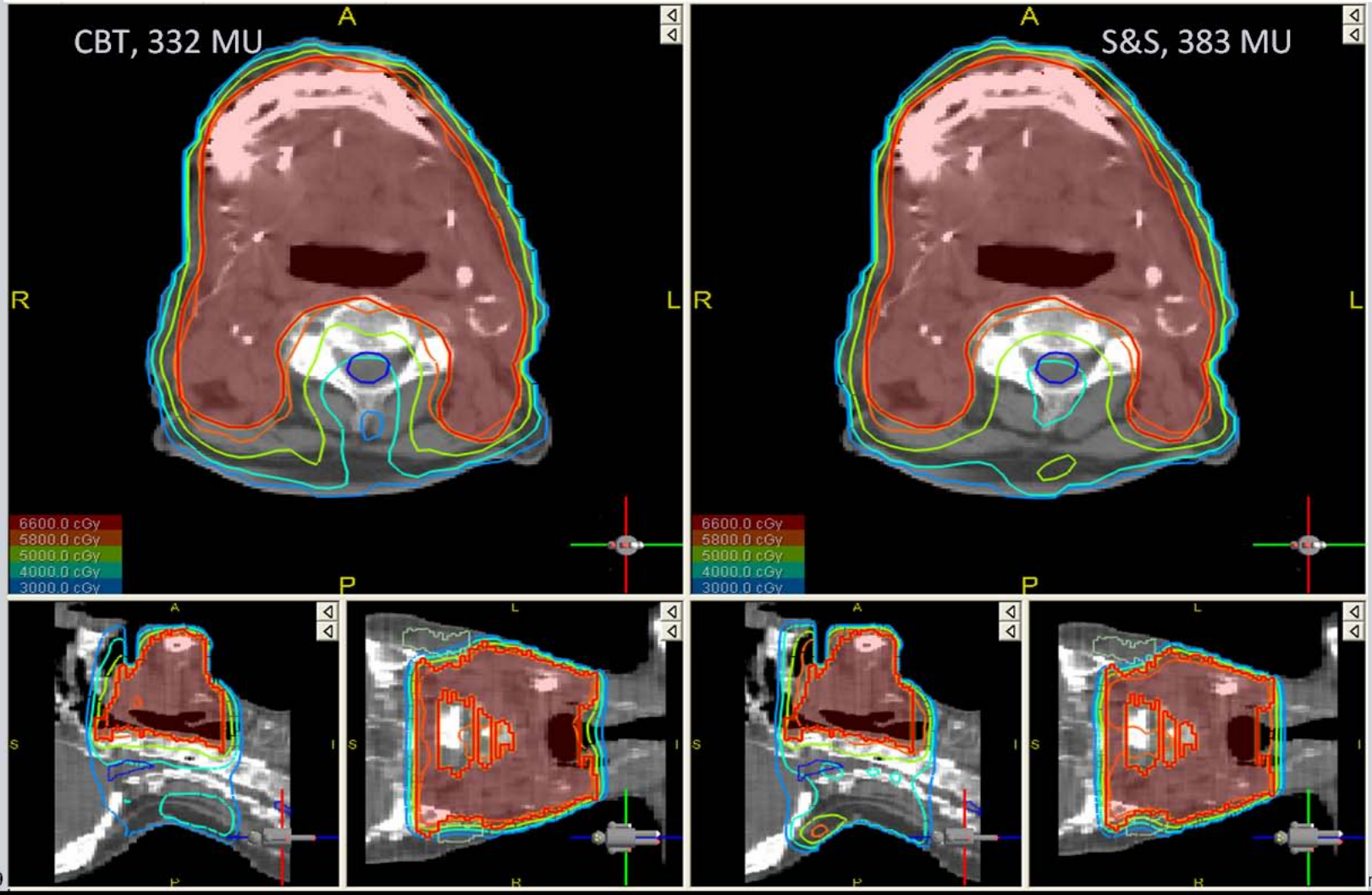
Prowess H&N IMRT (S&S and CBT) – MCW case 6/2009

- Step&Shoot IMRT (DAO) (dashed), and CBT (solid)
- S&S : 383 MU, 7 beams, 5 segments/beam
- CBT : 332 MU, 3-15 MU/OP, nominal gantry speed ~1.5 deg/s





SIEMENS



2009 rved.

VMAT Plan Design

- Single arc vs. Multi-arc delivery
- Coplanar vs. Noncoplanar

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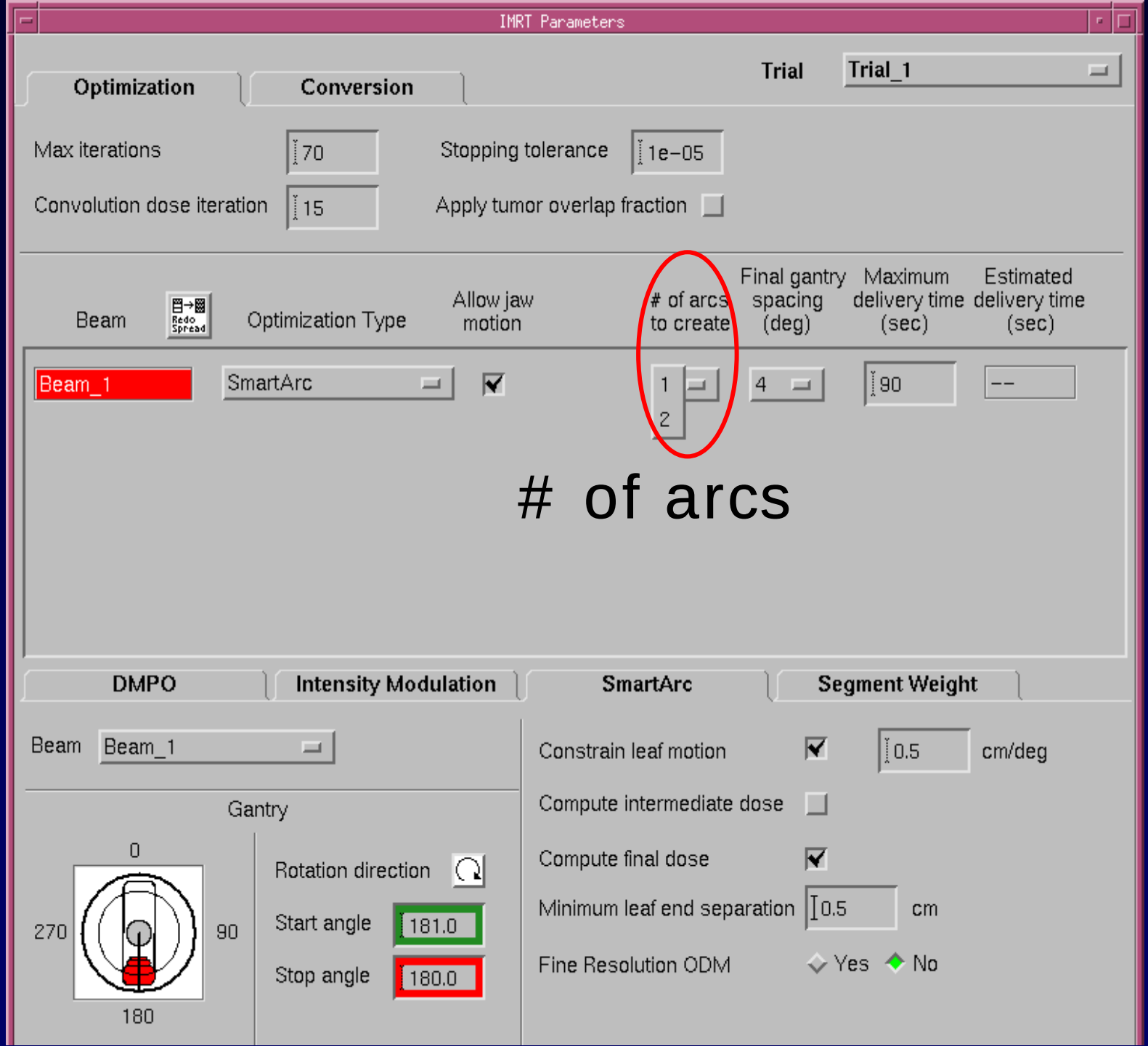
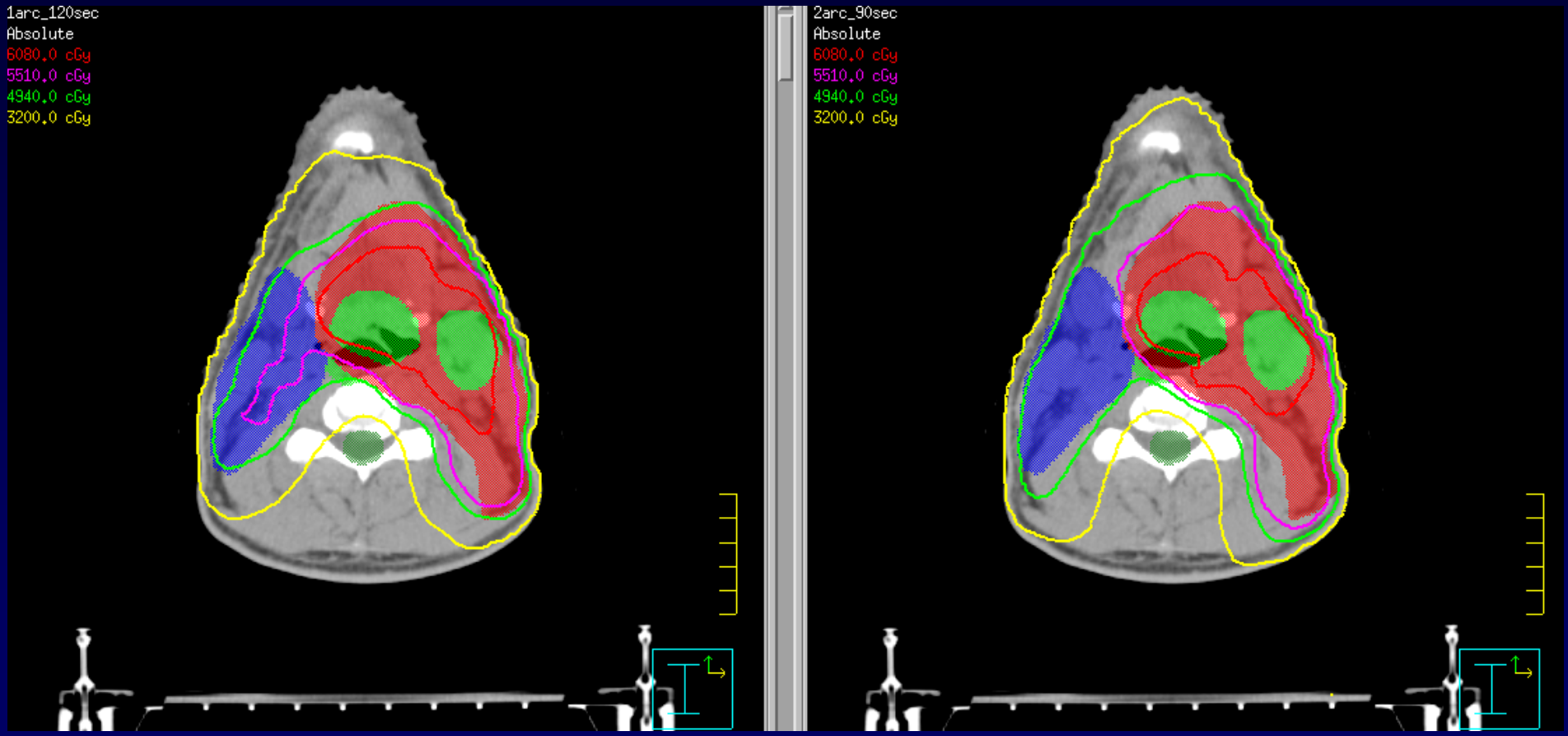
Single vs. Multi Arc

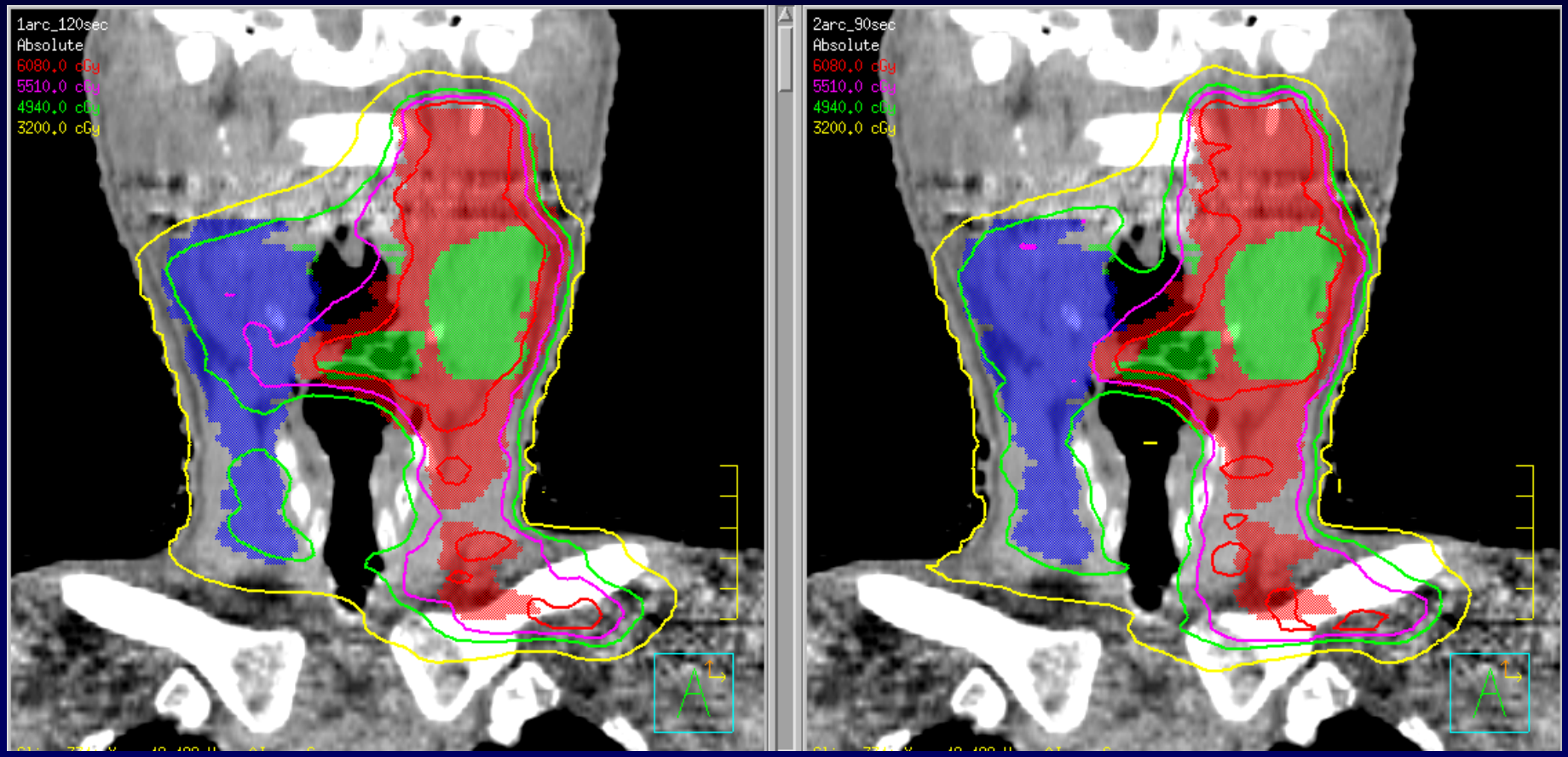
- Increasing the number of arcs provides additional flexibility in shaping the dose distribution.
- The key questions are which cases benefit from the use of multiple arcs and what number of arcs should be used.


IMRT Parameters
Trial
Trial_1
Optimization
Conversion
Max iterations
70
Stopping tolerance
1e-05
Convolution dose iteration
15
Apply tumor overlap fraction
Beam
Redo Spread
Optimization Type
Allow jaw motion
# of arcs to create
Final gantry spacing (deg)
Maximum delivery time (sec)
Estimated delivery time (sec)
Beam_1
SmartArc
1
2
4
90
--
# of arcs
DMPO
Intensity Modulation
SmartArc
Segment Weight
Beam
Beam_1
Gantry
0
270
90
180
Rotation direction
Start angle
181.0
Stop angle
180.0
Constrain leaf motion
0.5
cm/deg
Compute intermediate dose
Compute final dose
Minimum leaf end separation
0.5
cm
Fine Resolution ODM
Yes
No

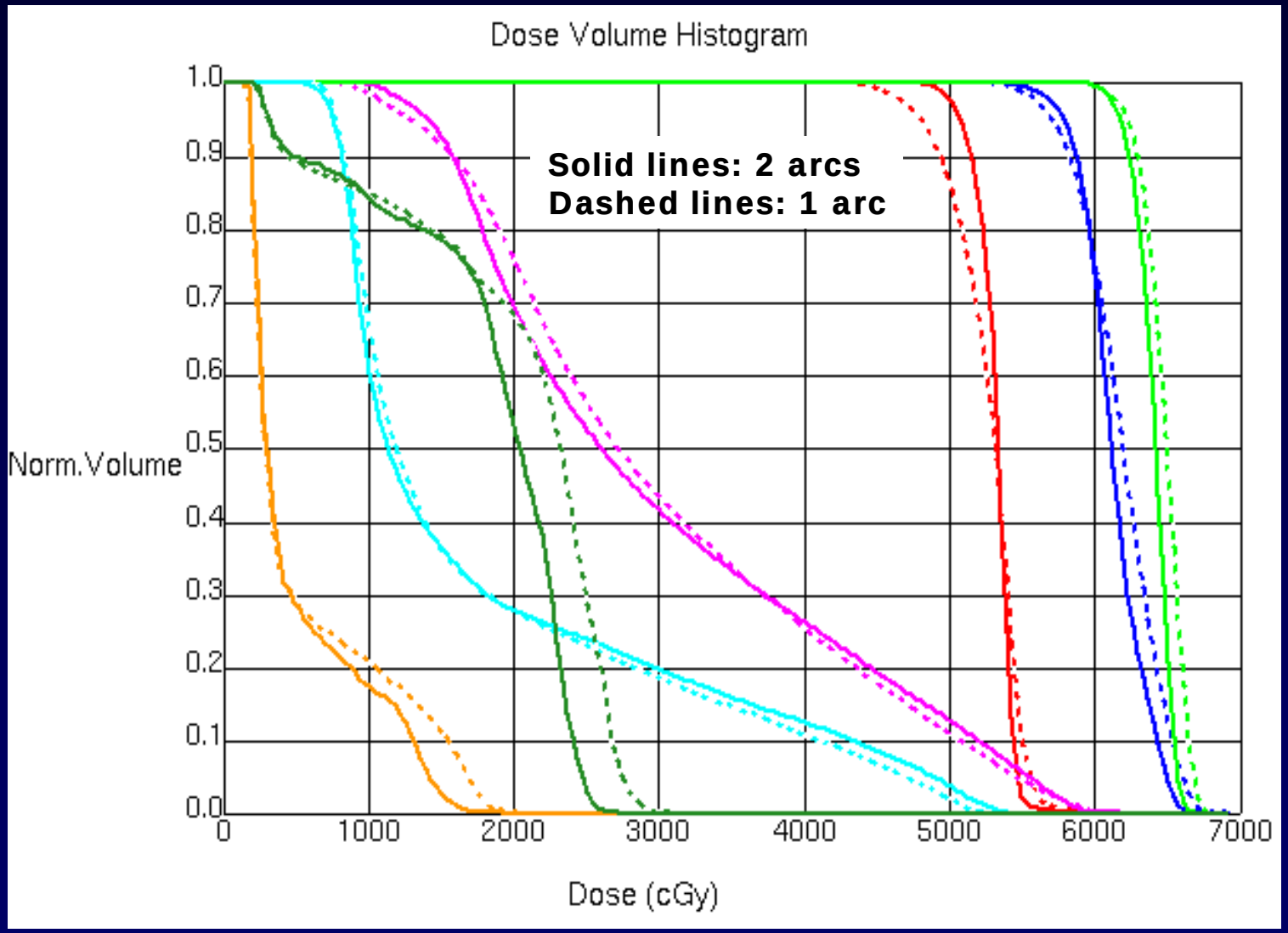
1 arc vs. 2 arcs



1 arc vs. 2 arcs



1 arc vs. 2 arcs



Delivery time: 1 arc= 124 sec, 2 arcs = 181 sec

What treatment site would most likely see a dosimetric benefit to increasing the # of VMAT arcs to more than 1?

20%	1. Lung
20%	2. Prostate
20%	3. Brain
20%	4. Pancreas
20%	5. Head & Neck

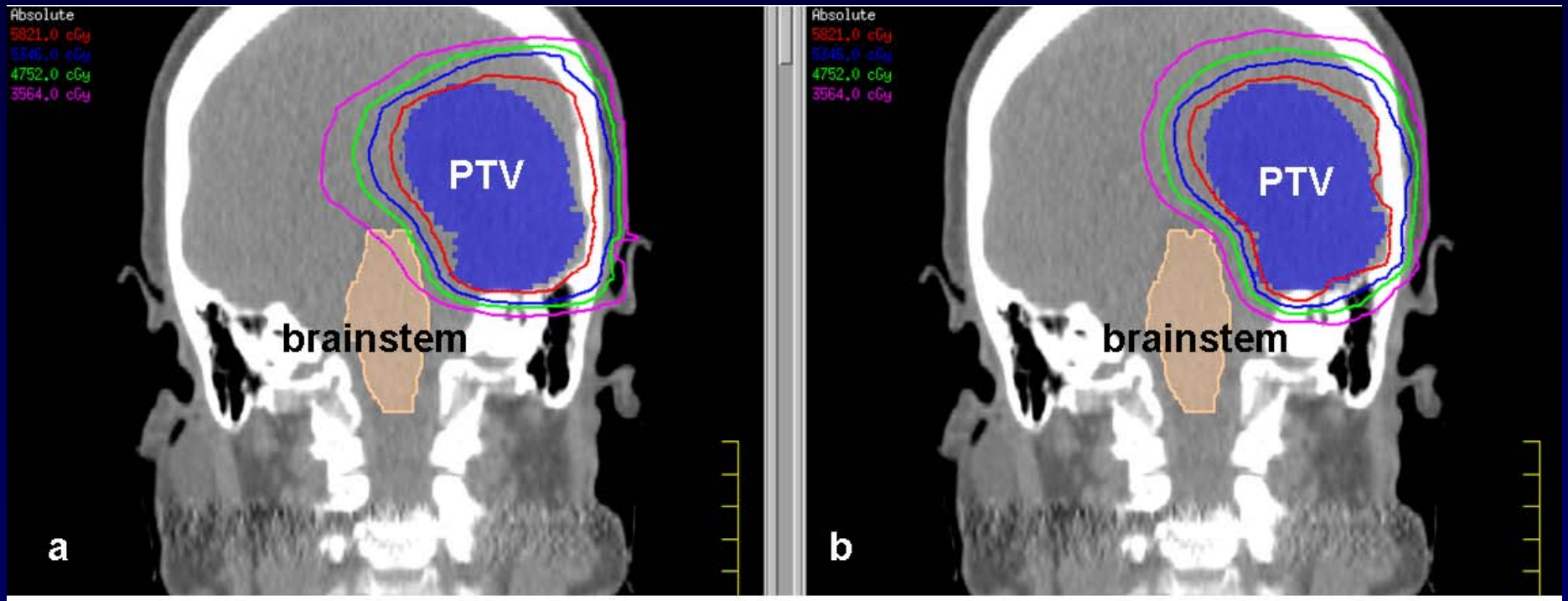
Answer:

- Due to the complex target volumes and the frequent use of multiple prescription levels head & neck cases are most likely to see significant dosimetric improvement when using more than 1 VMAT arc.

Reference:

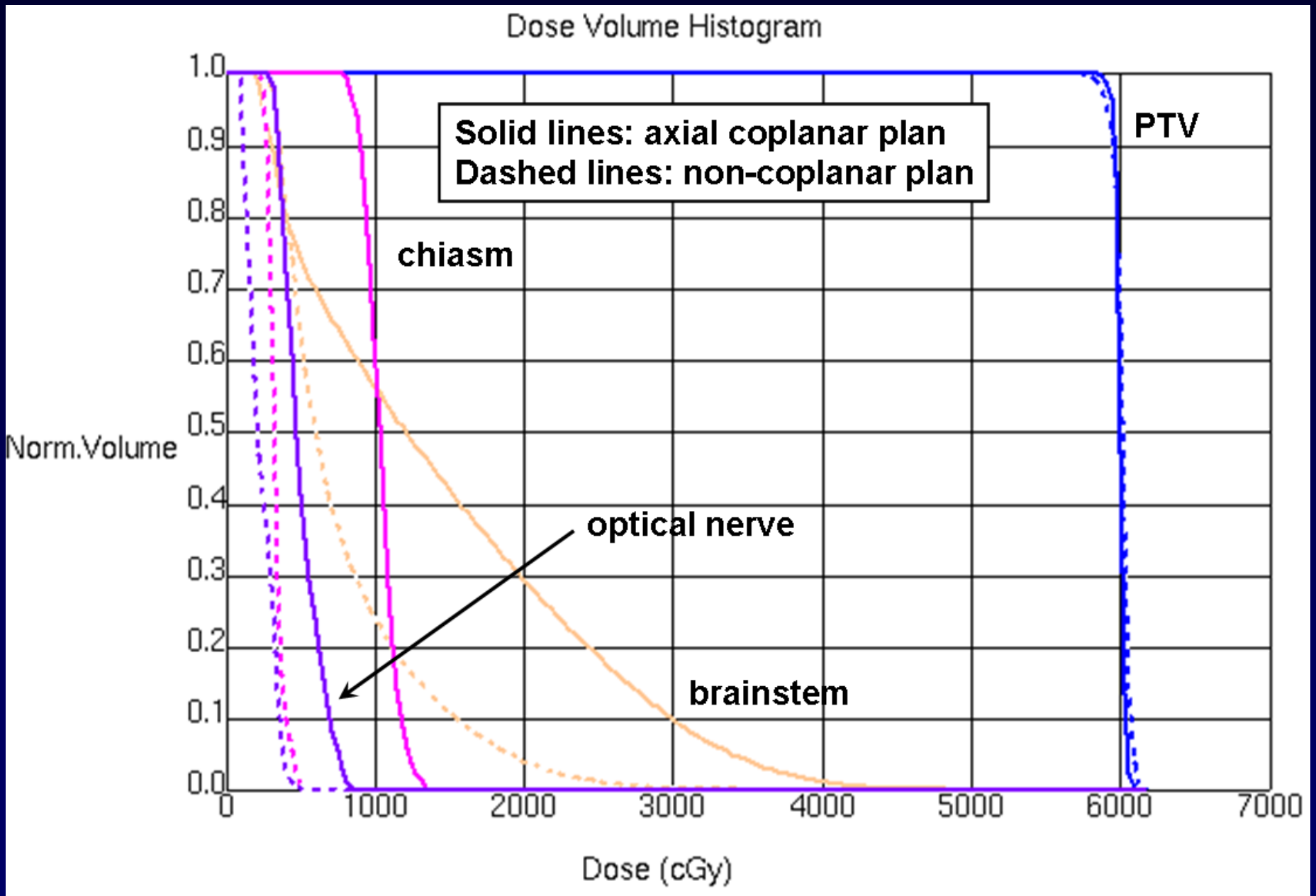
Single-Arc IMRT?, Thomas Bortfeld and Steve Webb, Physics in Medicine and Biology, Volume 54, Number 1

Coplanar vs. Non-coplanar VMAT



axial coplanar plan

non-coplanar plan


Dose Volume Histogram
Solid lines: axial coplanar plan
Dashed lines: non-coplanar plan
PTV
chiasm
optical nerve
brainstem
Norm.Volume
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1000
2000
3000
4000
5000
6000
7000
Dose (cGy)

Dosimetric Comparison of IMAT with Conventional IMRT Delivery Techniques

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VMAT vs. Tomotherapy: Comparison Study

- Collaborative study between Swedish Cancer Institute and University of Virginia.
- 6 prostate, 6 head-and-neck, and 6 lung cases were selected for this study.
- Fixed field IMRT, VMAT, and Tomotherapy were compared in terms of plan quality, delivery time, and delivery accuracy.

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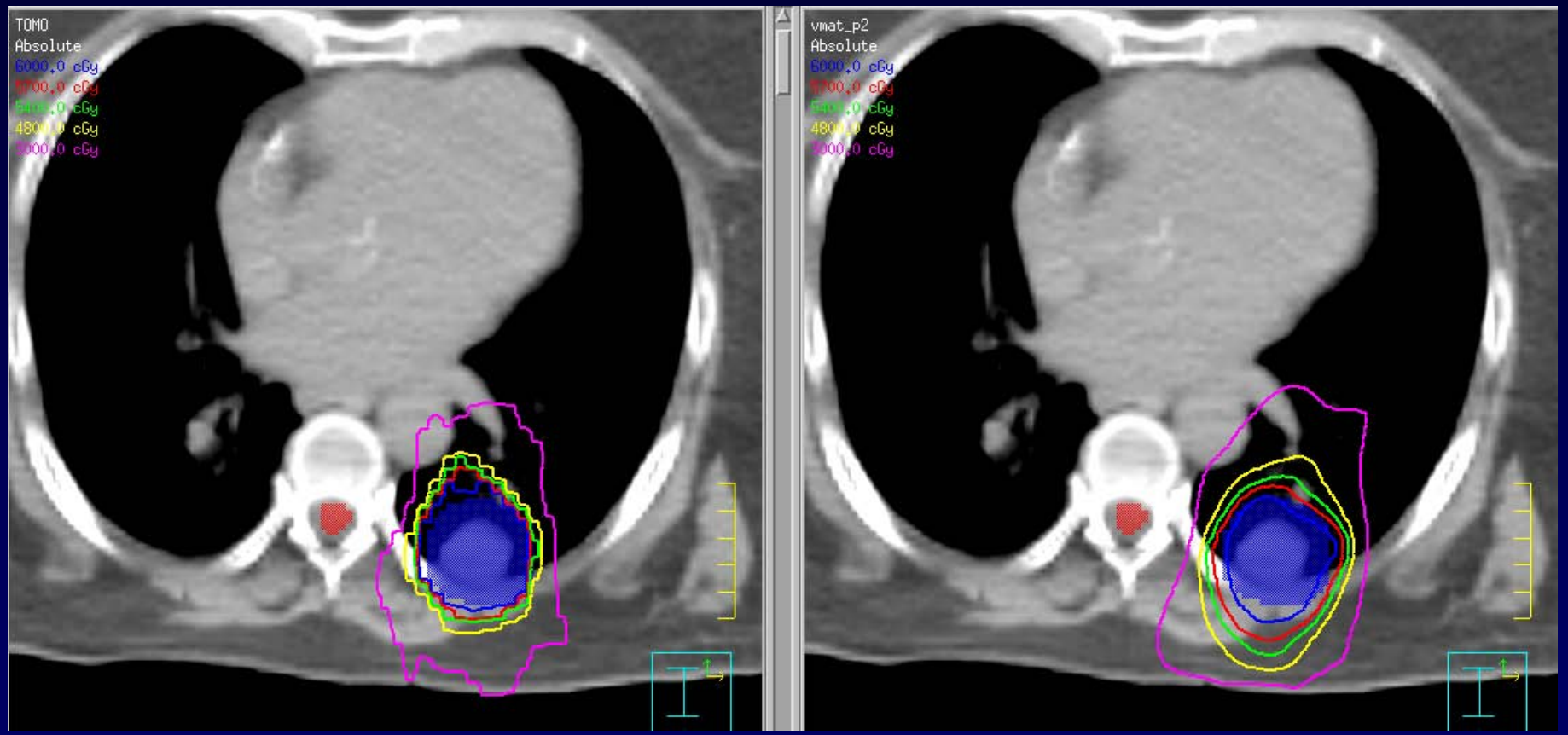
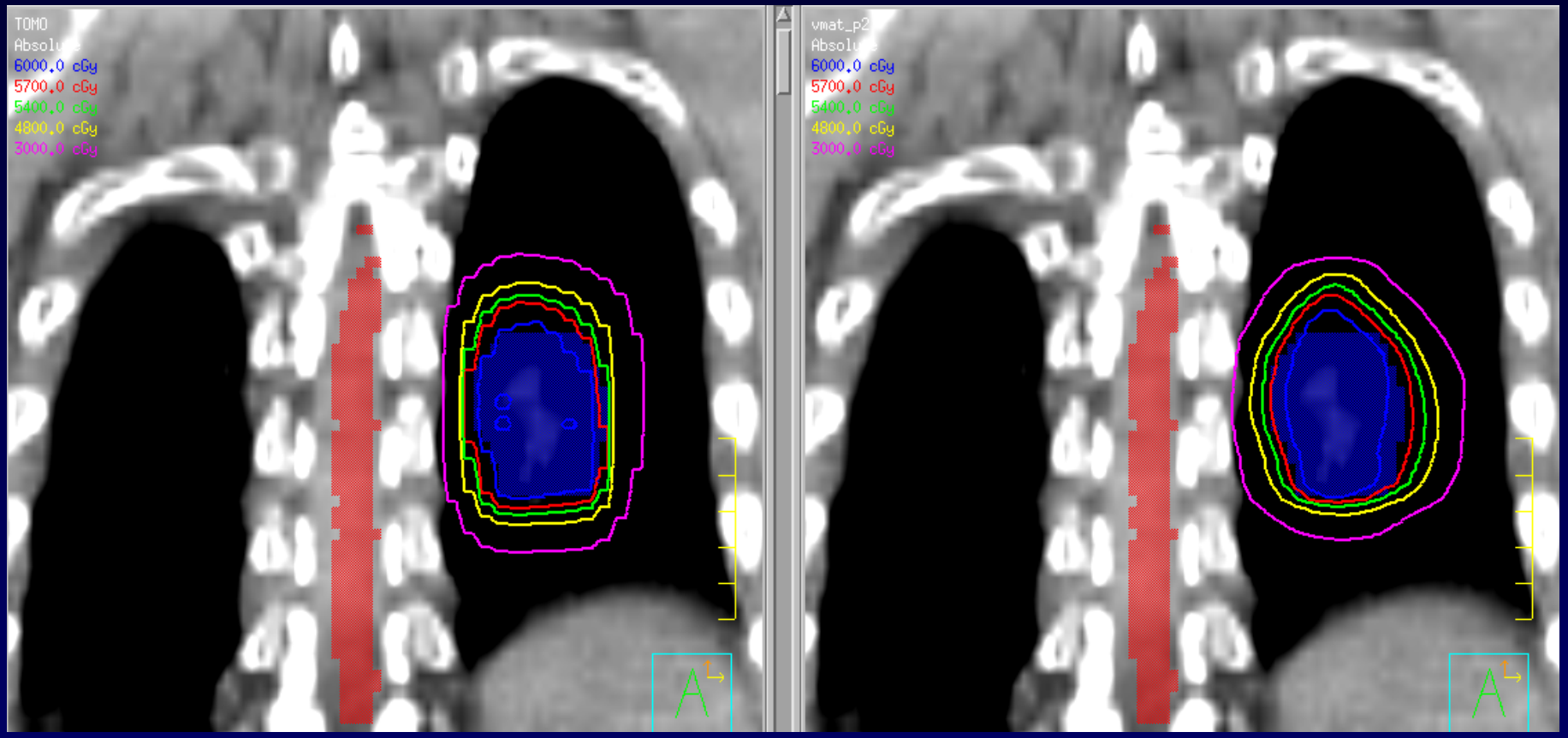
Lung Case



Helical Tomotherapy

1-arc VMAT

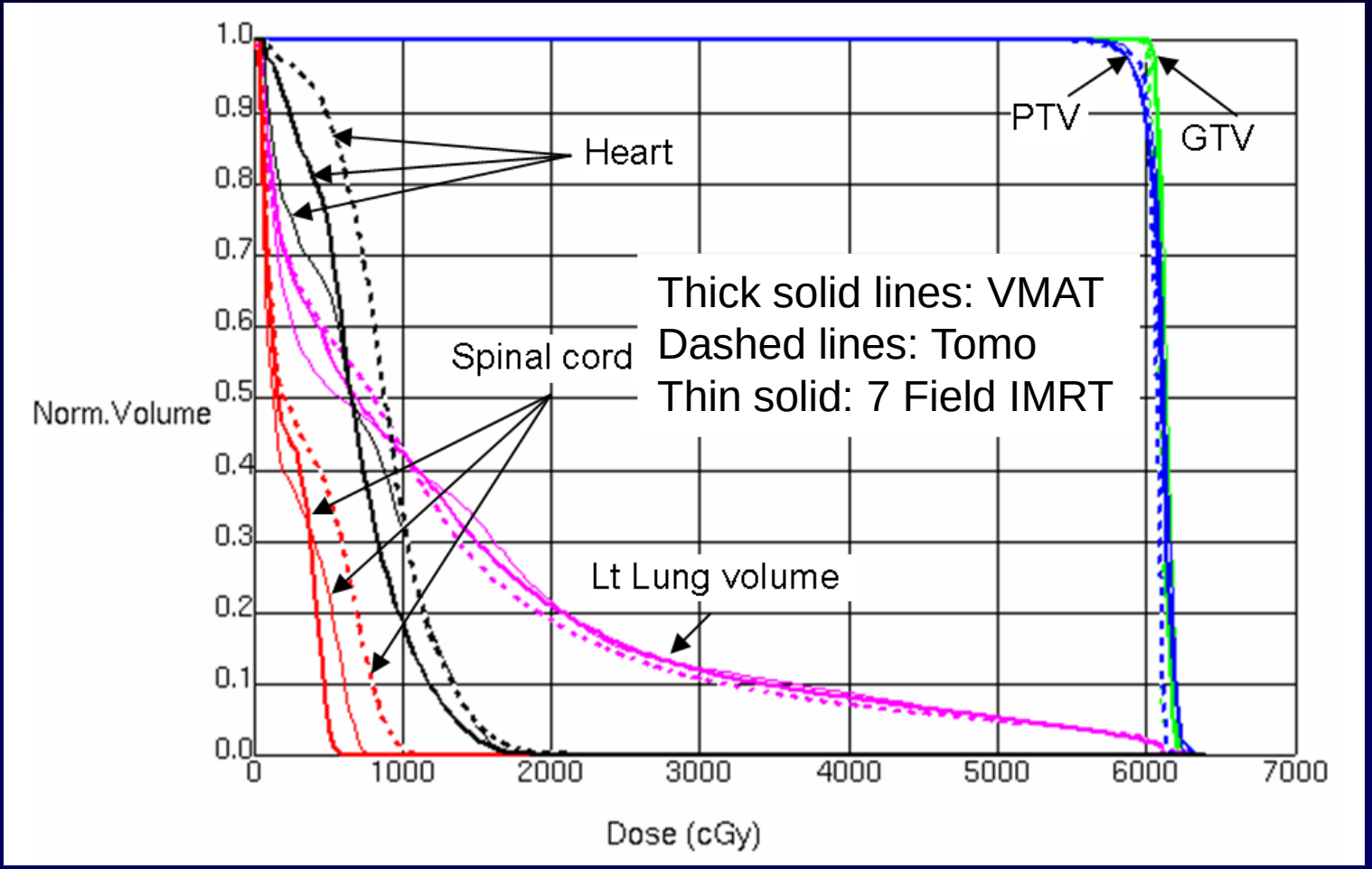
Lung Case



Helical Tomotherapy

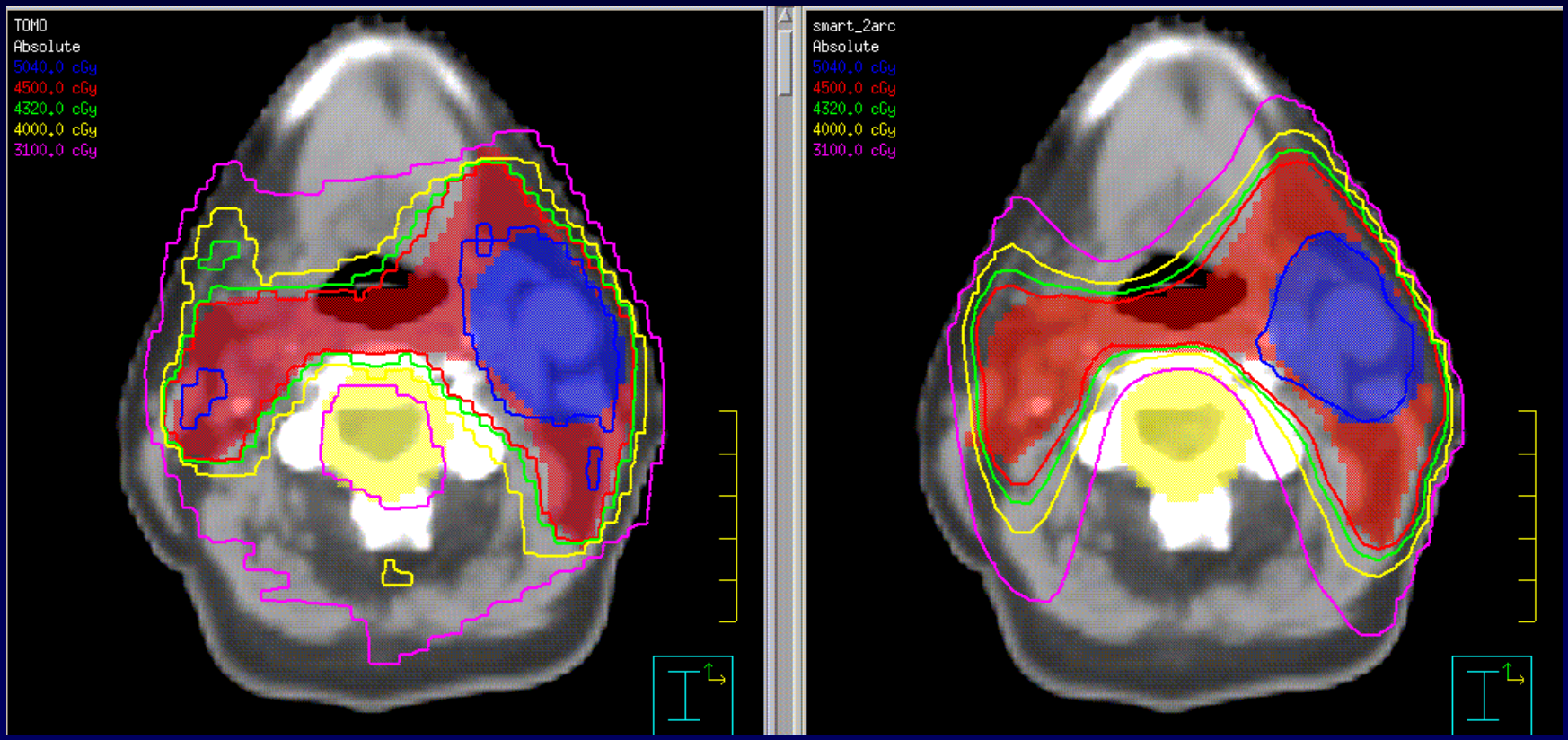
1-arc VMAT

Lung Case



- Delivery time for VMAT plan was 2’04”
- Delivery time for the Tomotherapy plan was 5’44”
- Delivery time for fixed field IMRT was 7’26”

Head & Neck Case #1

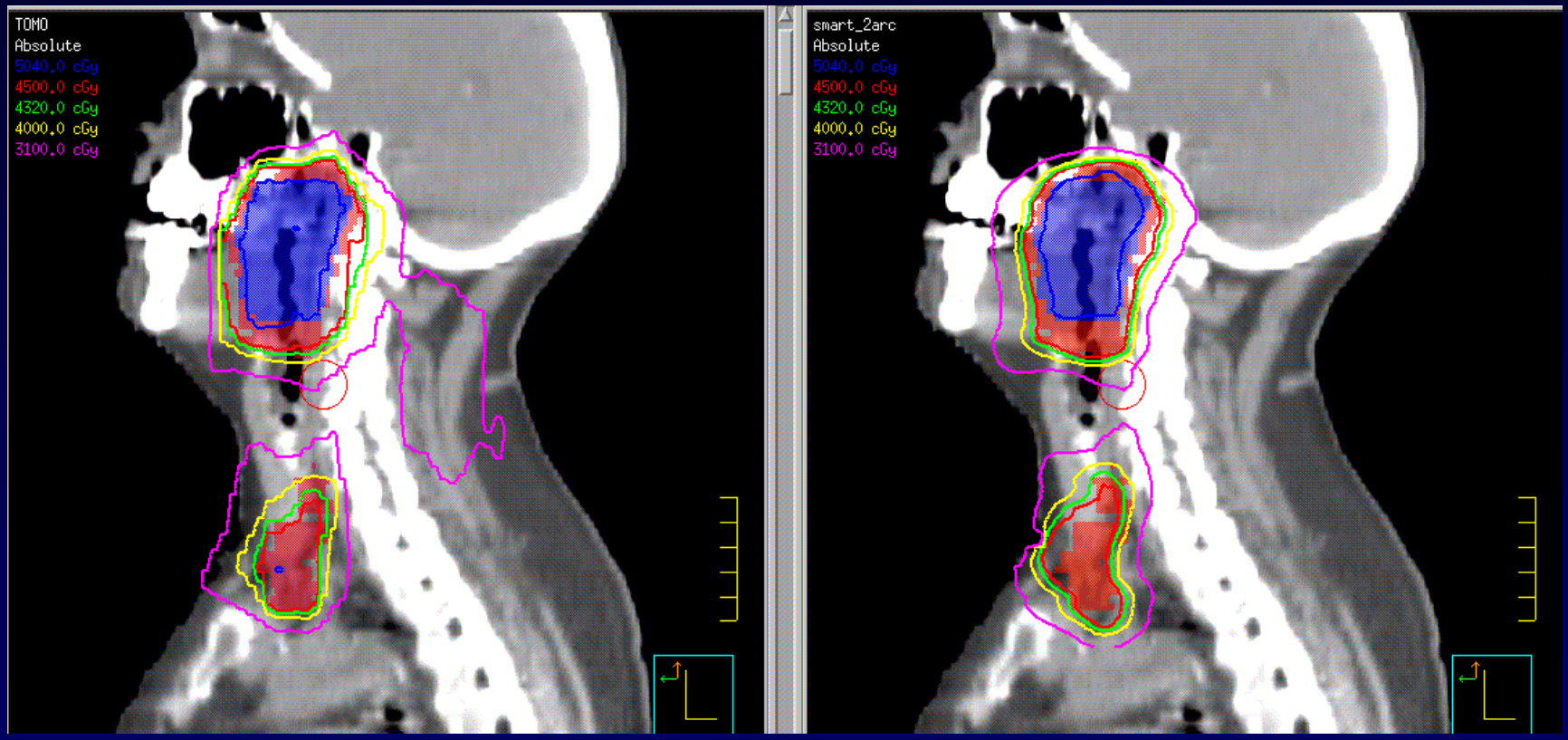


Helical Tomotherapy

2-arc VMAT

- Two targets with prescription levels of 5040 and 4500 cGy

Head & Neck Case #1

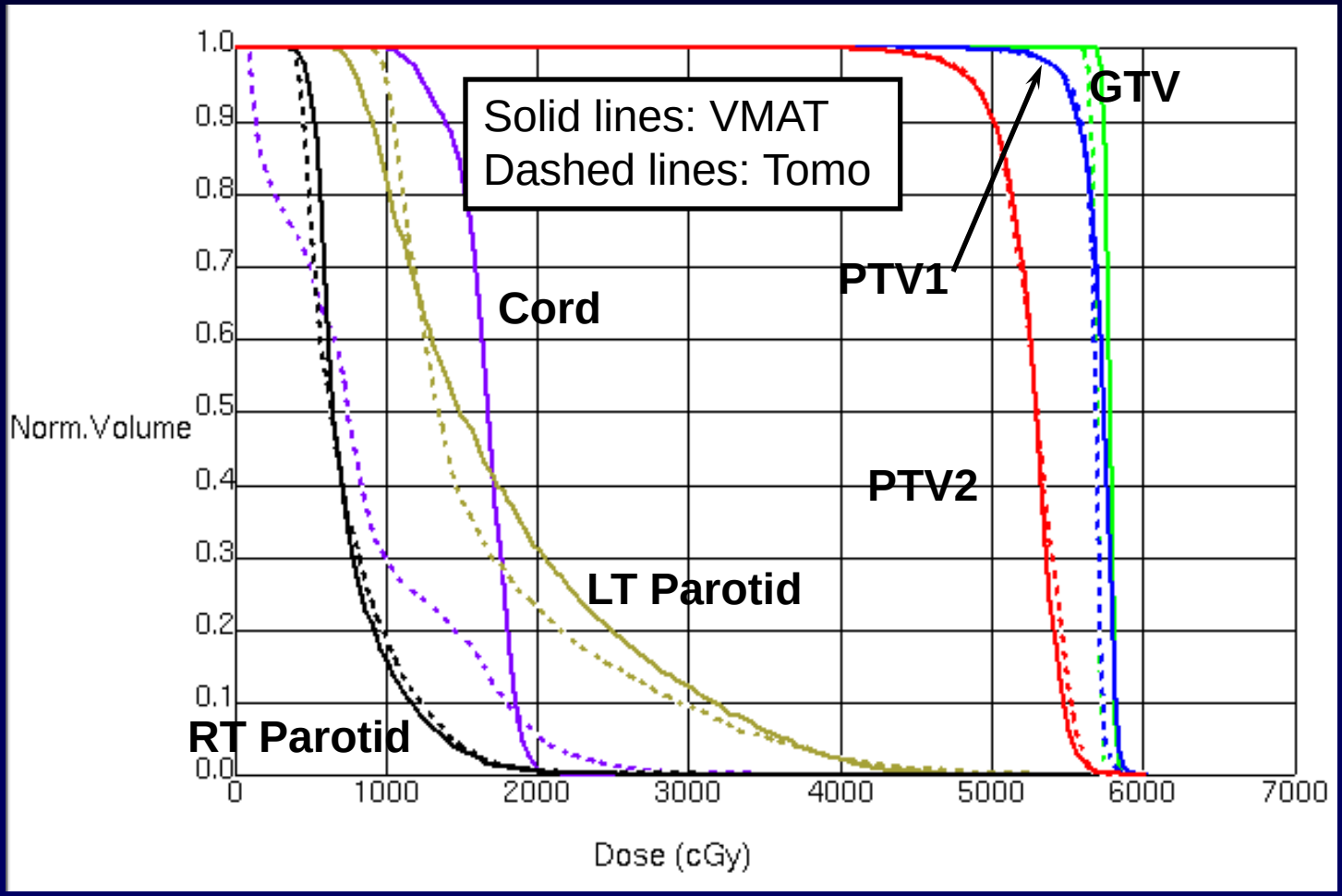


Helical Tomotherapy

2-arc VMAT

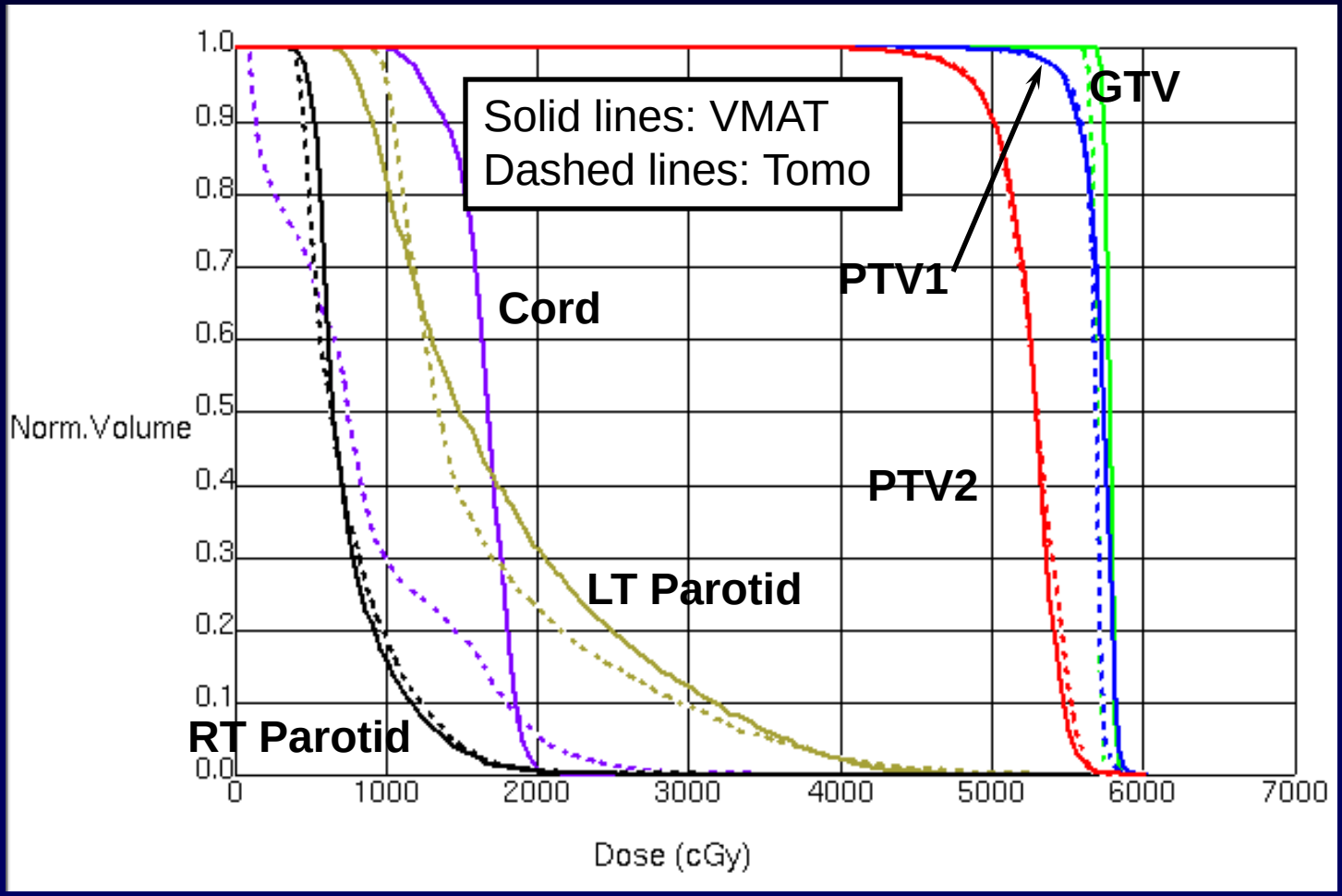
- Two targets with prescription levels of 5040 and 4500 cGy

Head & Neck Case #1



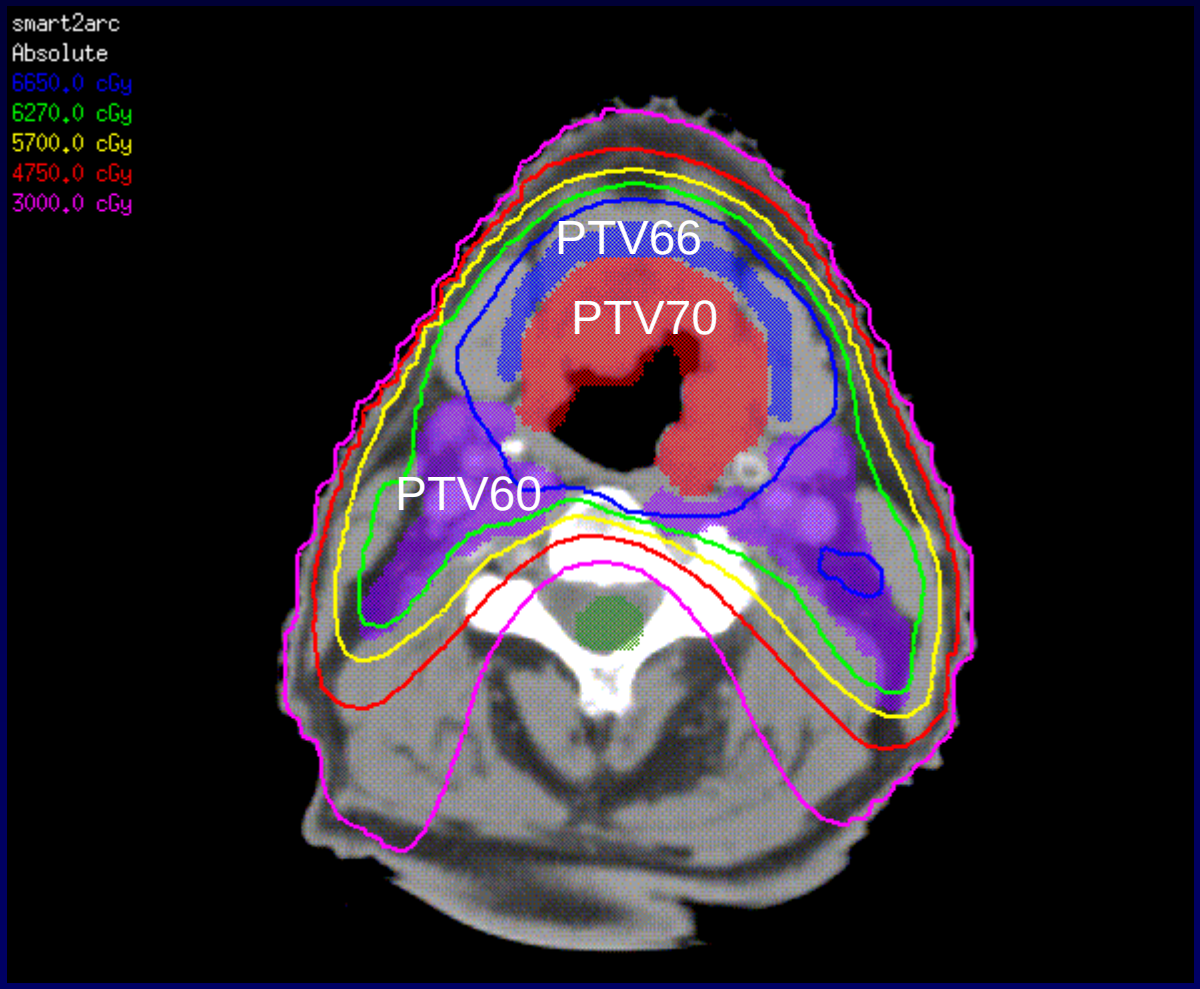
- Average V95: Tomotherapy = 98.4% and VMAT = 98.6%
- Max cord dose: Tomotherapy = 34.4 Gy and VMAT = 21.6 Gy
- Mean parotids dose: Tomotherapy = 12.1 GY and VMAT = 12.6 Gy.

Head & Neck Case #1



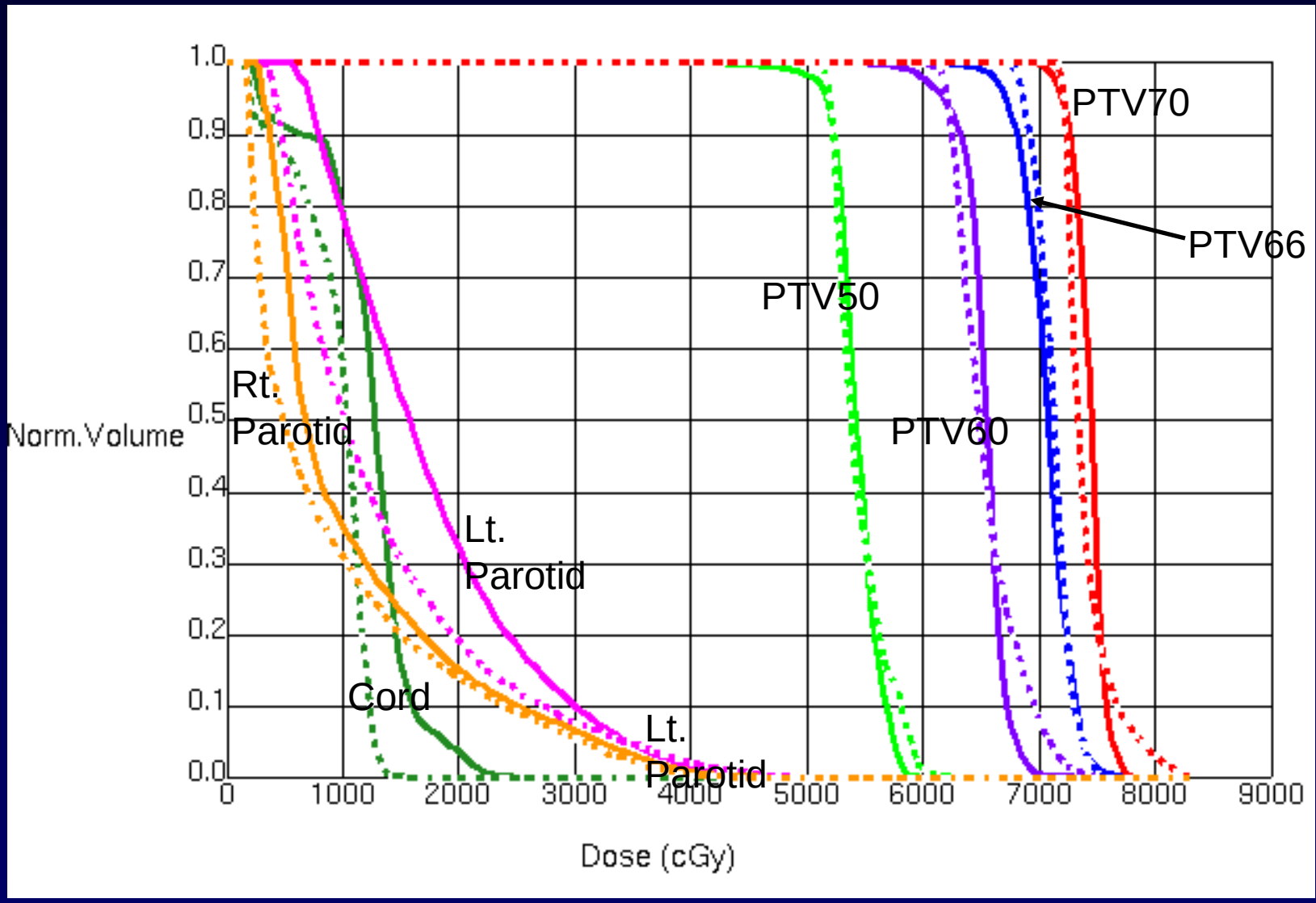
- Delivery time for VMAT plan was 4’25”
- Delivery time for the Helical Tomotherapy plan was 9’07”

H&N Example #2



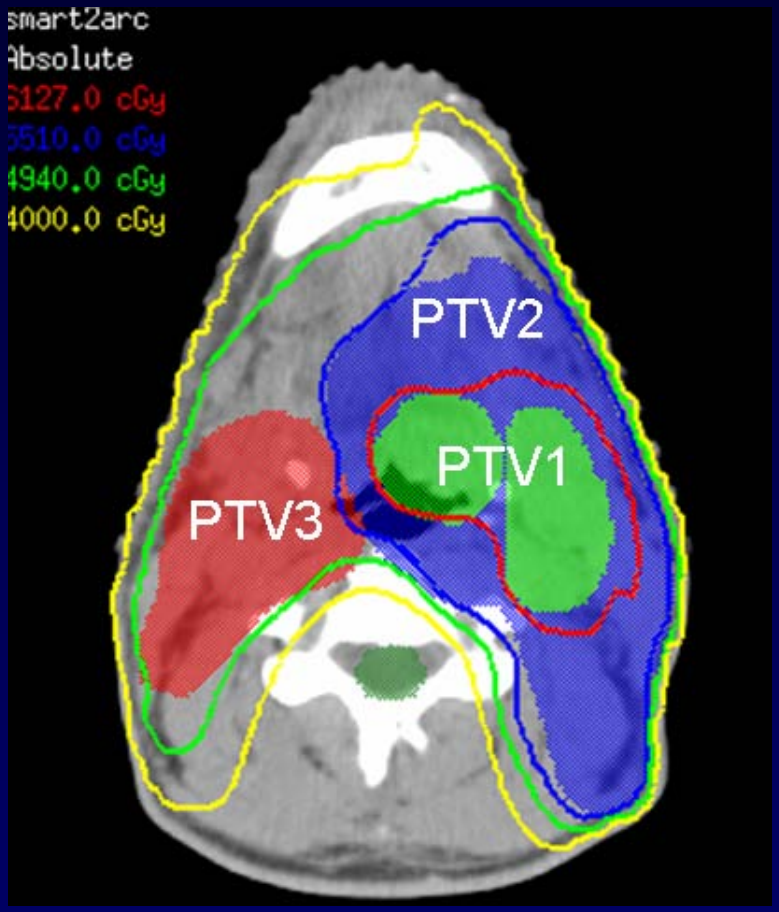
- 2 arcs, 512 monitor units
- Deliver time = 4 minutes 7 seconds

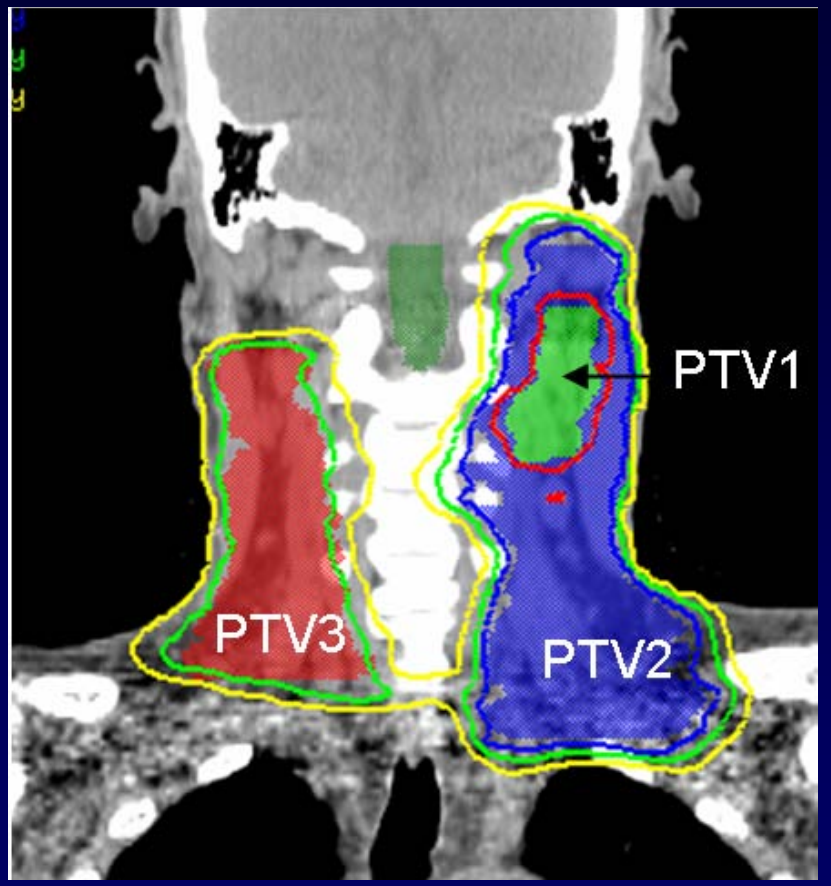
H&N Example #2



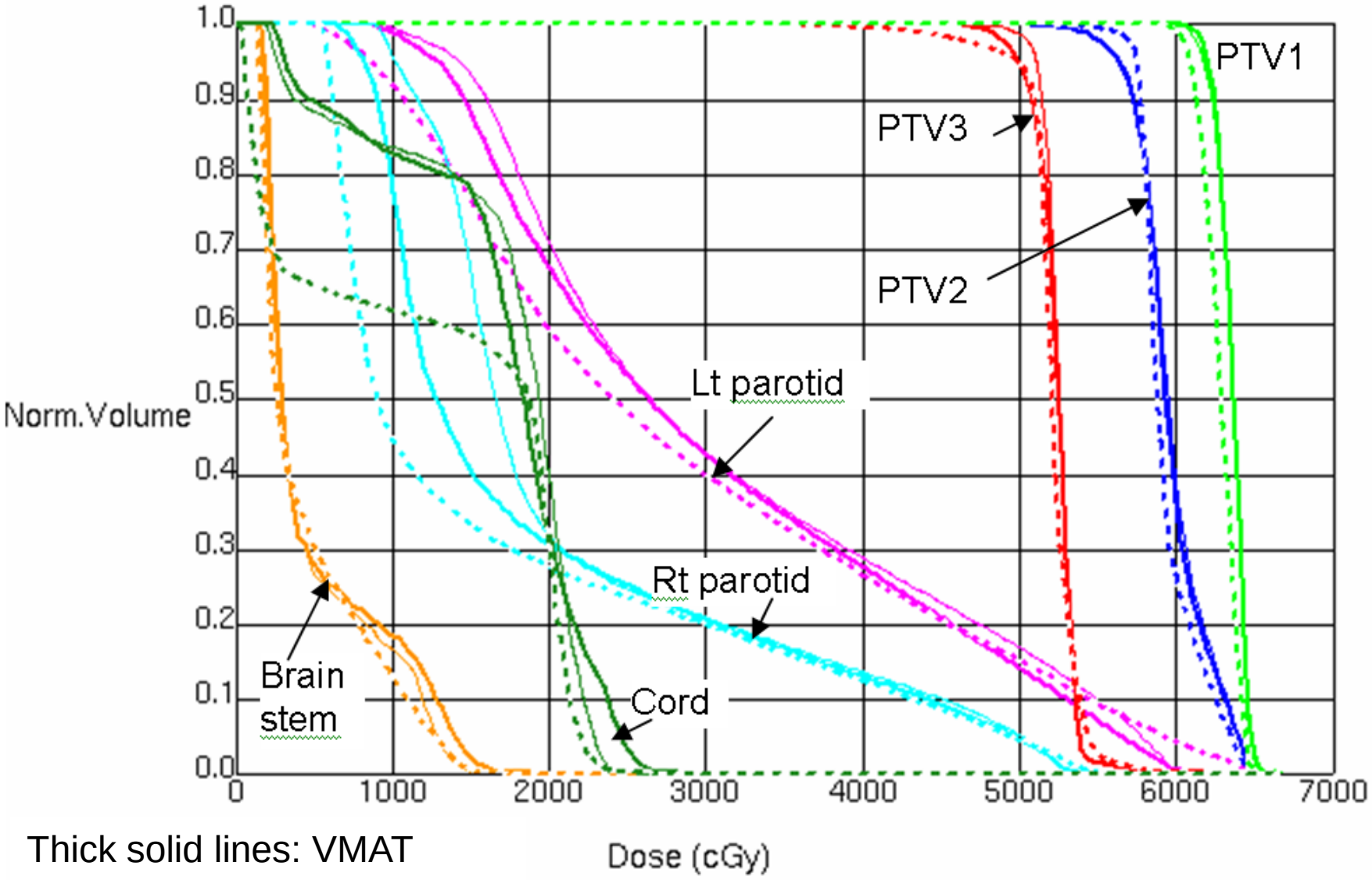
Solid = SmartArc Dashed = Tomotherapy

H&N Example #3





SmartArc Plan



Thick solid lines: VMAT
Dashed lines: Tomo
Thin solid: 9 Field IMRT

Table 1 Lung cases (6 patients): Plan comparison between fixed-field IMRT, VMAT and HT

	IMRT	VMAT	HT	Wilcoxon matched-pair signed rank test *p*
PTV				
V95 (%)	98.5 (95.0–100)	98.5 (95.0–100)	98.0 (91.7–100)	0.375
SD (Gy)	1.4 (0.7–2.1)	1.6 (0.8–2.5)	1.5 (0.7–3.2)	0.438
Lung				
D_{mean} (Gy)	9.8 (2.0–17.5)	10.0 (2.2–18.0)	10.0 (2.3–17.0)	0.844
V_{20Gy} (%)	15.3 (4.5–28.3)	15.4 (4.9–28.8)	15.8 (3.8–30.0)	0.625
Cord				
D_{max} (Gy)	19.8 (4.7–39.2)	19.9 (4.1–42.2)	19.9 (3.8–41.8)	0.563
D_{mean} (Gy)	5.6 (1.0–15.4)	5.7 (1.6–15.8)	5.3 (1.8–11.6)	0.844
Total body				
D_{mean} (Gy)	3.9 (1.0–9.0)	4.0 (1.3–9.3)	4.2 (1.3–8.7)	0.563
MU per fraction	569 (340–1108)	476 (348–904)	-	-
Delivery time (minutes)	7.9 (6.3–9.5)	2.1 (2.0–2.3)	5.4 (3.4–10.0)	0.031
QA passing rate (%)	99.3 (99.2–99.4)	99.0 (98.6–99.5)	99.6 (99.5-99.7)	-

Abbreviations: PTV = planning target volume; V95 = volume of PTV receiving 95% of prescription; SD = standard deviation of PTV dose; V_{nGy} = volume of structure receiving ≥ nGy. QA passing rate was obtained using gamma analysis with 3 mm/3% limit. Values expressed as mean (range). The Wilcoxon matched-pair signed rank test is listed for VMAT vs. HT.

Table 2 Prostate cases (6 patients): Plan comparison between fixed-field IMRT, VMAT and HT

	IMRT	VMAT	HT	Wilcoxon matched-pair signed rank test *p*
PTV				
V95 (%)	98.5 (97.3–99.7)	98.7 (97.3–99.7)	98.3 (96.2–99.8)	0.063
SD (Gy)	1.0 (0.7–1.3)	1.0 (0.6–1.4)	1.2 (0.5–1.6)	0.688
Rectum				
D_{max} (Gy)	56.7 (45.0–69.1)	56.1 (45.1–67.1)	57.3 (45.0–71.0)	0.156
D_{mean} (Gy)	25.7 (15.6–38.8)	24.5 (17.7–31.4)	26.5 (15.3–39.3)	0.688
$D_{20\%}$ /D_{pres} (%)	47.2 (27.2–87.9)	48.0 (27.2–88.6)	47.9 (27.2–91.8)	1.000
Bladder				
D_{max} (Gy)	58.0 (46.8–69.5)	57.4 (46.6–70.4)	58.6 (46.1–70.3)	0.438
D_{mean} (Gy)	20.1 (5.4–28.6)	19.9 (5.1–29.1)	20.5 (5.6–28.2)	0.219
Femoral head				
D_{max} (Gy)	25.5 (16.2–41.6)	24.3 (15.4–41.4)	25.6 (16.1–42.4)	0.031
D_{mean} (Gy)	16.5 (10.1–30.1)	16.7 (9.7–33.9)	16.1 (11.2–28.8)	0.844
Total body				
D_{mean} (Gy)	4.6 (3.3–8.1)	4.8(3.3–8.6)	4.9 (3.6–8.4)	0.313
MU per fraction	639 (595–731)	549 (449–603)	-	-
Delivery time (minutes)	8.1 (7.9–8.6)	2.2 (1.9–2.7)	4.0 (3.1–4.9)	0.031
QA passing rate (%)	98.5 (97.6–99.3)	98.9 (98.5–99.5)	99.9 (99.9-99.9)	-

Abbreviations: $D_{n\%}$ = minimal dose to n% of structure, D_{pres} = prescription to PTV; other abbreviations as in Table 1. Values expressed as mean (range). The Wilcoxon matched-pair signed rank test is listed for VMAT vs. HT.

Table 3 HN cases (6 patients): Plan comparison between fixed-field IMRT, VMAT and HT

	IMRT	VMAT	HT	Wilcoxon matched-pair signed rank test *p*
PTV				
V95 (%)	98.3 (96.7–99.6)	98.6 (97.1–99.7)	98.9 (98.4–99.7)	0.625
SD (Gy)	1.6 (1.4–1.7)	1.6 (0.9–2.1)	1.5 (1.1–2.0)	0.844
Spinal cord				
D_{max} (Gy)	26.8 (18.1–36.6)	27.3 (20.8–39.9)	28.0 (14.4–34.4)	1.000
D_{mean} (Gy)	13.2 (9.5–20.8)	13.3 (8.5–23.6)	11.7 (8.6–16.4)	0.438
Parotid				
D_{max} (Gy)	47.8 (27.3–61.6)	46.6 (25.3–62.6)	48.5 (26.8–65.9)	0.156
D_{mean} (Gy)	19.0 (13.0–24.8)	17.9 (12.6–24.8)	16.5 (10.5–22.8)	0.094
Brain stem				
D_{max} (Gy)	30.4 (13.7–42.7)	30.6 (16.0–47.0)	31.1 (6.3–46.4)	0.844
D_{mean} (Gy)	11.4 (2.3–18.9)	11.3 (2.7–20.2)	9.8 (1.8–19.0)	0.031
Total body				
D_{mean} (Gy)	9.9 (5.3–18.1)	9.7 (5.5–17.2)	10.0 (5.7–18.0)	0.156
MU per fraction	777 (607–1229)	620 (495–683)	-	-
Delivery time (minutes)	11.1 (10.9–12.4)	4.6 (3.7–6.0)	7.0 (6.0–9.1)	0.031
QA passing rate (%)	97.7 (96.1–99.3)	98.3 (96.0–99.8)	99.3 (99.0-99.6)	-

Values expressed as mean (range). The Wilcoxon matched-pair signed rank test is listed for VMAT vs. HT.

Future Developments

- With the current HiArt system, the jaw width and the couch speed are set to constant values for each plan.
- In 2011, Tomotherapy Inc. will offer a new option with dynamic jaw motion and dynamic couch motion.
- Initial studies indicate that the dynamic jaw capability should significantly reduce tomotherapy treatment times.

VMAT Planning - Summary

1. All major planning vendors now offer inverse planning solutions for VMAT with varying levels of robustness.
2. Initial work on VMAT has largely focused on single arc coplanar delivery. The advantages of using multiple arcs and non-coplanar beams are now being more fully explored.
3. With current technology, VMAT can provide similar plan quality as current tomotherapy systems with a more efficient delivery.

First Generation IMAT
2000-2007

- Treatment plans were developed using forward planning or simple beam shaping based on the patient's anatomy.
- The dose rate was constant as the gantry rotated around the patient.

Next Generation IMAT
2008-

- Treatment plans with full inverse planning.
- The dose rate varies as the gantry rotates around the patient.

SmartArc Planning Steps

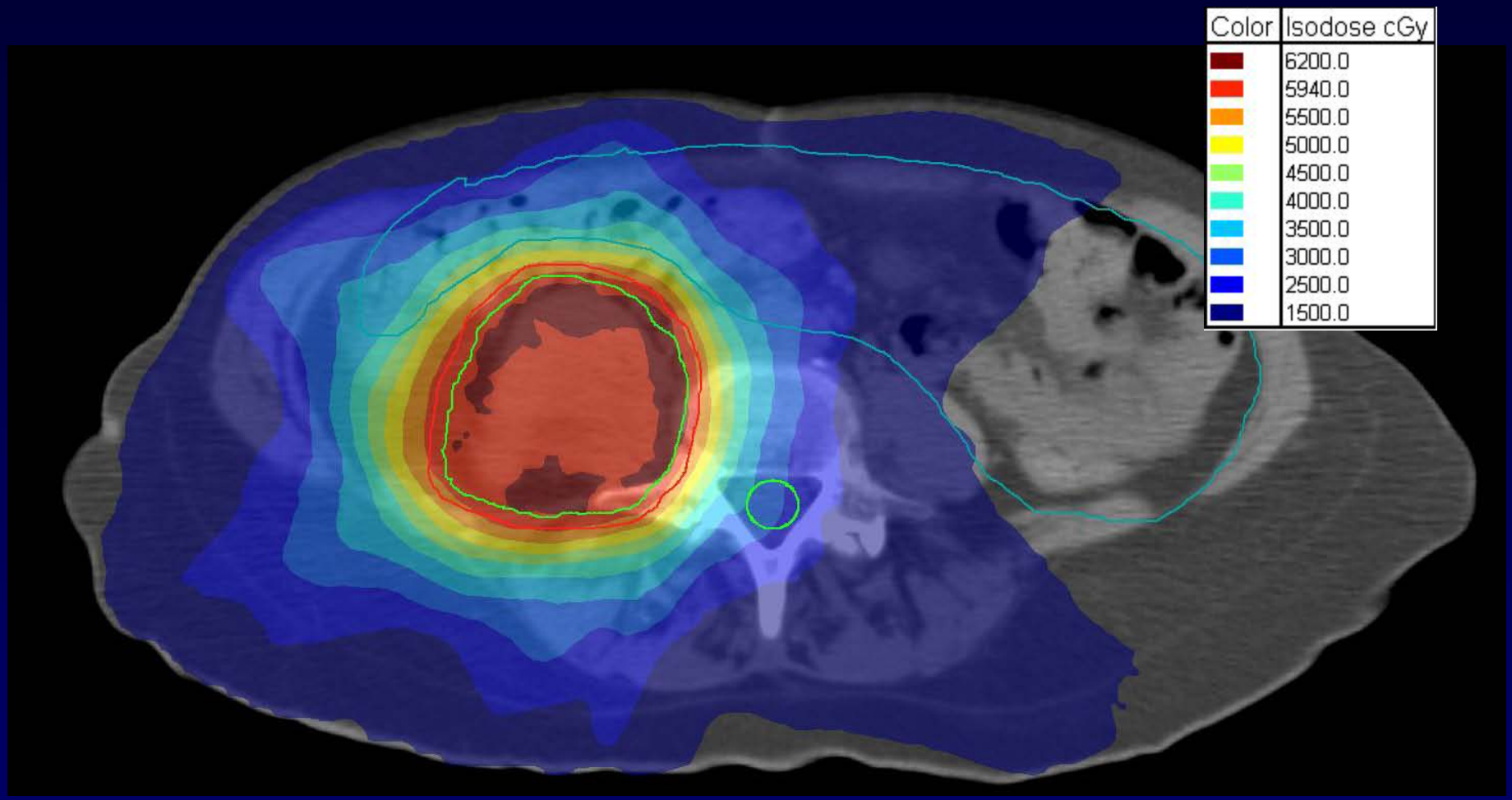
1. Add a dynamic arc beam
2. Specify couch, collimator, and beam angles
3. Specify dose objectives
4. Specify SmartArc optimization parameters
5. Optimize
6. Compute final convolution dose

SWEDISH

Courtesy Kevin Reynolds

Monaco VMAT

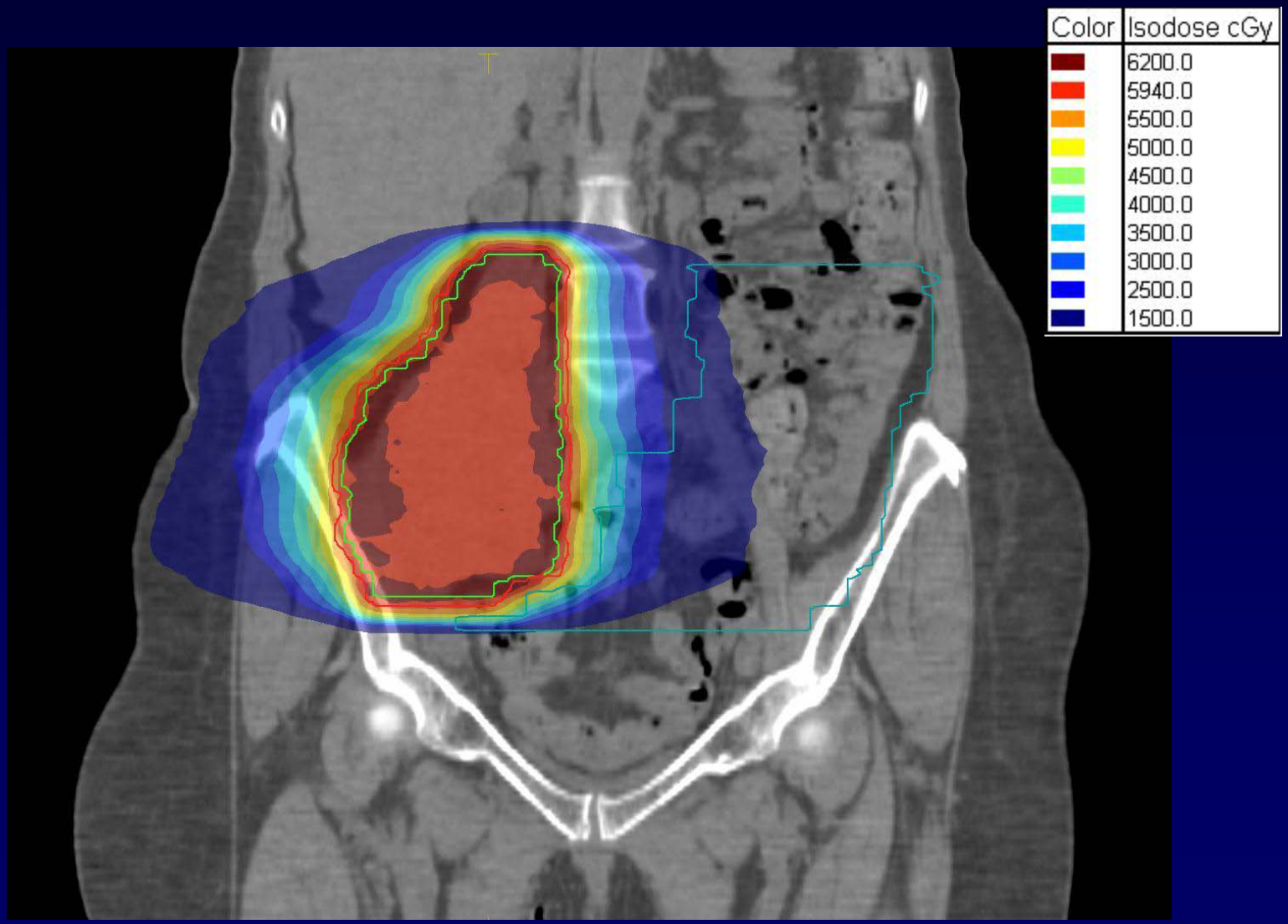
Case #3 – Pelvic Mass



- 180 cGy/fraction, 463 MU
- Delivery time = 4 min 40 sec

Monaco VMAT

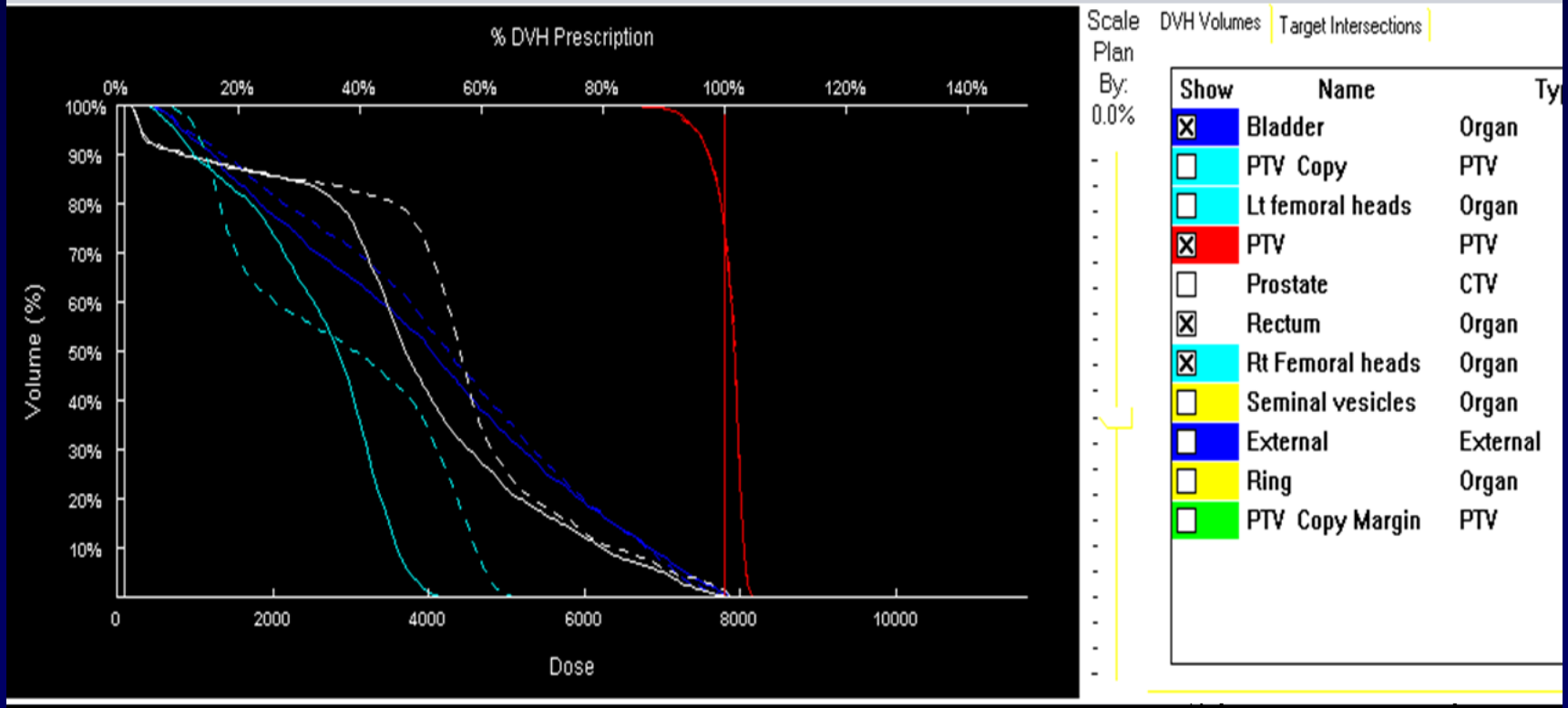
Case #3 – Pelvic Mass



SIEMENS

Prostate IMRT (S&S and CBT) – MCW case 6/2009

- Step&Shoot IMRT (DAO) (dashed), and CBT (solid)
- S&S : 430 MU, 5 beams, 5 segments/beam
- CBT : 515 MU, 9 -29 MU/OP, nominal gantry speed ~2 deg/s



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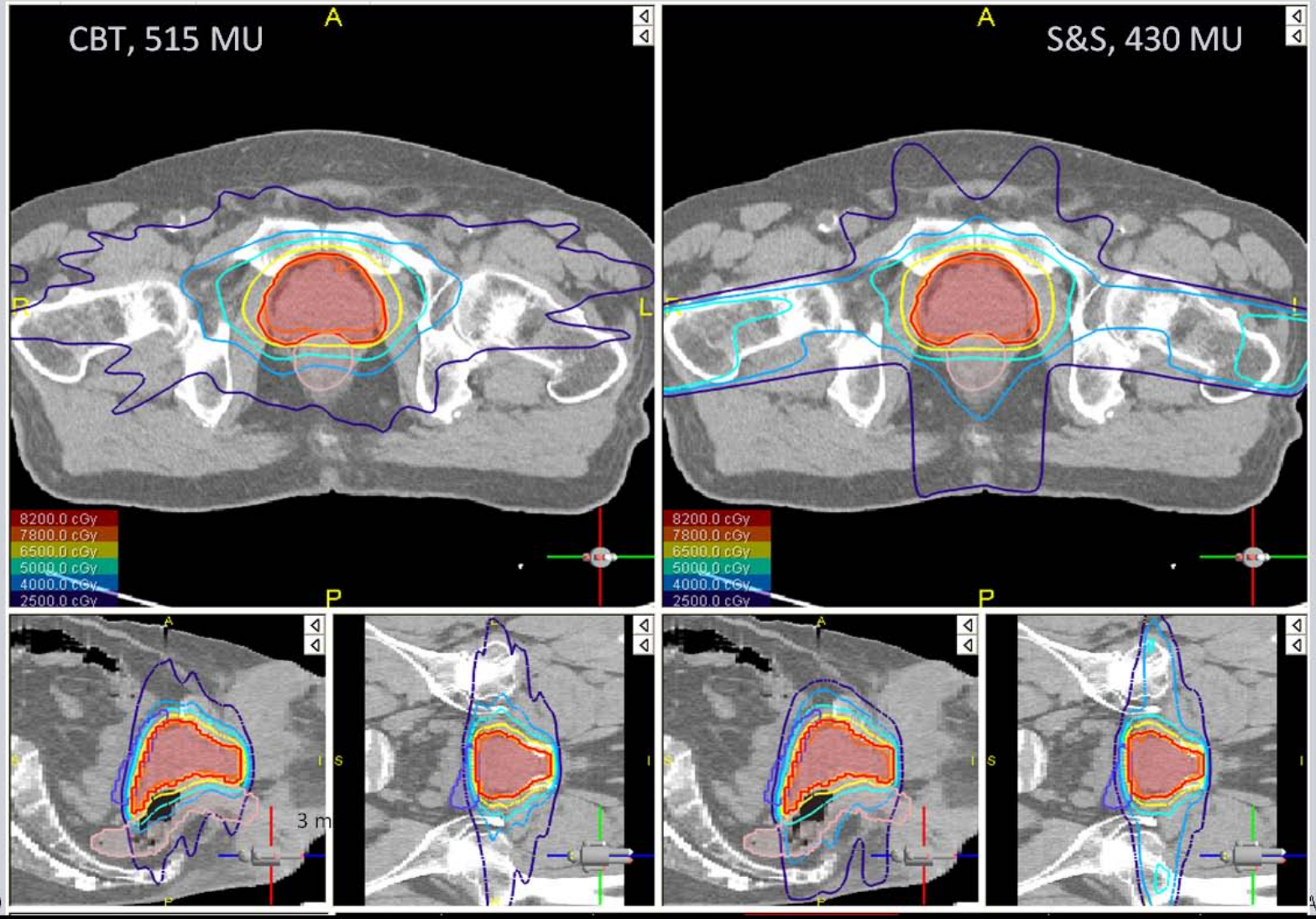

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Direct aperture optimization: A turnkey solution for step-and-shoot IMRT

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(Received 26 September 2001; accepted for publication 12 March 2002; published 13 May 2002)

IMRT treatment plans for step-and-shoot delivery have traditionally been produced through the optimization of intensity distributions (or maps) for each beam angle. The optimization step is followed by the application of a leaf-sequencing algorithm that translates each intensity map into a set of deliverable aperture shapes. In this article, we introduce an automated planning system in which we bypass the traditional intensity optimization, and instead directly optimize the shapes and the weights of the apertures. We call this approach "direct aperture optimization." This technique allows the user to specify the maximum number of apertures per beam direction, and hence provides significant control over the complexity of the treatment delivery. This is possible because the machine dependent delivery constraints imposed by the MLC are enforced within the aperture optimization algorithm rather than in a separate leaf-sequencing step. The leaf settings and the aperture intensities are optimized simultaneously using a simulated annealing algorithm. We have tested direct aperture optimization on a variety of patient cases using the EGS4/BEAM Monte Carlo package for our dose calculation engine. The results demonstrate that direct aperture optimization can produce highly conformal step-and-shoot treatment plans using only three to five apertures per beam direction. As compared with traditional optimization strategies, our studies demonstrate that direct aperture optimization can result in a significant reduction in both the number of beam segments and the number of monitor units. Direct aperture optimization therefore produces highly efficient treatment deliveries that maintain the full dosimetric benefits of IMRT. © *2002 American Association of Physicists in Medicine.* [DOI: 10.1118/1.1477415]

Key words: IMRT, inverse treatment planning, optimization, intensity modulation

SmartArc Optimization (1)

1. Beams are generated at the start and the stop angles and at 24° increments from the start angle.
2. A fluence map optimization is performed.
3. The fluence maps are sequenced and filtered so that there are only 2 control points per initial beam angle.

Courtesy of Philips Medical

SmartArc Optimization (2)

4. These control points are distributed to adjacent gantry angles and additional control points are added to achieve the desired final gantry spacing.
5. All control points are processed to comply with the motion constraints of VMAT.

Courtesy of Philips Medical

SmartArc Optimization (3)

6. The DMPO algorithm is applied with an aperture based optimization that takes into account all of the VMAT delivery constraints.
7. A final dose calculation is performed followed by a segment weight optimization.

Courtesy of Philips Medical

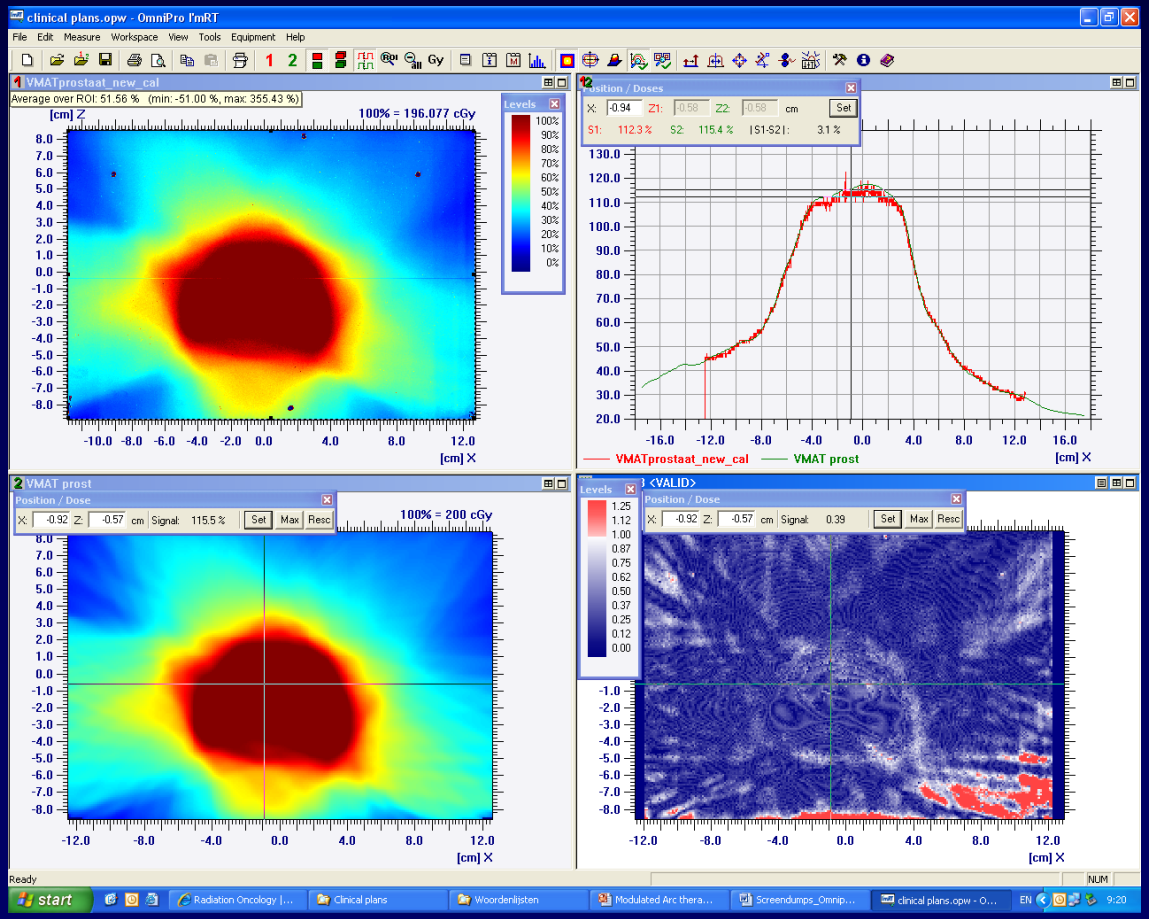
Prostate Verification

1-arc VMAT

γ(3%,1mm)

planned

measured



Clinical Implementation of SmartArc @ SCI

- We began using SmartArc clinically in February 2009, and have treated 80 patients.

SWEDISH

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ELSEVIER

doi:10.1016/j.ijrobp.2009.07.1686

PHYSICS CONTRIBUTIONS

DYNAMIC JAWS AND DYNAMIC COUCH IN HELICAL TOMOTHERAPY

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*Department of Radiation Oncology, University of Heidelberg, Germany; and †Tomotherapy Incorporated, Madison, Wisconsin

Purpose: To investigate the next generation of helical tomotherapy delivery with dynamic jaw and dynamic couch movements.

Methods and Materials: The new technique of dynamic jaw and dynamic couch movements is described, and a comparative planning study is performed. Ten nasopharyngeal cancer patients with skull base infiltration were chosen for this comparison of longitudinal dose profiles using regular tomotherapy delivery, running-start-stop treatment, and dynamic jaw and dynamic couch delivery. A multifocal simultaneous integrated boost concept was used (70.4Gy to the primary tumor and involved lymph nodes; 57.4Gy to the bilateral cervical lymphatic drainage pathways, 32 fractions). Target coverage, conformity, homogeneity, sparing of organs at risk, integral dose, and radiation delivery time were evaluated.

Results: Mean parotid dose for all different deliveries was between 24.8 and 26.1Gy, without significant differences. The mean integral dose was lowered by 6.3% by using the dynamic technique, in comparison with a 2.5-cm-field width for regular delivery and 16.7% with 5-cm-field width for regular delivery. Dynamic jaw and couch movements reduced the calculated radiation time by 66% of the time required with regular 2.5-cm-field width delivery (199 sec vs. 595 sec, $p < 0.001$).

Conclusions: The current delivery mode of helical tomotherapy produces dose distributions with conformal avoidance of parotid glands, brain stem, and spinal cord. The new technology with dynamic jaw and couch movements improves the plan quality by reducing the dose penumbra and thereby reducing the integral dose. In addition, radiation time is reduced by 66% of the regular delivery time. © 2009 Elsevier Inc.

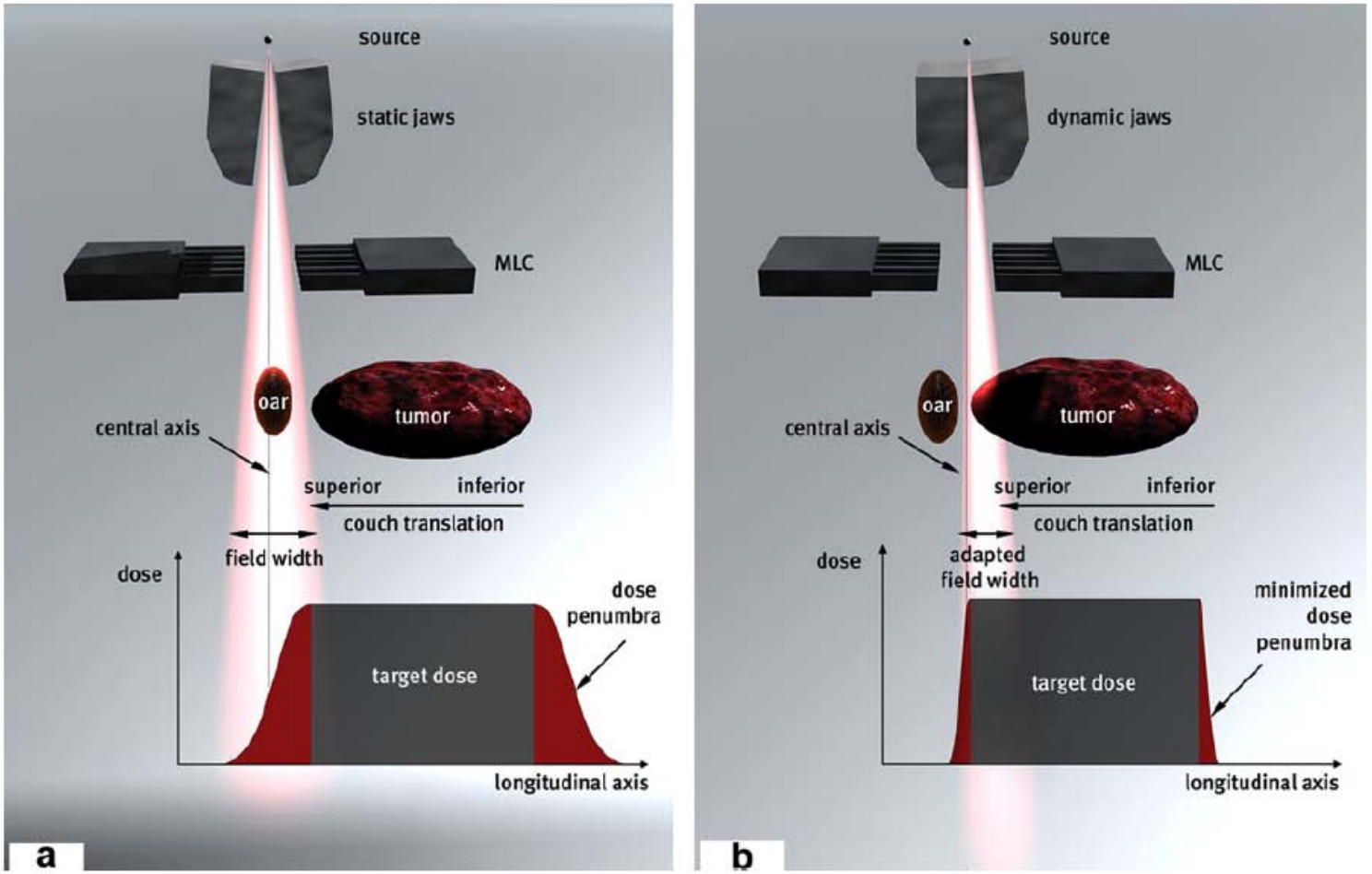

Fig. 1. Outline of jaw and fan beam characteristics of different delivery modes: (a) regular tomotherapy delivery causes a considerable dose penumbra above and below the target, whereas (b) RSS delivery with dynamic jaws reduces this dose exposure to healthy tissue. oar = organ at risk.

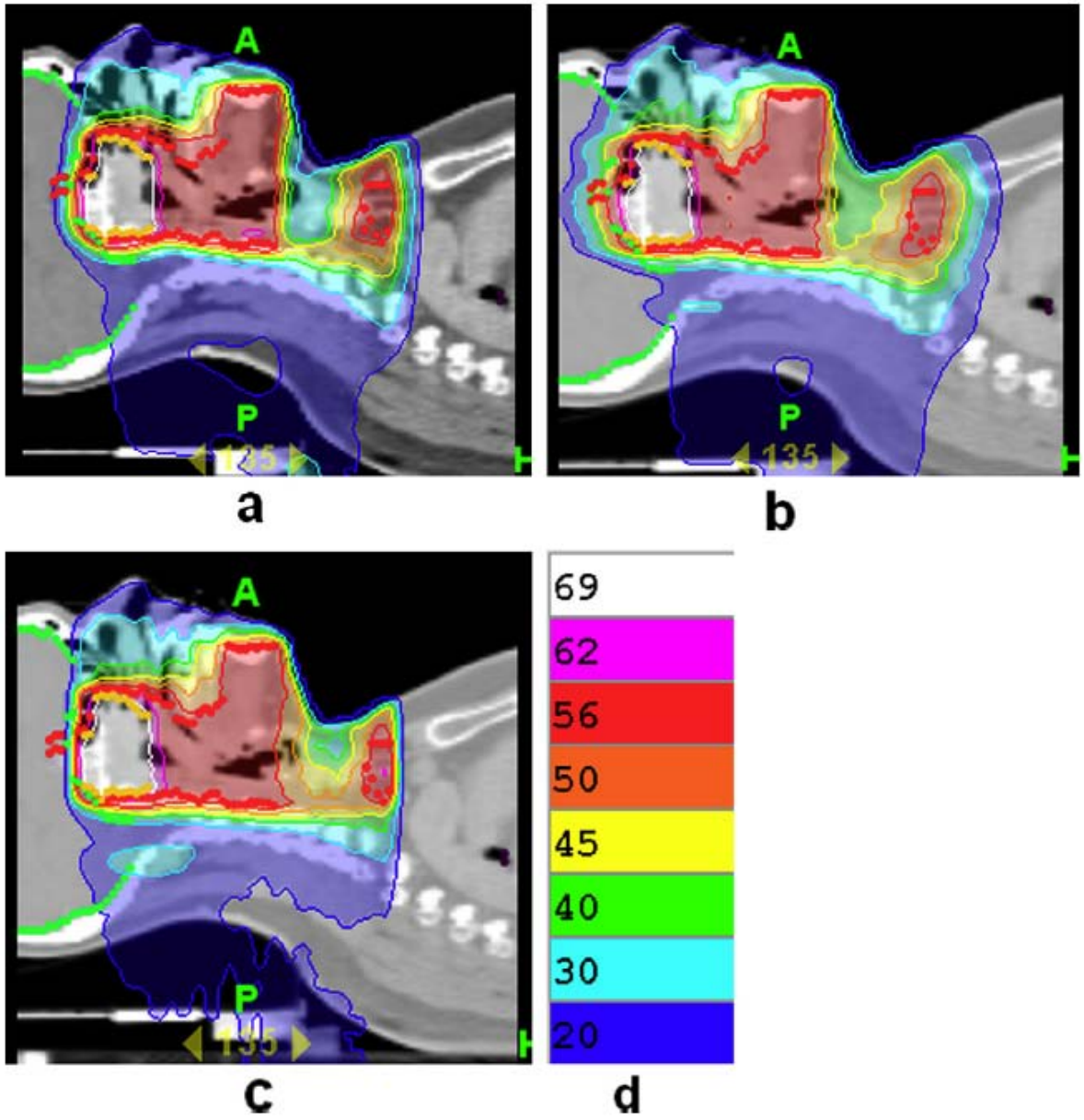

Fig. 3. (a–d) Dose distribution for one patient of regular delivery with 2.5-cm-field width (REG 2.5) and 5-cm-field width (REG 5) and DJDC delivery with 5 cm (DJDC 5), doses are shown in Gy.

INSTITUTE OF PHYSICS PUBLISHING PHYSICS IN MEDICINE AND BIOLOGY

Phys. Med. Biol. **48** (2003) 1–15 PII: S0031-9155(03)57398-5

Inverse planning for intensity modulated arc therapy using direct aperture optimization

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Dynamic Jaws/Dynamic Couch

- DJ/DC couch plans were developed for 10 nasopharyngeal patients.
- As compared with the traditional 2.5 cm jaw setting, the mean integral dose was reduced by 6.3% and the average delivery time was reduced by 66%.

Comparison of Elekta VMAT with helical tomotherapy and fixed field IMRT: Plan quality, delivery efficiency and accuracy

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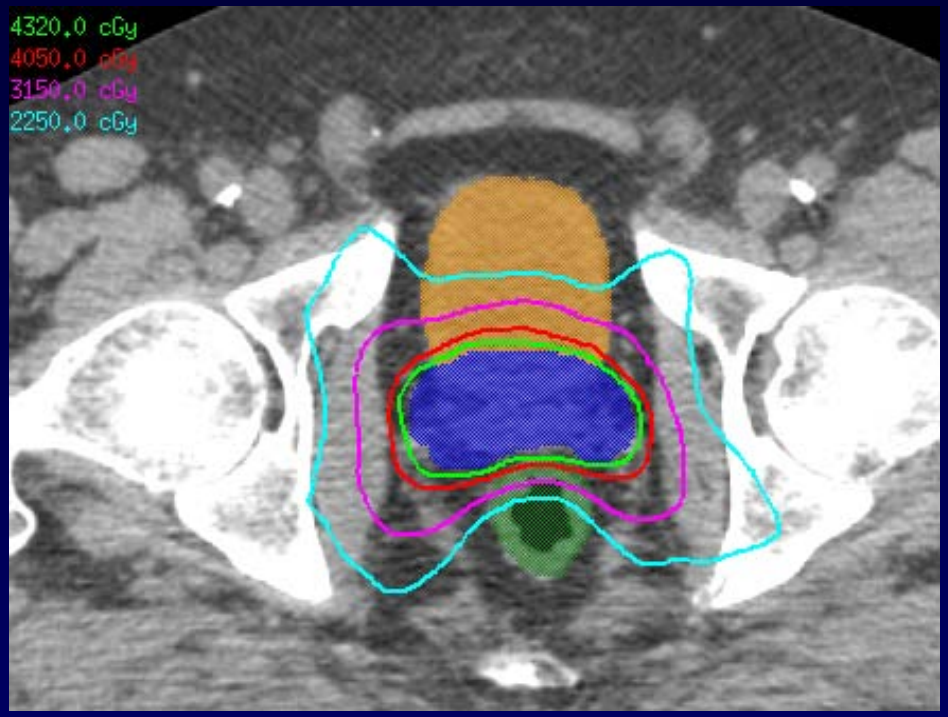
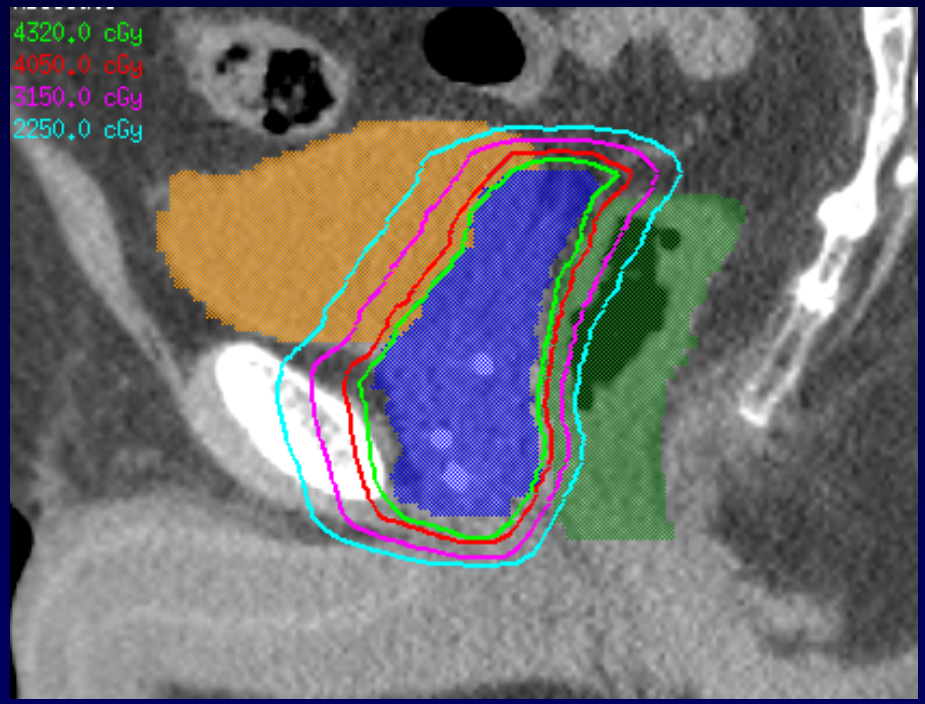
(Received 11 August 2009; revised 26 January 2010; accepted for publication 27 January 2010; published 1 March 2010)

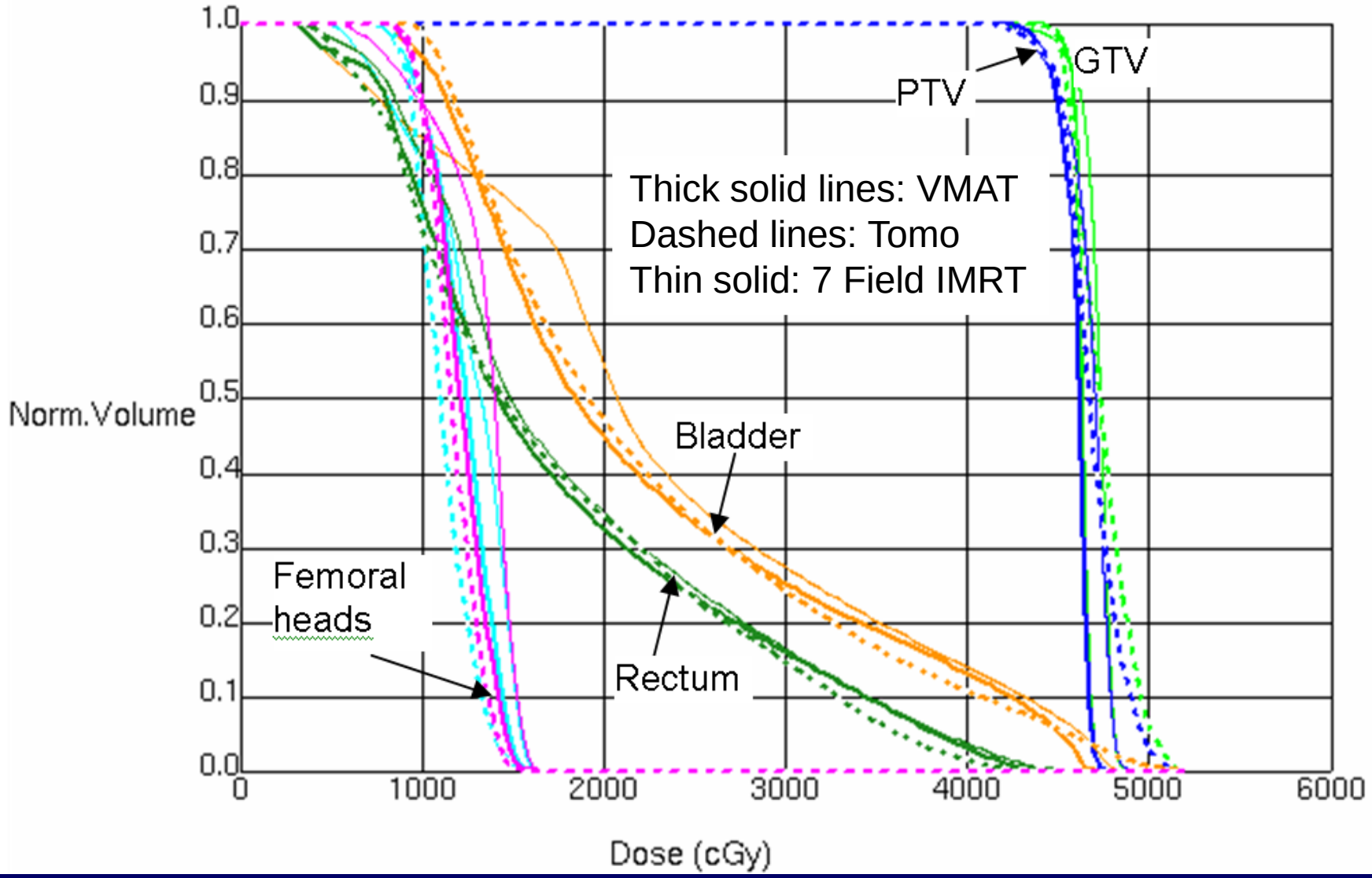
Purpose: Helical tomotherapy (HT) and volumetric modulated arc therapy (VMAT) are arc-based approaches to IMRT delivery. The objective of this study is to compare VMAT to both HT and fixed field IMRT in terms of plan quality, delivery efficiency, and accuracy.
Methods: Eighteen cases including six prostate, six head-and-neck, and six lung cases were selected for this study. IMRT plans were developed using direct machine parameter optimization in the Pinnacle^3 treatment planning system. HT plans were developed using a Hi-Art II planning station. VMAT plans were generated using both the Pinnacle^3 SmartArc IMRT module and a home-grown arc sequencing algorithm. VMAT and HT plans were delivered using Elekta's PreciseBeam VMAT® linac control system (Elekta AB, Stockholm, Sweden) and a TomoTherapy Hi-Art II system (TomoTherapy Inc., Madison, WI), respectively. Treatment plan quality assurance (QA) for VMAT was performed using the IBA MatriXX™ system while an ion chamber and films were used for HT plan QA.
Results: The results demonstrate that both VMAT and HT are capable of providing more uniform target doses and improved normal tissue sparing as compared with fixed field IMRT. In terms of delivery efficiency, VMAT plan deliveries on average took 2.2 min for prostate and lung cases and 4.6 min for head-and-neck cases. These values increased to 4.7 and 7.0 min for HT plans.
Conclusions: Both VMAT and HT plans can be delivered accurately based on their own QA standards. Overall, VMAT was able to provide approximately a 40% reduction in treatment time while maintaining comparable plan quality to that of HT. © *2010 American Association of Physicists in Medicine*. [DOI: 10.1118/1.3326965]

Prostate Case





SmartArc Plan


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Norm.Volume
0
1000
2000
3000
4000
5000
6000
Dose (cGy)
PTV
GTV
Thick solid lines: VMAT
Dashed lines: Tomo
Thin solid: 7 Field IMRT
Bladder
Femoral heads
Rectum

Ergo++

- Ergo++ designs simplified IMAT arcs with each beam based on the patient's anatomy.
- This can work well for simple targets but can break down for more complex target geometries.

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

- With the latest advances in IMAT planning and delivery, we can now test if IMAT can serve as a true alternative to tomotherapy in terms of plan quality and delivery efficiency.