Volumetric Modulated Arc Therapy

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Disclaimer

- Our VMAT work has been sponsored in part by Elekta.

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Outline

David Shepard

- VMAT Basics and VMAT Plan Quality
- Commissioning a VMAT delivery system
- Commercial VMAT Solutions

Richard Popple

- VMAT Patient Specific Quality Assurance
- Advanced VMAT Techniques
- Starting a VMAT program

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20 Years Ago

Tomotherapy: A new concept for the delivery of dynamic conformal radiotherapy

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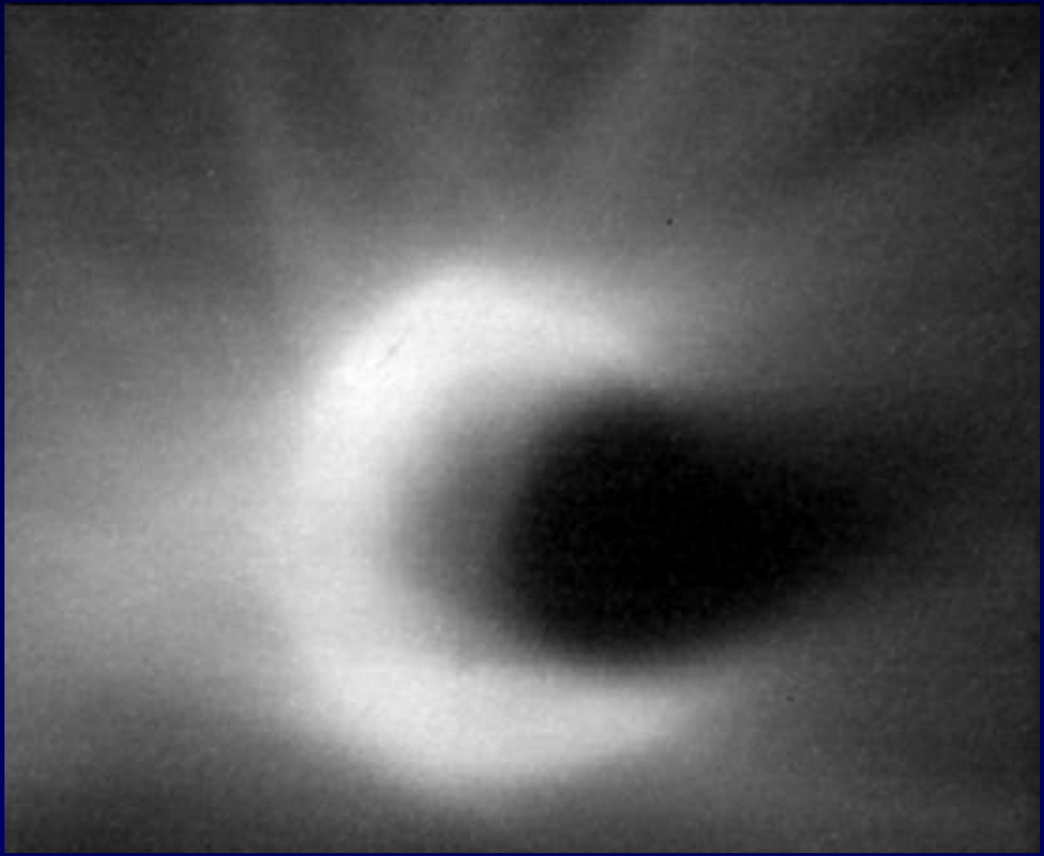
(Received 20 July 1992; accepted for publication 14 June 1993)

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



Volumetric modulated arc therapy: IMRT in a single gantry arc

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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

VMAT Basics

- An arced-based approach to IMRT that can be delivered on a conventional linear accelerator with a conventional MLC.
- During each arc, the leaves of the MLC move continuously as the gantry rotates.
- The degree of intensity modulation is related to the number of beam shapes per arc and the number of arcs.

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Arc Based IMRT – The First Decade

- Serial tomotherapy: NOMOS Peacock binary MLC and Corvus planning system served as first commercial IMRT solution.
- Helical tomotherapy: Tomotherapy Inc. introduced the Hi-Art system with the first patients treated in 2002 at the University of Wisconsin.
- IMAT/VMAT: largely withered on the vine:
  1. Linac manufacturers did not have control systems capable of delivering IMAT.
  2. No robust inverse planning tools for IMAT.

Efforts to Revive Interest in IMAT

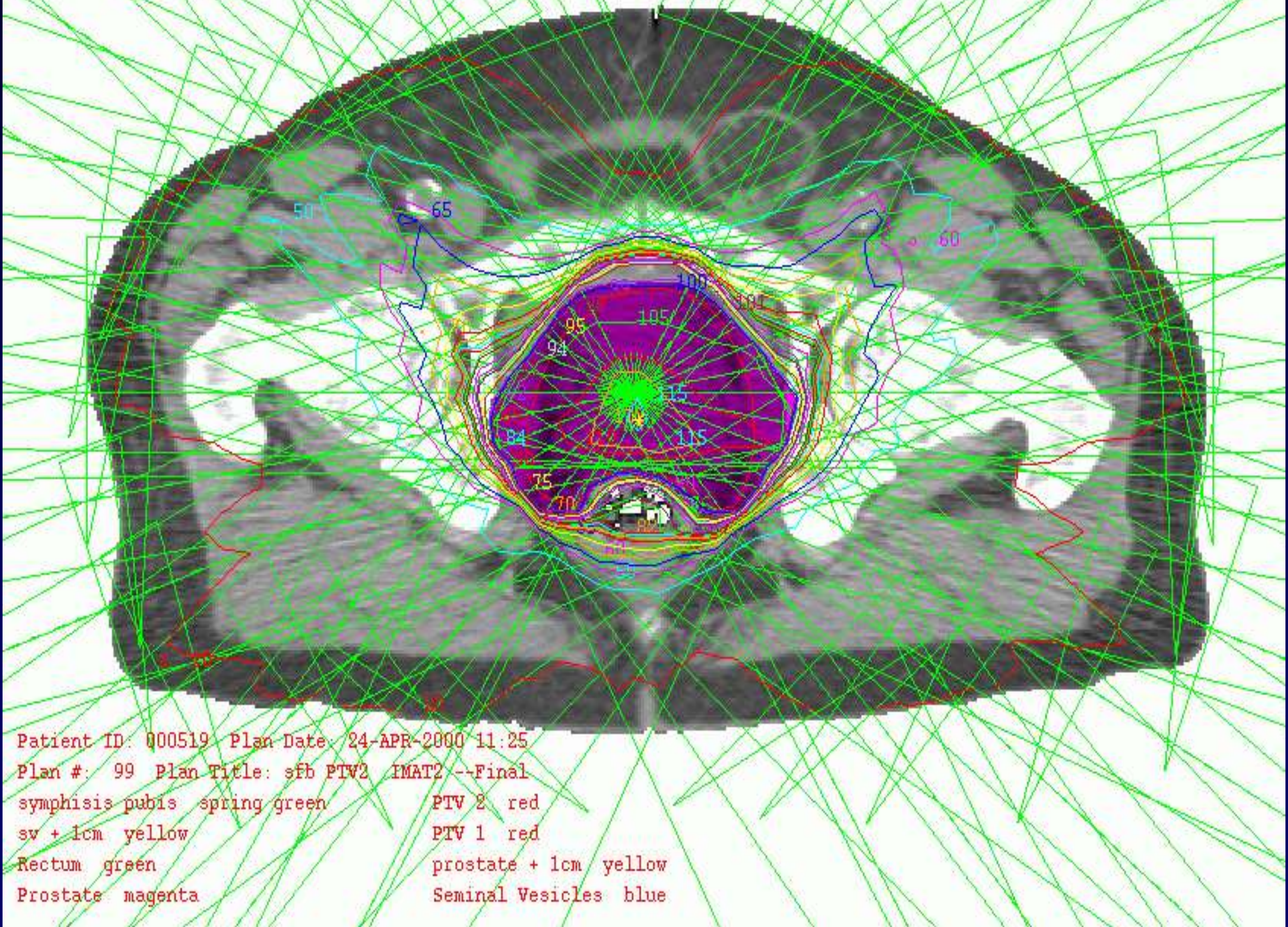
University of Maryland School of Medicine

- In 2000, we conducted a phase 1 clinical trial under an IRB protocol where IMAT plans were delivered to 50 patients.
- Key limitations were: (1) constant dose rate during rotation; and (2) no inverse planning.

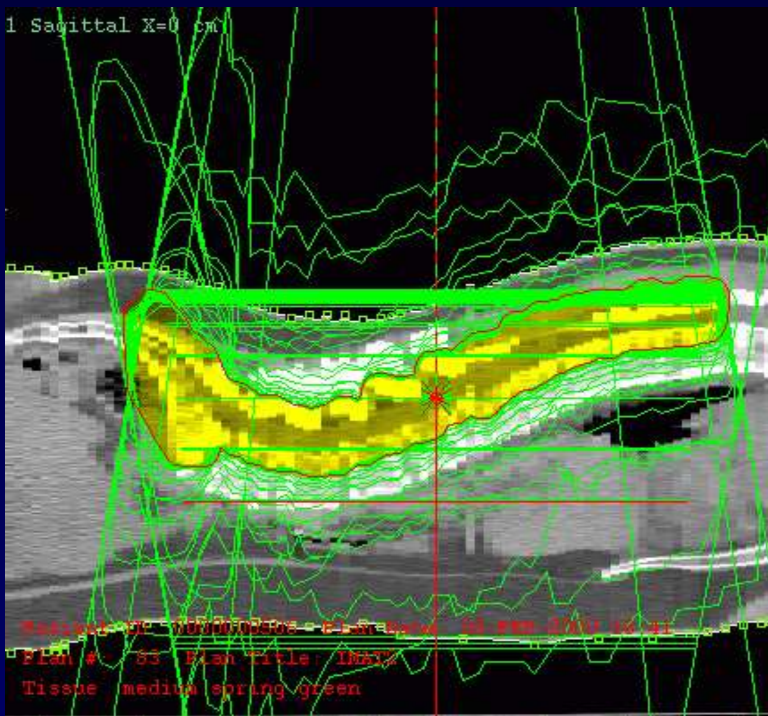
Example 1 - Prostate

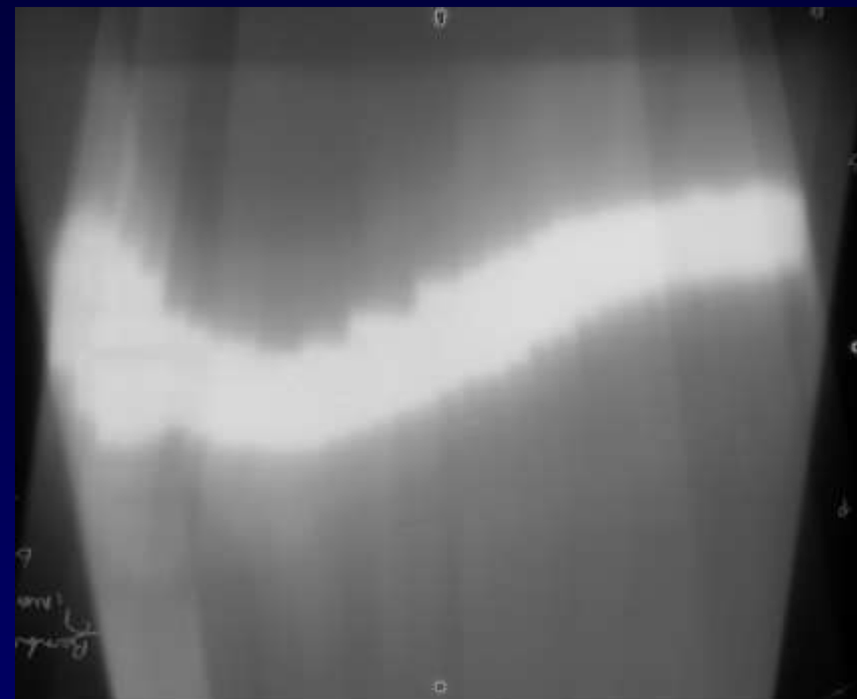
- Two sets of bilateral arcs.
- 1 set of arcs matches BEV of prostate.
- 1 matches BEV of prostate – rectum.
- Weights of arcs are optimized.

Example 1 - Prostate



Example 2: Spinal Ependymoma





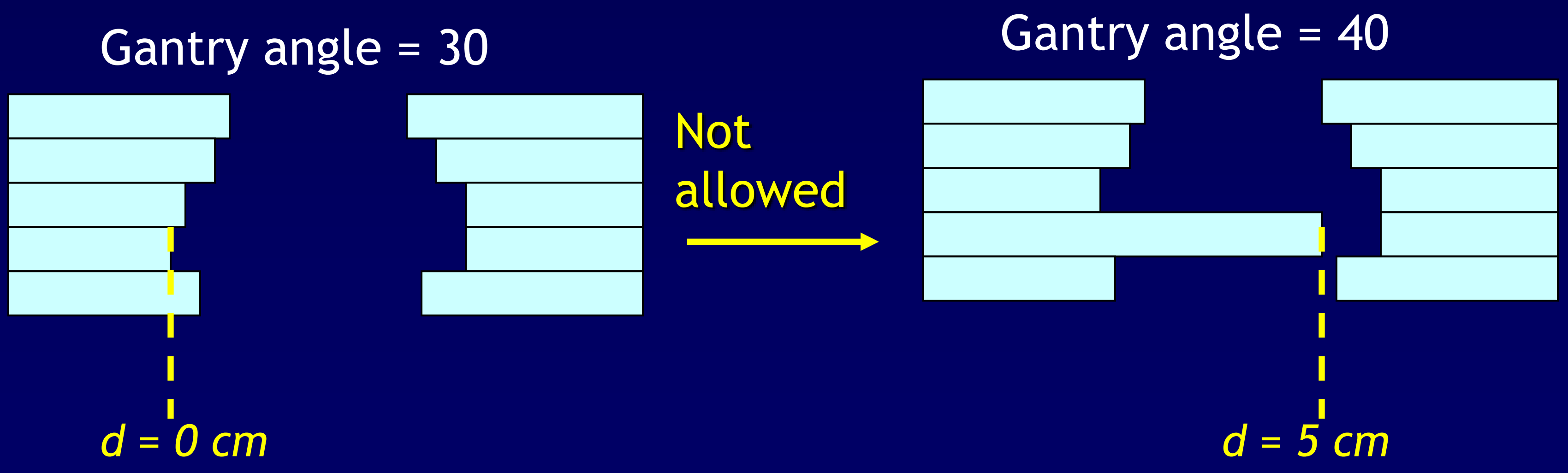
5 arc treatment

Inverse Planning for IMAT

- A robust inverse planning solution is required to take advantage of the capabilities of IMAT.
- IMAT inverse planning, however, proved to be highly complicated due the need to account for the interconnectedness of the beam shapes within arc.

Interconnectedness of 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.



IMAT - Inverse Planning

- We developed two IMAT inverse planning approaches:
  1. Direct Aperture Optimization for IMAT (2003)
     - Directly optimizes aperture shapes and weights throughout each arc.
  2. An “arc-sequencing” algorithm (2006)
     - Converts optimized fixed field IMRT plan into IMAT plan

VMAT Commercial Introduction

- In 2008, Elekta and Varian introduced control systems that are capable of delivering IMAT.
- Key innovation was that the dose rate, gantry speed, and MLC leaf positions could be changed dynamically during rotational beam delivery.
- The term VMAT was suggested by Karl Otto to differentiate single arc rotational IMRT.

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VMAT Plan Quality:
Comparison with Tomotherapy

VMAT and Tomotherapy Plan Comparison

- 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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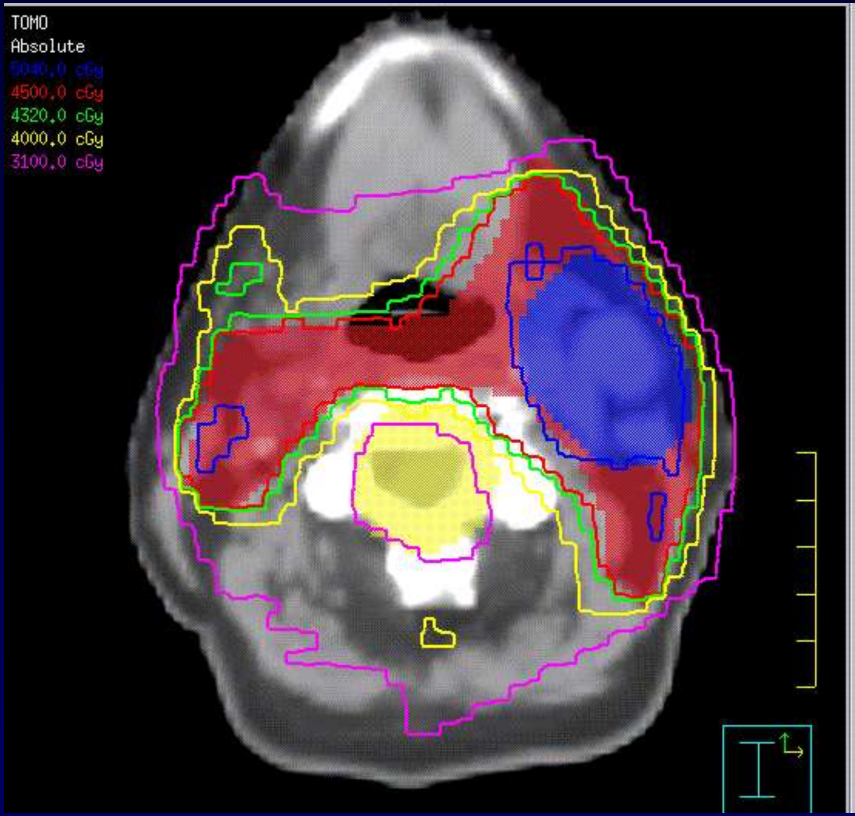
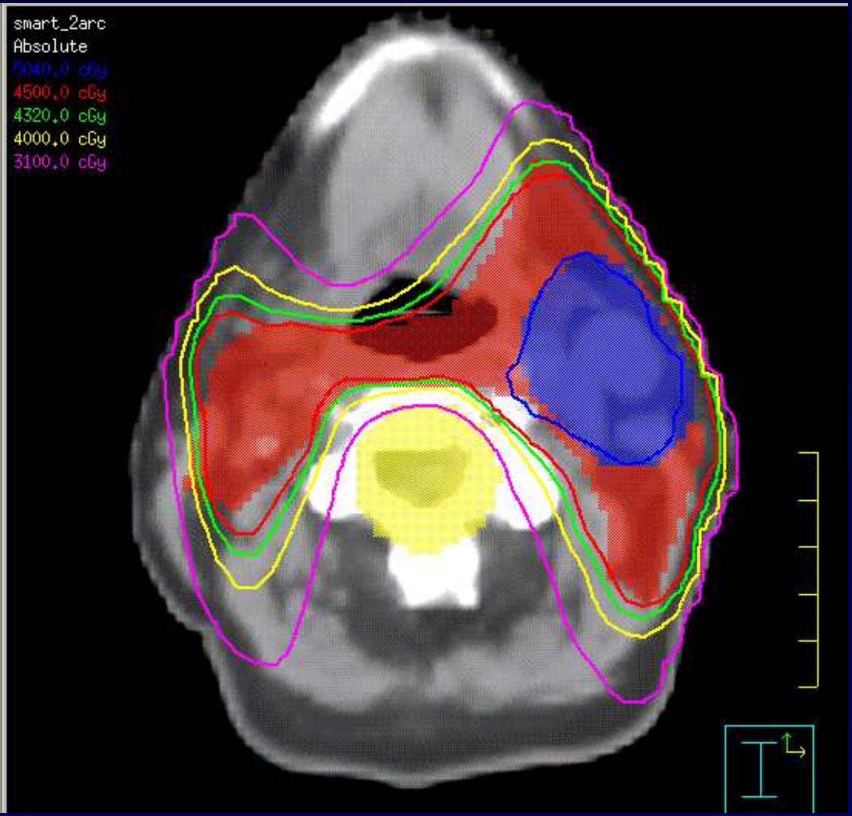
Head & Neck Case #1



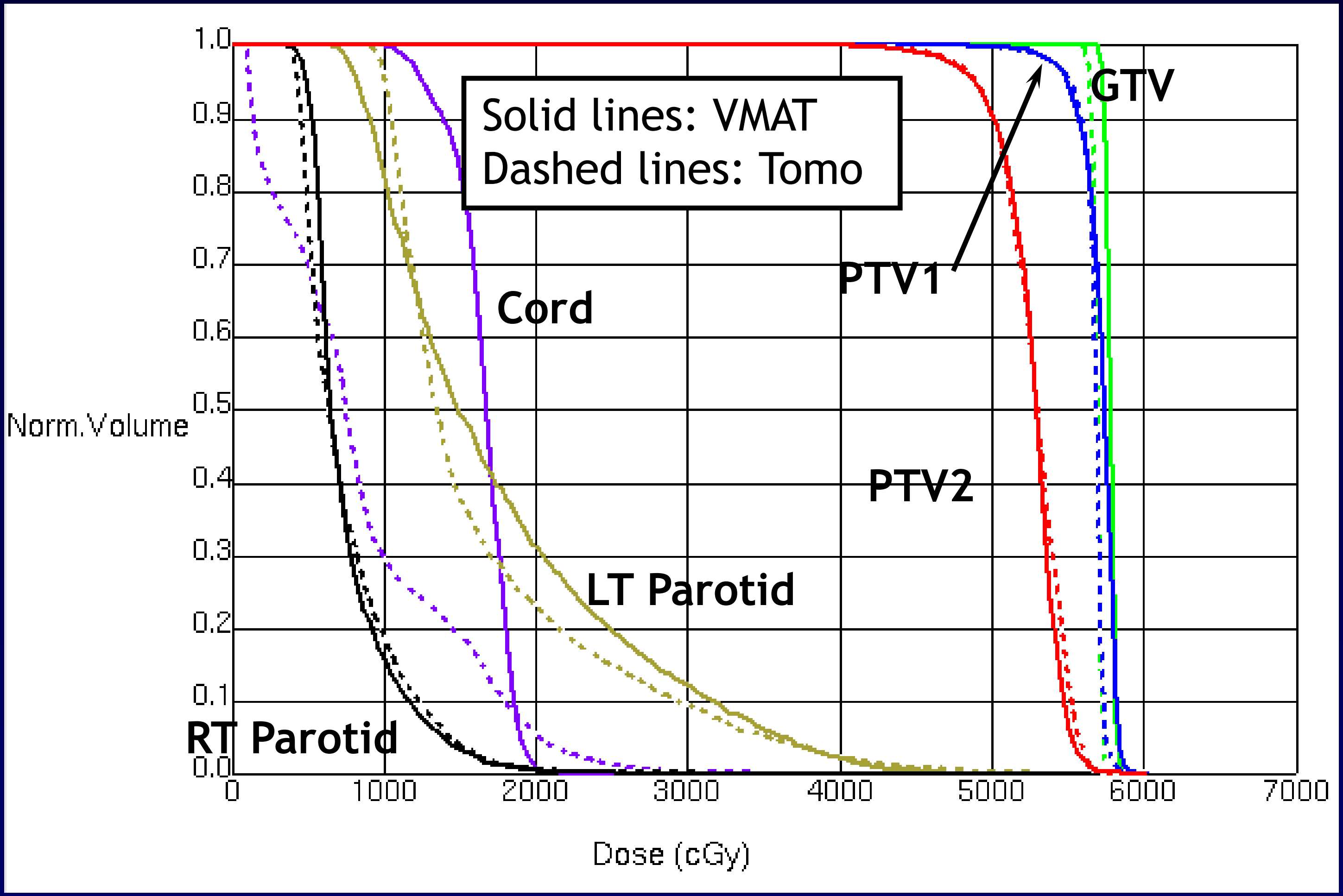
Helical Tomotherapy



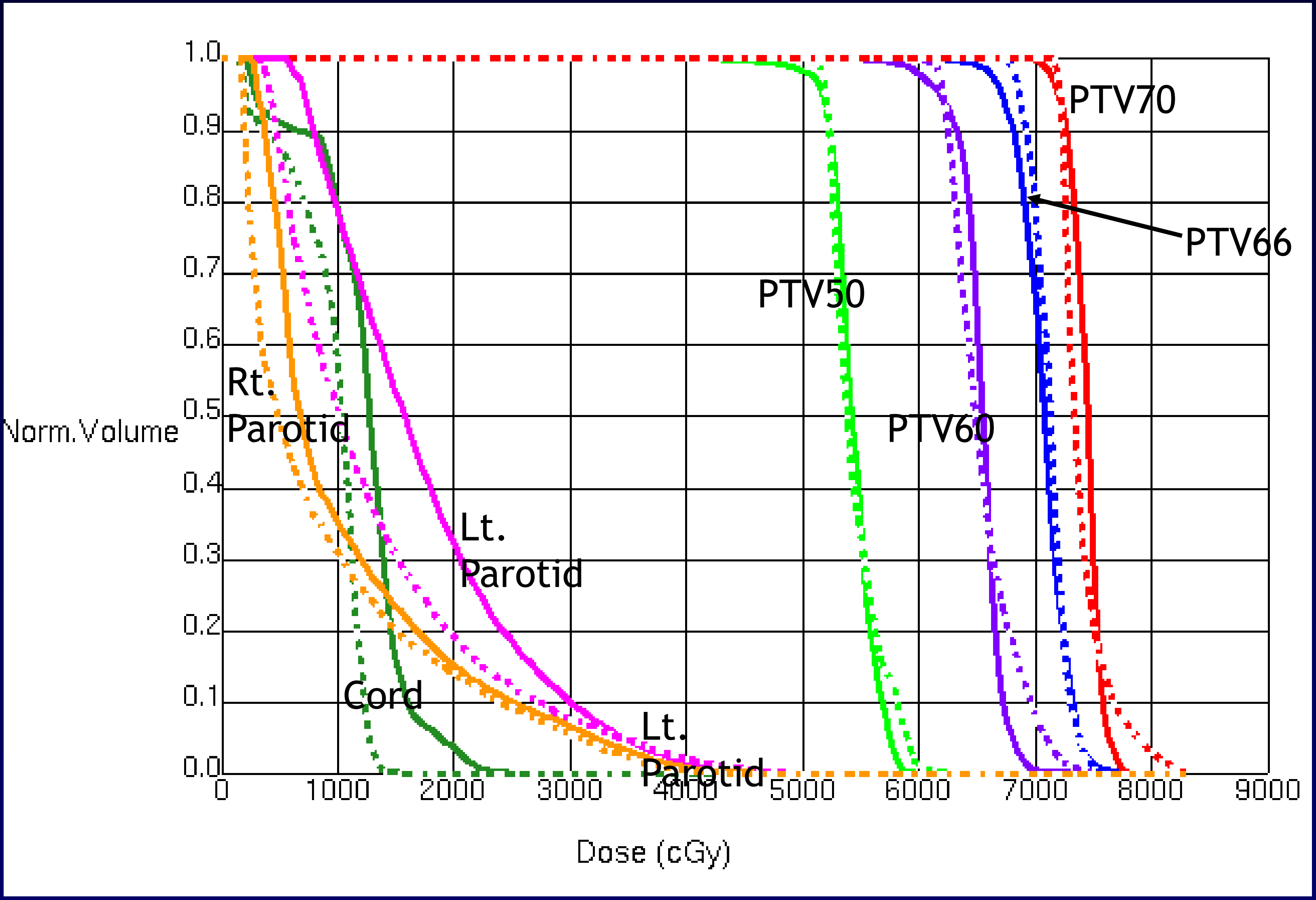
2-arc VMAT

- Two targets with prescription levels of 5040 and 4500 cGy

Head & Neck Case #1



H&N Example #2



Solid = VMAT   Dashed = Tomotherapy

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)	-

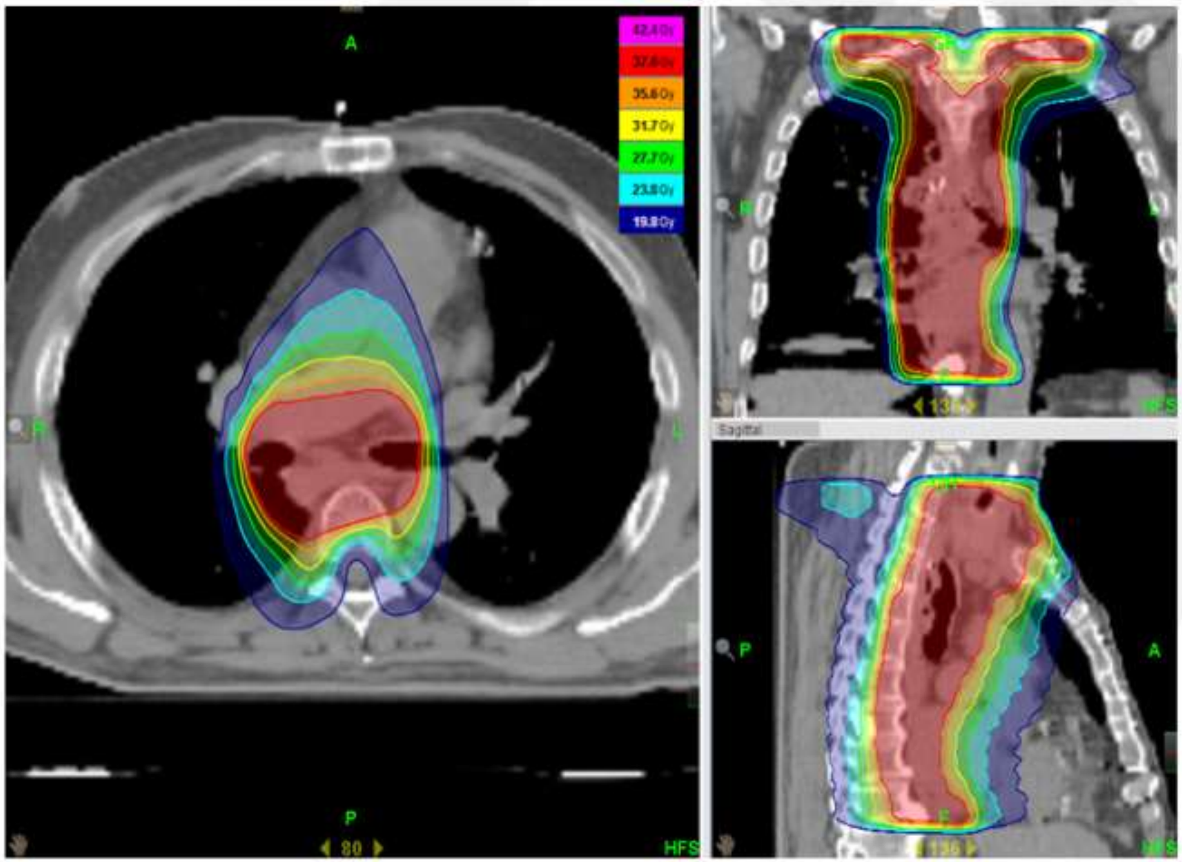
Values expressed as mean (range). The Wilcoxon matched-pair signed rank test is listed for VMAT vs. HT.

Tomotherapy Developments

- With the Tomotherapy HiArt system, the jaw width and the couch speed were set to constant values for each plan.
- A new option with dynamic jaw motion and dynamic couch motion is now available that results in improved plan quality and delivery efficiency.
- First system was installed at the University of Heidelberg in March 2013.

Oesophagus Cancer

TomoEDGE™



22 Fractions
- 1.8 Gy
- Brachy Boost

Dynamic Jaws
5cm

Beam-on
3.6 min

Courtesy of PD Dr. Med. Florian Sterzing, Heidelgerg, Germany

Element on workflow / Heidelberg

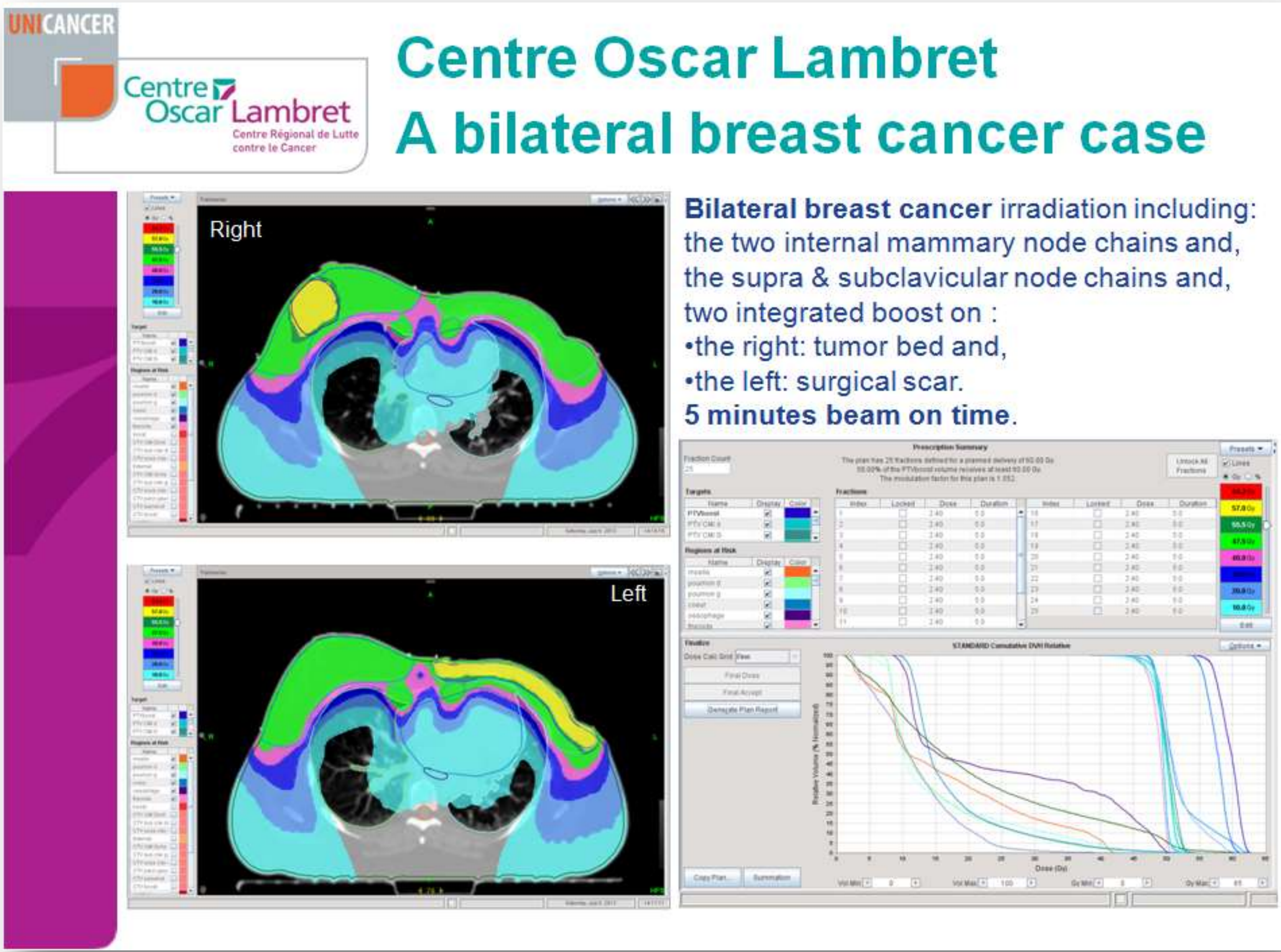
12 minutes timeslot & beam-on < 5 minutes

72 Patients

Average beam-on is < 5min

- 12 minutes timeslot
- 60 patients in 12 hours
- Prostate 2-3 min
- Neck 3-4 min
- Pelvis 6-7 min

Courtesy of PD Dr. Med. Florian Sterzing, Heidelgerg, Germany



Courtesy of Prof. Eric Lartigau, Lille, France

VMAT Commissioning

VMAT Commissioning

- VMAT commissioning and routine quality assurance builds upon your existing IMRT beam models and fixed-field IMRT QA program.
- During VMAT delivery, the MLC leaves are moving, the gantry is rotating, and the dose rate is changing.
- The dynamic nature of the delivery must be accounted for in the quality assurance.

VMAT Commissioning

- No AAPM guidance document has been produced and there is not a general consensus on the tests that must be performed as part of the commissioning of VMAT.
- The most commonly referenced document is a paper from Ling and colleagues from Memorial Sloan Kettering.

Int. J. Radiation Oncology Biol. Phys., Vol. 72, No. 2, pp. 575–581, 2008

0360-3016/08/$–see front matter

ELSEVIER

doi:10.1016/j.ijrobp.2008.05.060

PHYSICS CONTRIBUTION

COMMISSIONING AND QUALITY ASSURANCE OF RAPIDARC RADIOTHERAPY DELIVERY SYSTEM

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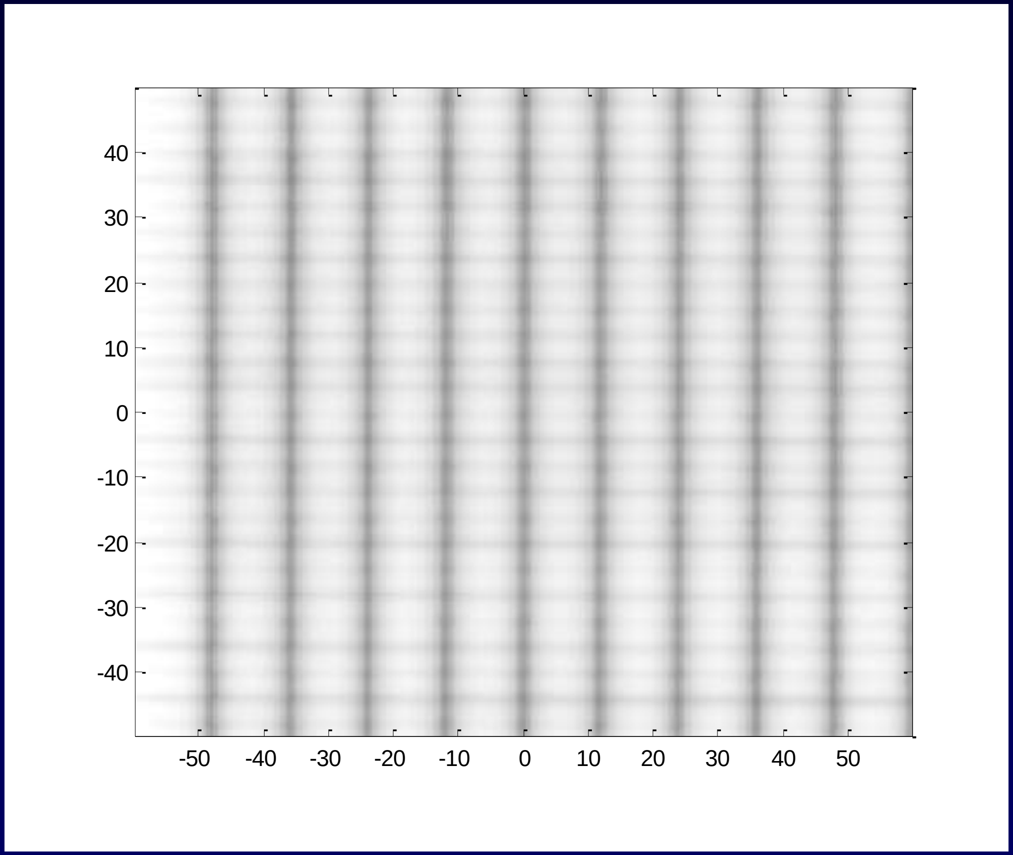
*Varian Medical Systems, Palo Alto, CA; †Memorial Sloan-Kettering Cancer Center, New York, NY; and ‡University of Maryland, Baltimore, MD

Purpose: The Varian RapidArc is a system for intensity-modulated radiotherapy (IMRT) treatment planning and delivery. RapidArc incorporates capabilities such as variable dose-rate, variable gantry speed, and accurate and fast dynamic multileaf collimators (DMLC), to optimize dose conformality, delivery efficiency, accuracy and reliability. We developed RapidArc system commissioning and quality assurance (QA) procedures.
Methods and Materials: Tests have been designed that evaluate RapidArc performance in a stepwise manner. First, the accuracy of DMLC position during gantry rotation is examined. Second, the ability to vary and control the dose-rate and gantry speed is evaluated. Third, the combined use of variable DMLC speed and dose-rate is studied.
Results: Adapting the picket fence test for RapidArc, we compared the patterns obtained with stationary gantry and in RapidArc mode, and showed that the effect of gantry rotation on leaf accuracy was minimal (≤0.2 mm). We then combine different dose-rates (111–600 MU/min), gantry speeds (5.5–4.3°/s), and gantry range ($\Delta\theta$ = 90–12.9°) to give the same dose to seven parts of a film. When normalized to a corresponding open field (to account for flatness and asymmetry), the dose of the seven portions show good agreement, with a mean deviation of 0.7%. In assessing DMLC speed (0.46, 0.92, 1.84, and 2.76 cm/s) during RapidArc, the analysis of designed radiation pattern

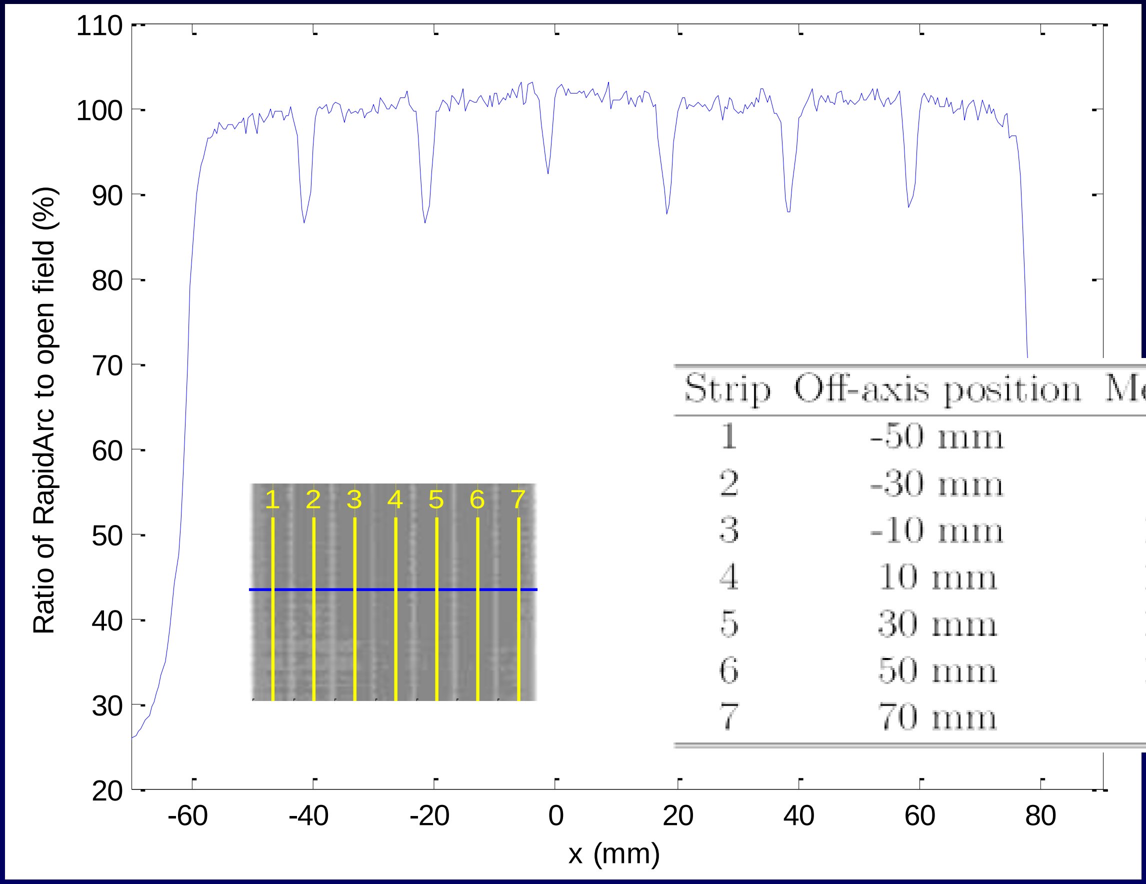
Test 1: Accuracy of DMLC positioning during VMAT



Picket fence pattern is delivered with a rotating gantry. Here, a film was mounted on the blocking tray. Results are compared to a picket fence delivered in stationary mode.

Courtesy Richard Popple

Test 2: Ability to vary dose rate and gantry speed during VMAT

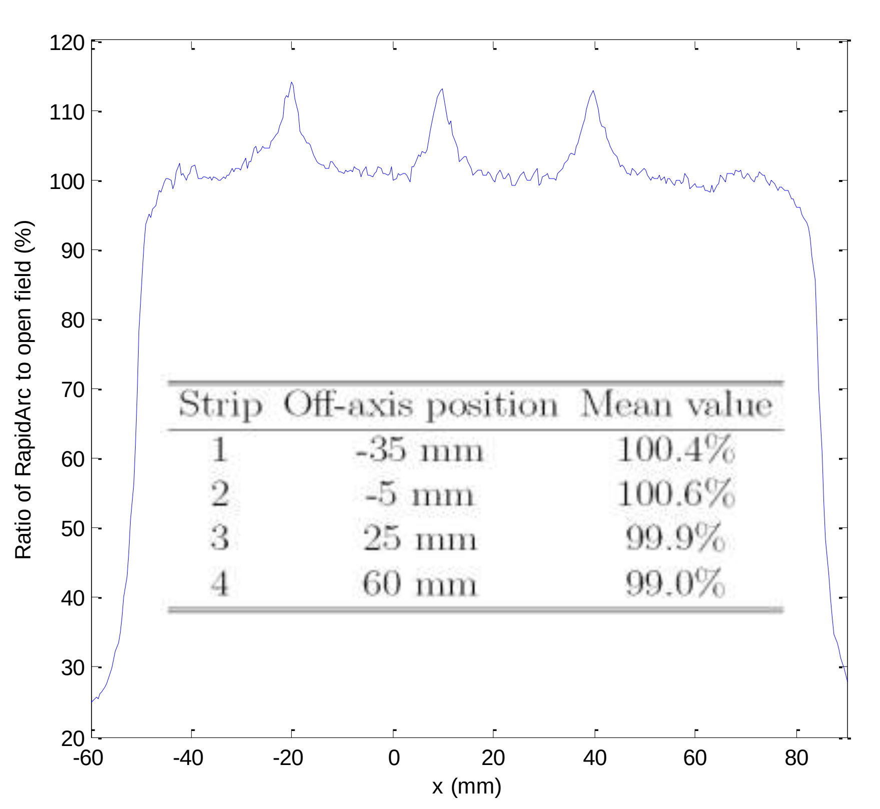


Strip	Off-axis position	Mean value
1	-50 mm	98.7%
2	-30 mm	99.7%
3	-10 mm	100.6%
4	10 mm	100.7%
5	30 mm	100.0%
6	50 mm	100.8%
7	70 mm	99.3%

Each strip on the film is irradiated to the same MU using varying combinations of dose rate and gantry rotation speed.

Courtesy Richard Popple

Test 3: Ability to accurately vary MLC speed during VMAT

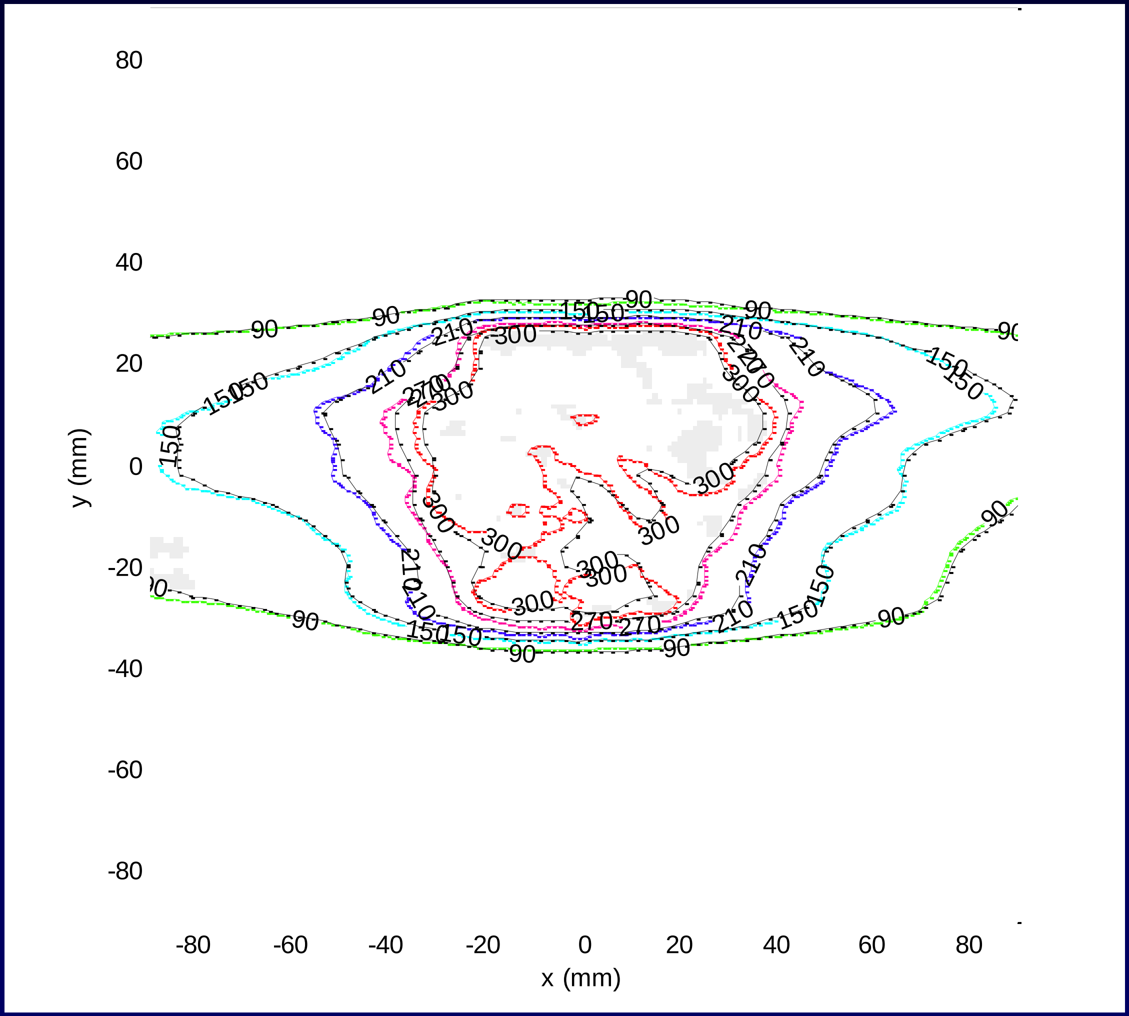


Strip	Off-axis position	Mean value
1	-35 mm	100.4%
2	-5 mm	100.6%
3	25 mm	99.9%
4	60 mm	99.0%

Different parts of the film are exposed to the same dose using the DMLC sliding window technique, combining different leaf speeds with different dose rates to achieved a designed dose pattern.

Courtesy Richard Popple

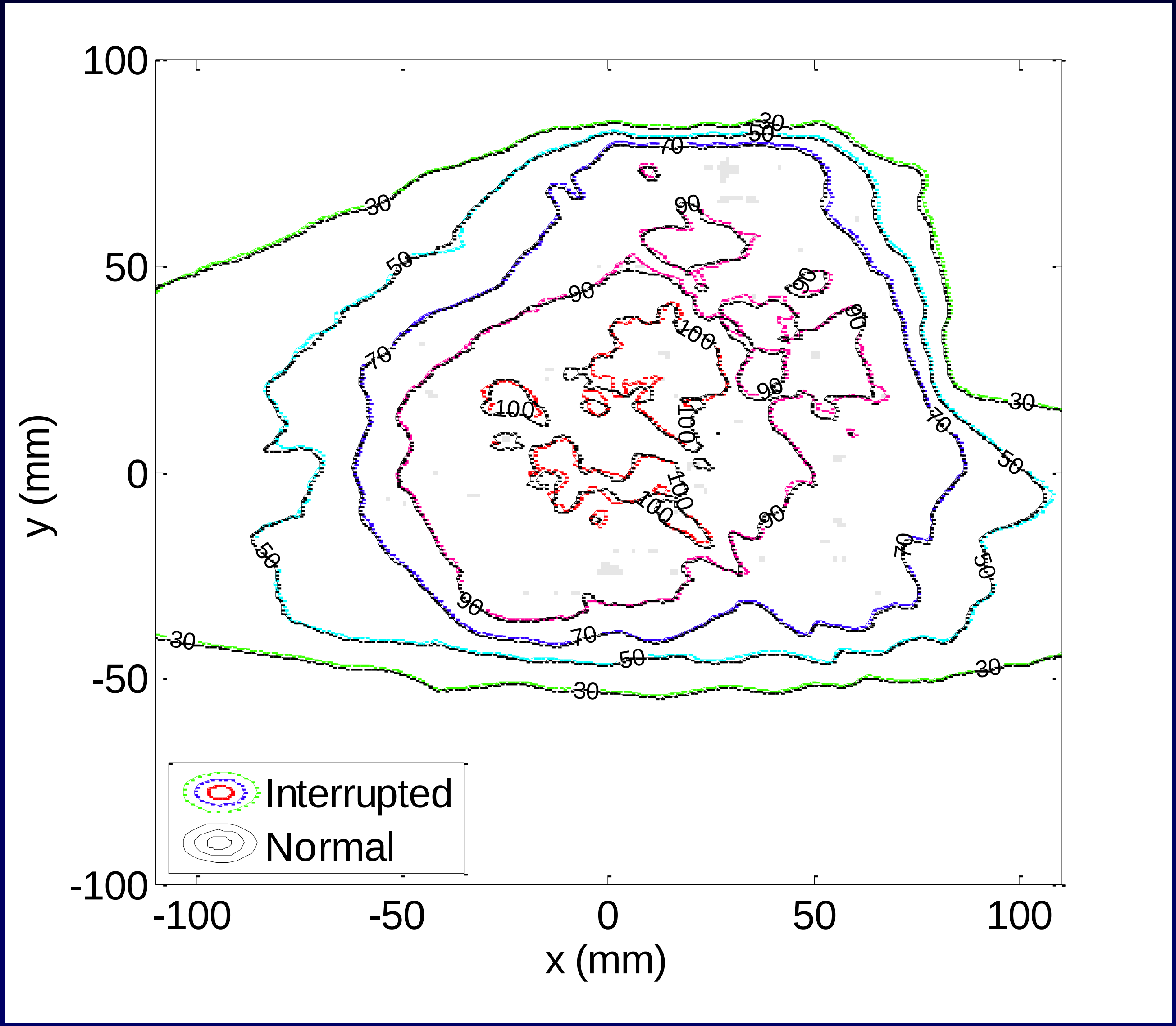
End-to-end test: Prostate - coronal



4.9% of pixels have $\gamma > 1$ (3%/3 mm)

Courtesy Richard Popple

Interrupted delivery



Courtesy Richard Popple

VMAT Treatment Planning Considerations

TPS - Commissioning

- Beams that are well modelled for fixed-field IMRT may not need to be re-modelled for VMAT.
- It is critical, however, to verify the accuracy of your beam models through extensive measurements.

VMAT – Commercial TPS Solutions

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

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VMAT Planning Process

- The VMAT planning process is very similar to that for fixed-field IMRT.
- Additional VMAT-specific parameters may need to be selected. For example, in Pinnacle:
  - Number of arcs
  - Allowable delivery time per arc
  - Maximum leaf speed

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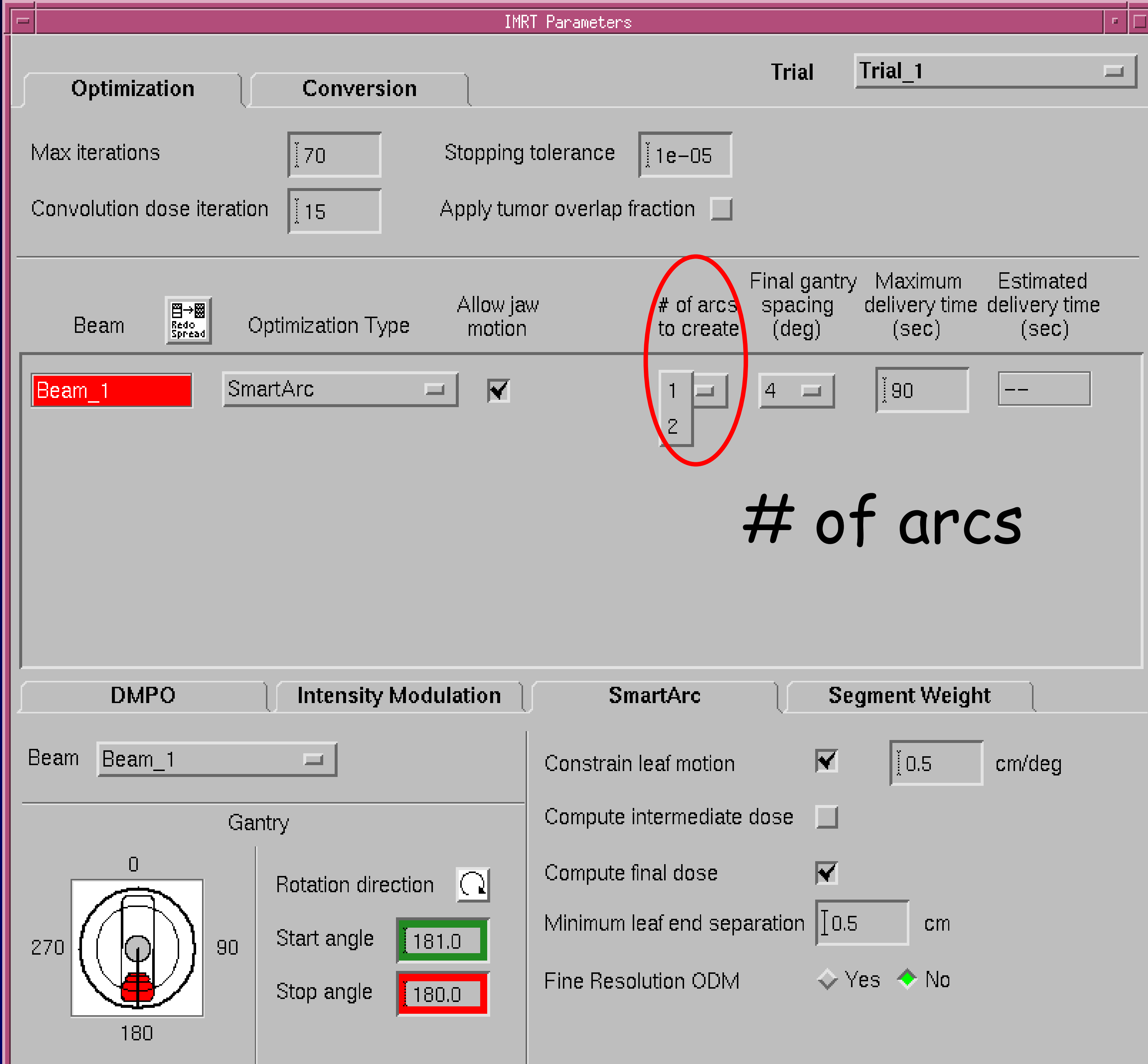
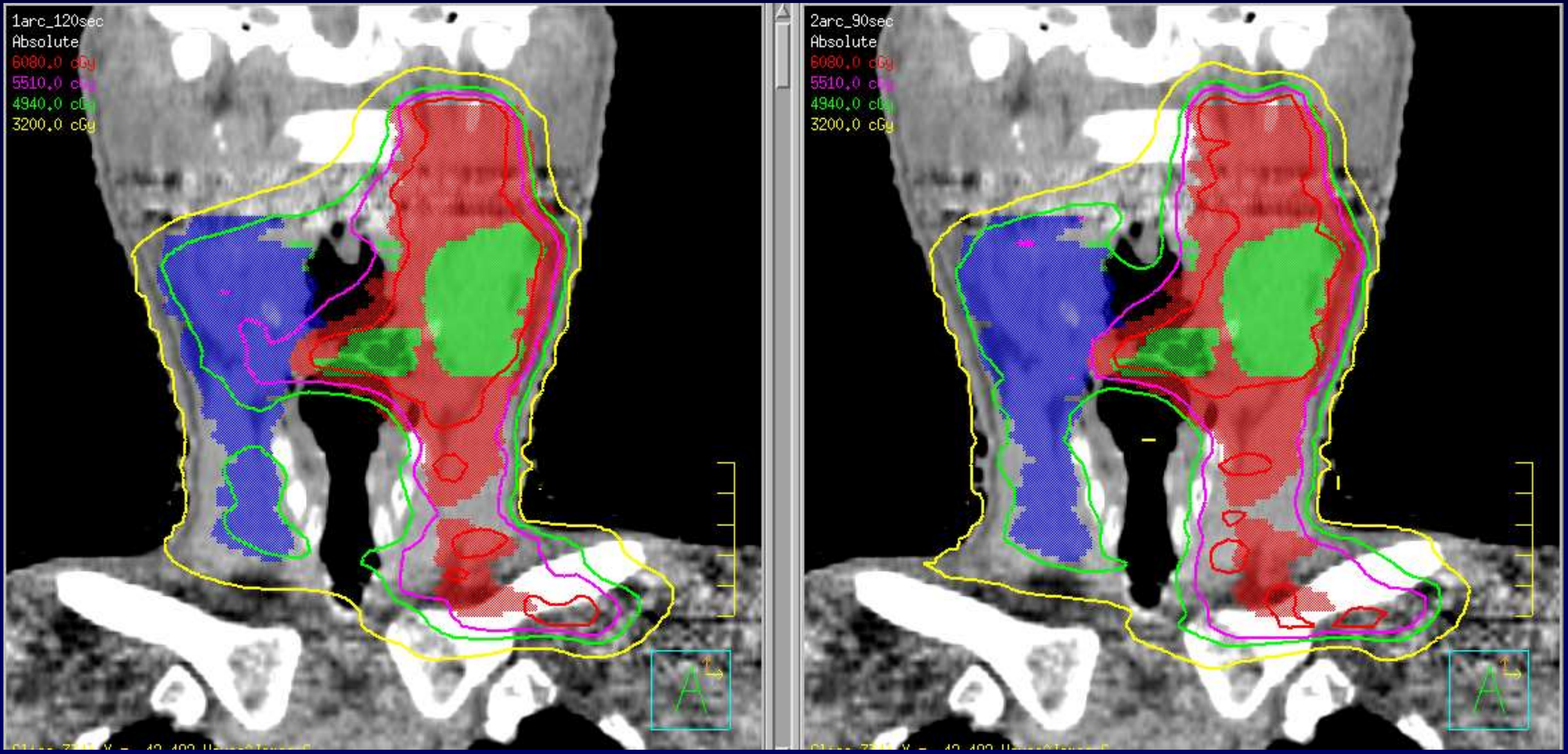
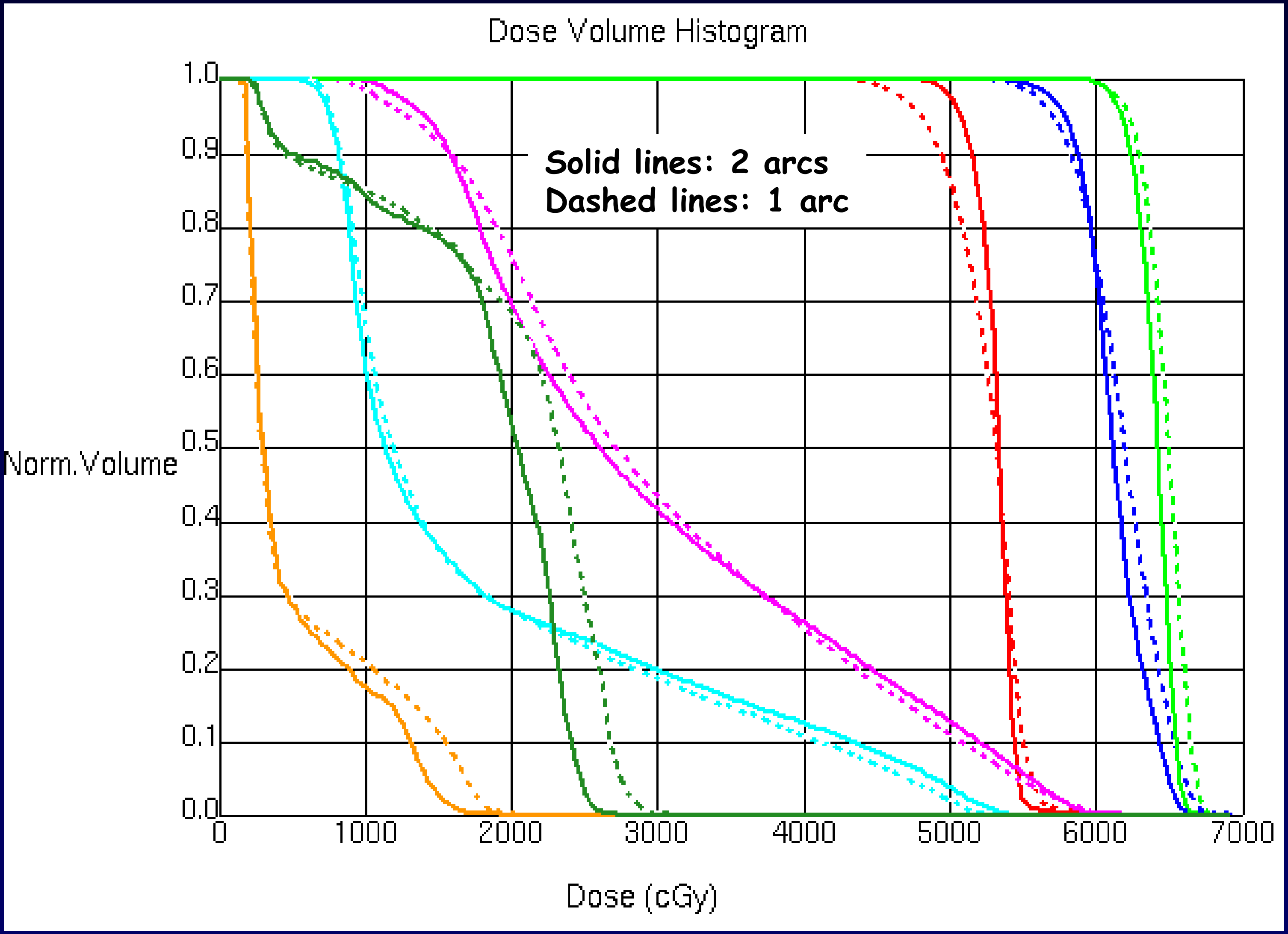

IMRT Parameters
Optimization
Conversion
Trial
Trial_1
Max iterations
70
Stopping tolerance
1e−05
Convolution dose iteration
15
Apply tumor overlap fraction
Beam
Redo Spread
Optimization Type
Allow jaw motion
# of arcs to create
Final gantry spacing (deg)
Maximum delivery time (sec)
Estimated delivery 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

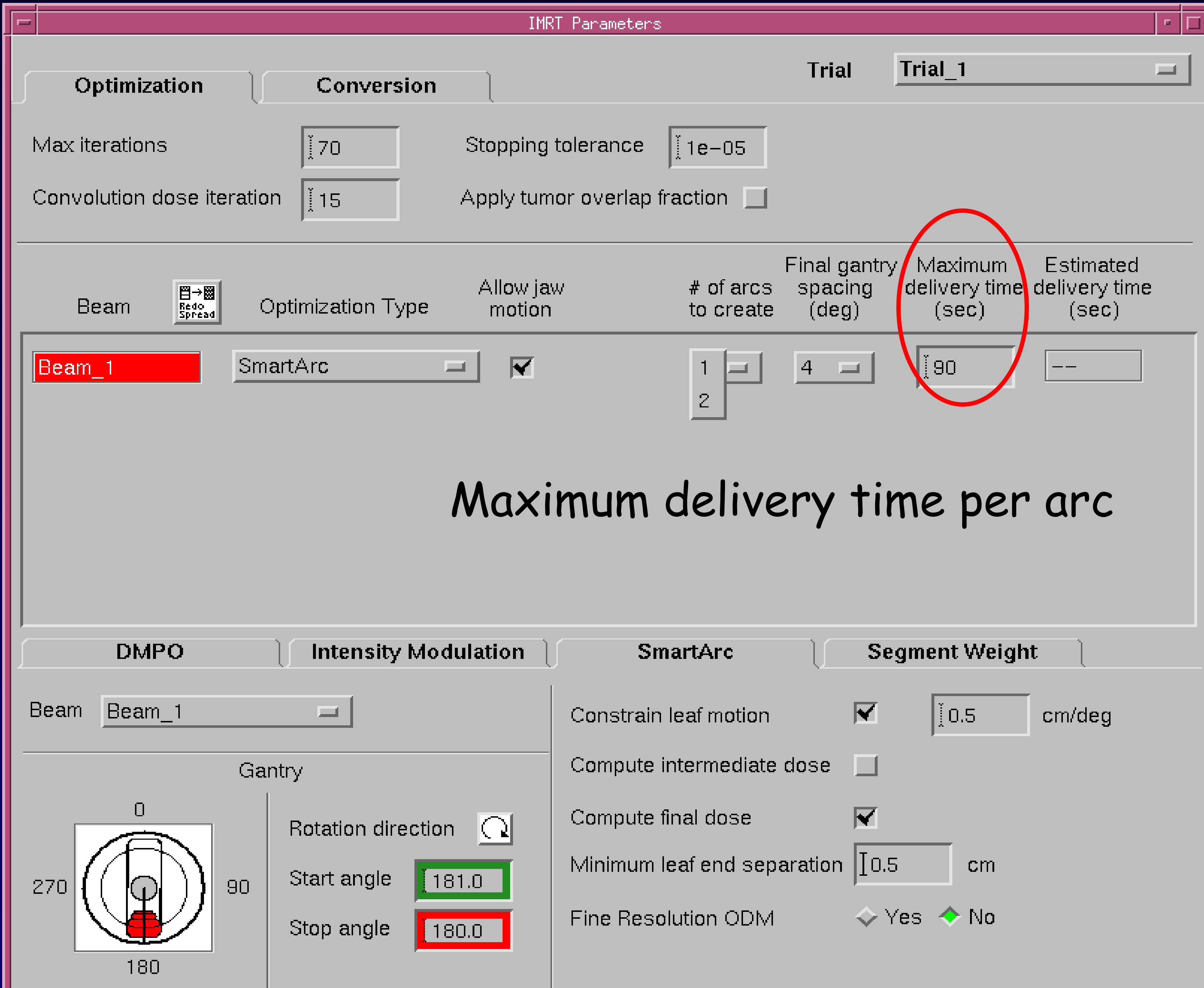
1 arc vs. 2 arcs



1 arc vs. 2 arcs



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


IMRT Parameters
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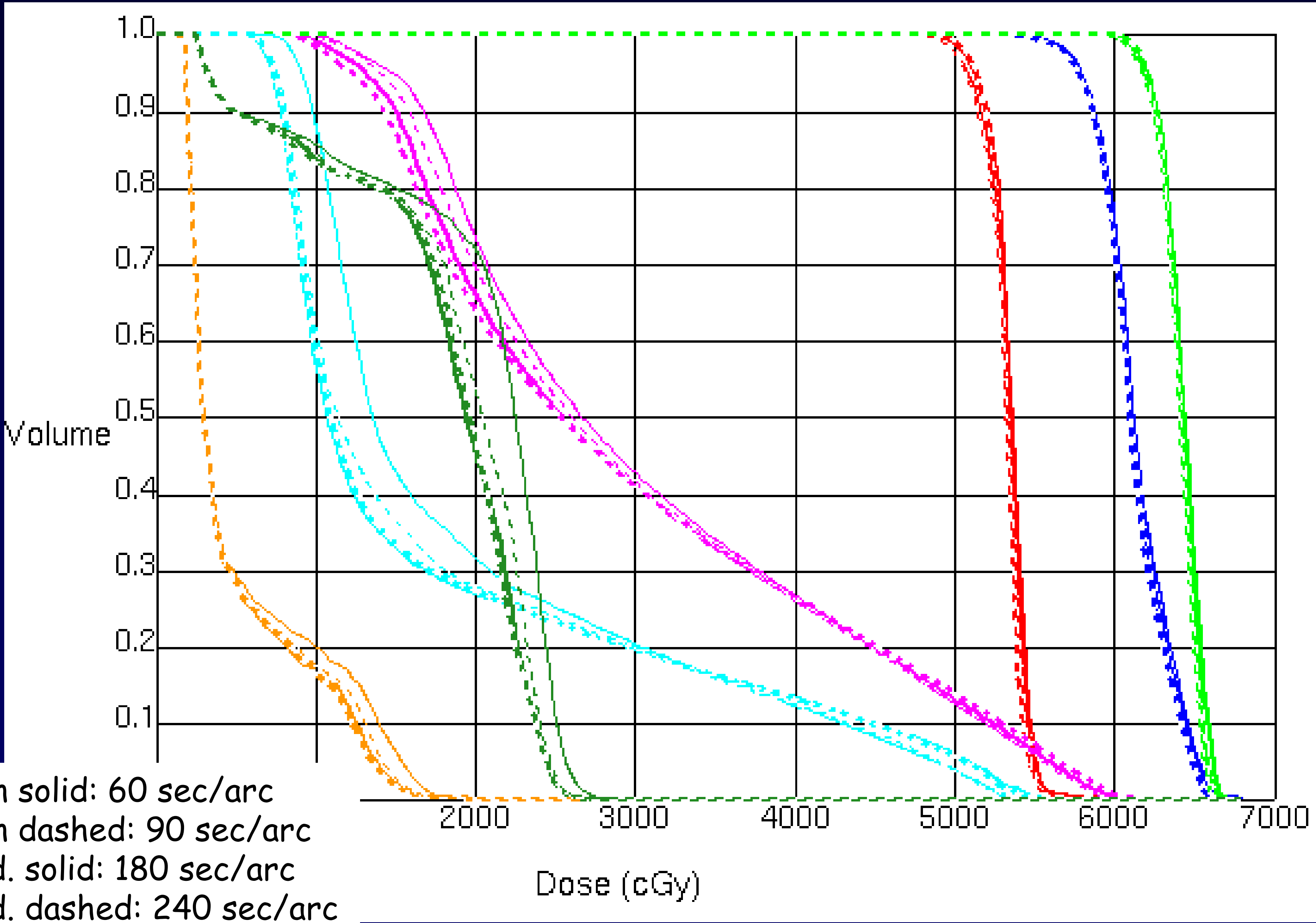
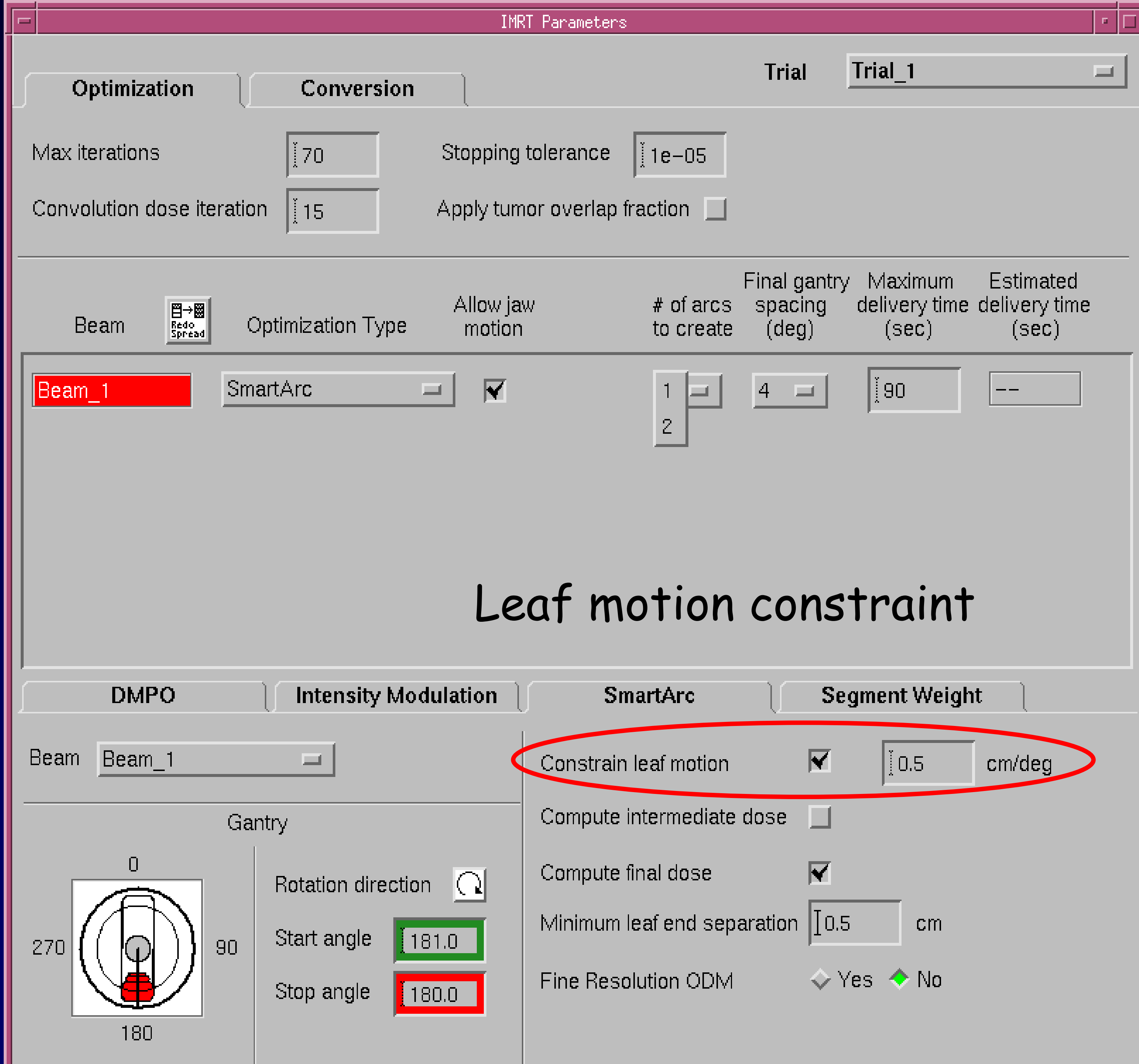
Beam
Optimization Type
Allow jaw motion
# of arcs to create
Final gantry spacing (deg)
Maximum delivery time (sec)
Estimated delivery time (sec)
Beam_1
SmartArc
1
2
4
90
--
Maximum delivery time per arc
DMPO
Intensity Modulation
SmartArc
Segment Weight
Beam
Beam_1
Gantry
0
270
90
180
Rotation direction
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

Delivery time



Thin solid: 60 sec/arc
Thin dashed: 90 sec/arc
Med. solid: 180 sec/arc
Med. dashed: 240 sec/arc


IMRT Parameters
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Trial
Trial_1
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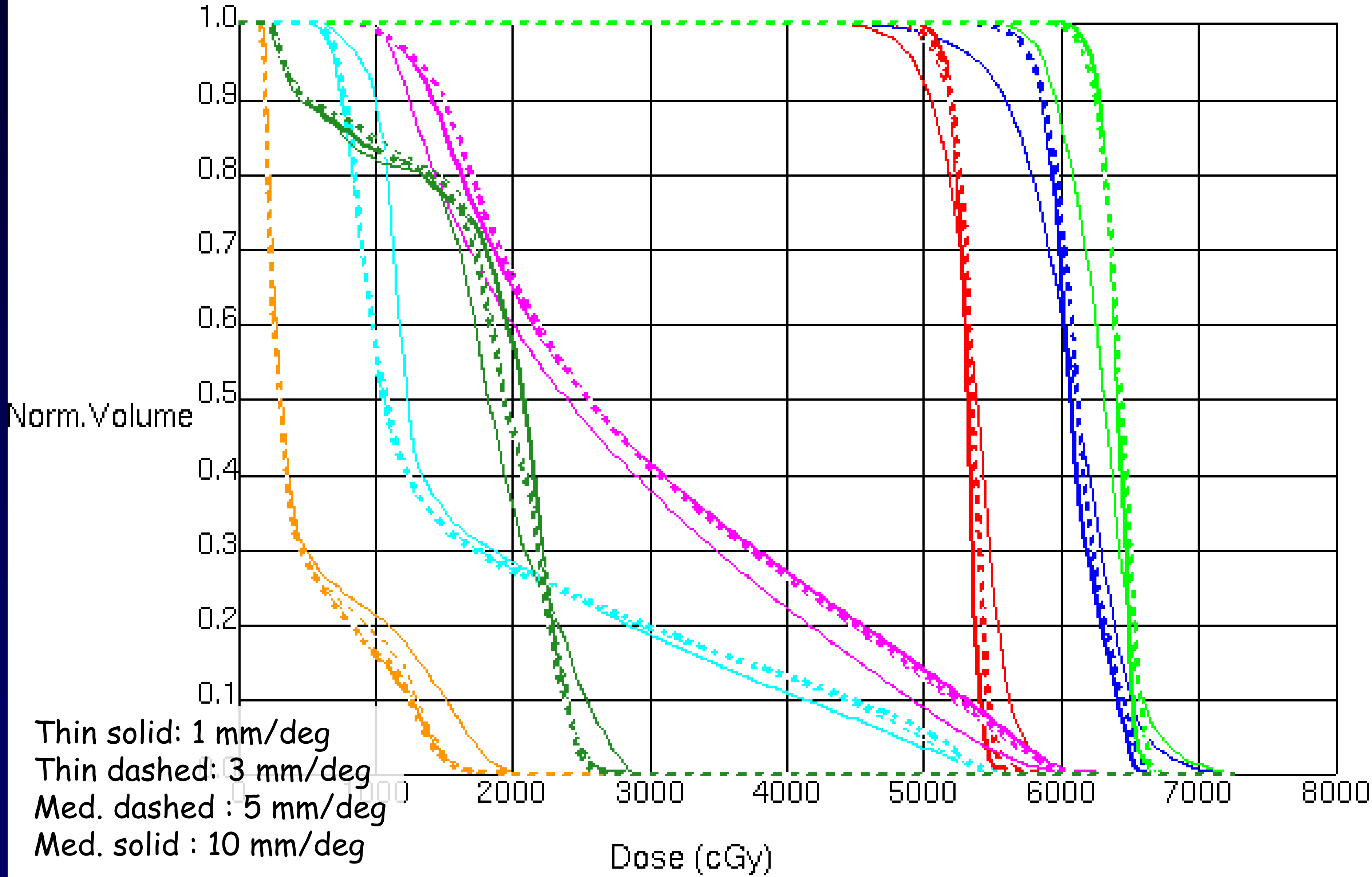
70
Stopping tolerance
1e−05
Convolution dose iteration
15
Apply tumor overlap fraction
Beam
Redo Spread
Optimization Type
Allow jaw motion
# of arcs to create
Final gantry spacing (deg)
Maximum delivery time (sec)
Estimated delivery time (sec)
Beam_1
SmartArc
1
2
4
90
--
Leaf motion constraint
DMPO
Intensity Modulation
SmartArc
Segment Weight
Beam
Beam_1
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
Gantry
0
270
90
180
Rotation direction
Start angle
181.0
Stop angle
180.0

Leaf motion



Thin solid: 1 mm/deg
Thin dashed: 3 mm/deg
Med. dashed : 5 mm/deg
Med. solid : 10 mm/deg

VMAT Planning Parameters
SmartArc Experience

- 1 arc is sufficient for simple cases such as prostate, but 2 arcs are needed for more complex cases such as H&N.
- We typically set a delivery time of 90sec/arc.
- We generally restrict the leaf motion to be 3mm/degree of gantry rotation for prostate cases and 4 or 5mm/degree for H&N cases.

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Summary

- Since 2008, VMAT has become a widely adopted IMRT delivery technique.
- VMAT combines highly efficient delivery (< 2 minutes per arc) with highly conformal dose distributions.
- VMAT is a complex delivery technique requiring a thorough commissioning process.

SWEDISH

Acknowledgments

- Daliang Cao
- Vivek Mehta
- Min Rao
- Fan Chen
- Richard Popple
- Ke Sheng

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Swedish Medical Center

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Delivery time

Maximum time (sec/arc)	Delivery time (sec)
60	140
90	181
180	325
240	356

Heidelberg 1st TomoEDGE™ and Lille 1st TomoHDA™

UniversitätsKlinikum Heidelberg

UNICANCER

Centre Oscar Lambret
Centre Régional de Lutte contre le Cancer

1st TomoEDGE installed
1st patient on the 25th of March 2013

1st TomoHDA installed
1st patient on the 23rd of April 2013

UniversitätsKlinikum Heidelberg

TomoEDGE™

Improved flexibility and treatment times

Berlin

May 11th, 2013

PD Dr. med. Florian Sterzing
Radioonkologie und Strahlentherapie
Universitätsklinikum Heidelberg

Courtesy of PD Dr. Med. Florian Sterzing, Heidelgerg, Germany

Significant change in the use of 5cm jaws

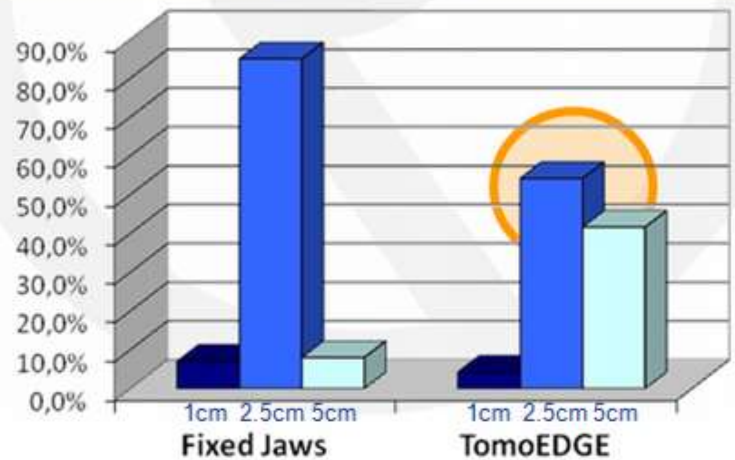
With TomoEDGE™

Before TomoEDGE™

- 1 cm: 5 %
- 2.5 cm: 90 %
- 5 cm: 5 %

With TomoEDGE™: **72 Patients**

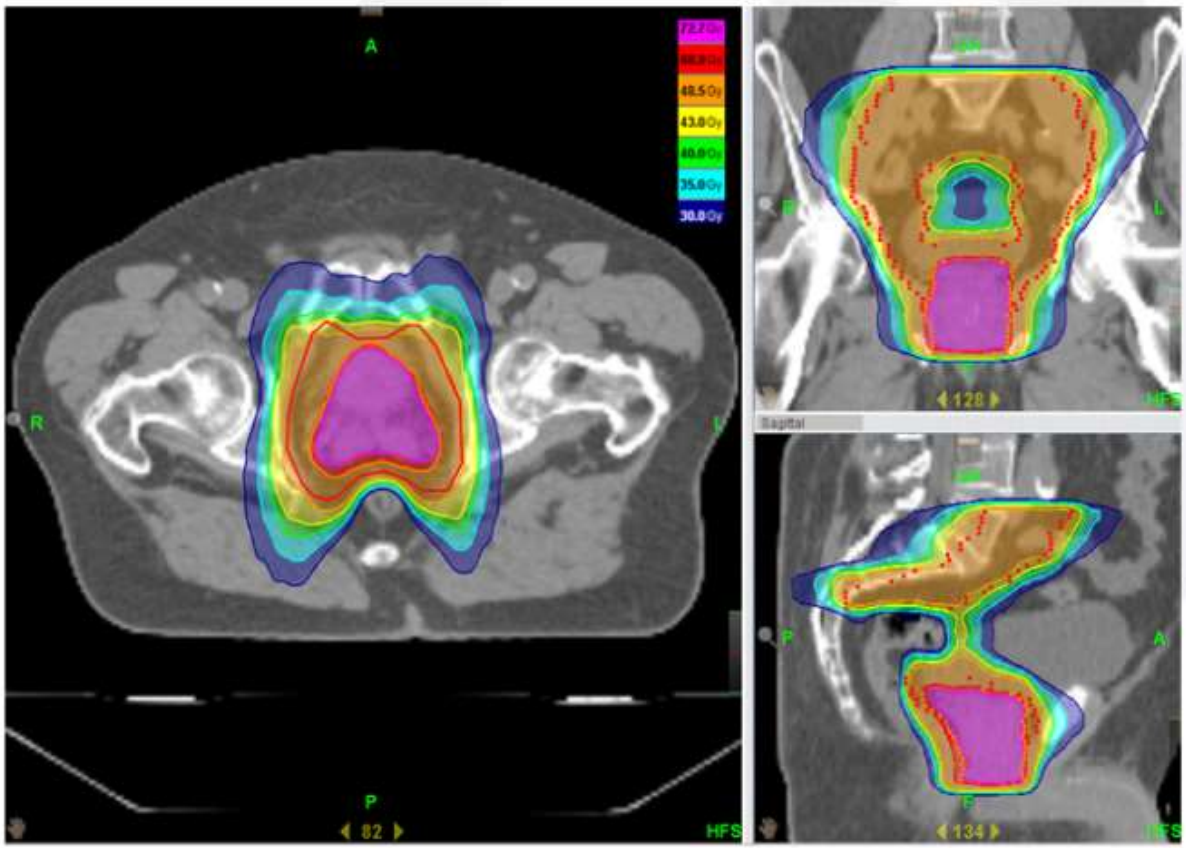
- 1 cm: 3 (4.2%)
- 2.5 cm: 39 (54.2%)
- 5 cm: 30 (41.6%)



Courtesy of PD Dr. Med. Florian Sterzing, Heidelgerg, Germany

Prostate cancer: 25th of March 2013

1st patient with TomoEDGE™



34 fractions
- 51.0 Gy
- SIB: 76.5 Gy

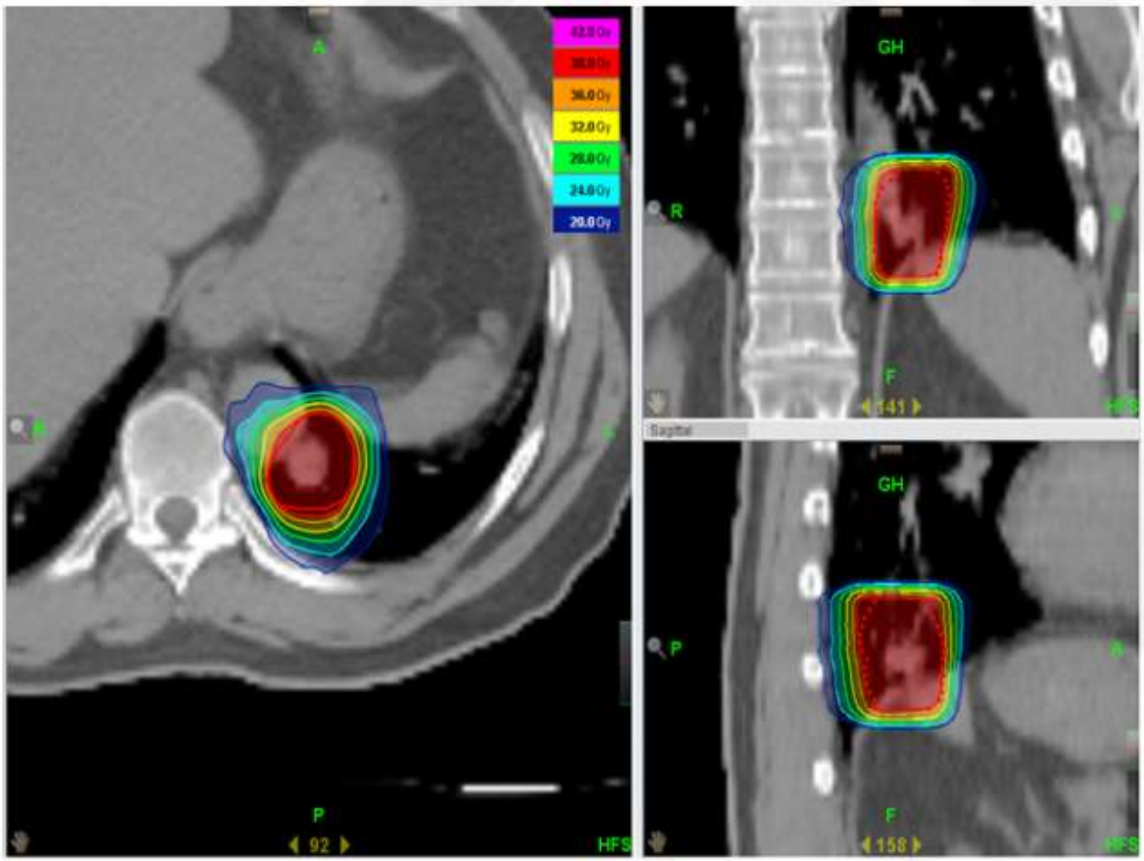
Dynamic Jaws
2.5 cm

Beam-on time
5.7 min

Courtesy of PD Dr. Med. Florian Sterzing, Heidelgerg, Germany

Lung metastases of a rectal cancer

TomoEDGE™



8 fractions
▪7.5 Gy per fraction

Dynamic Jaws 5cm

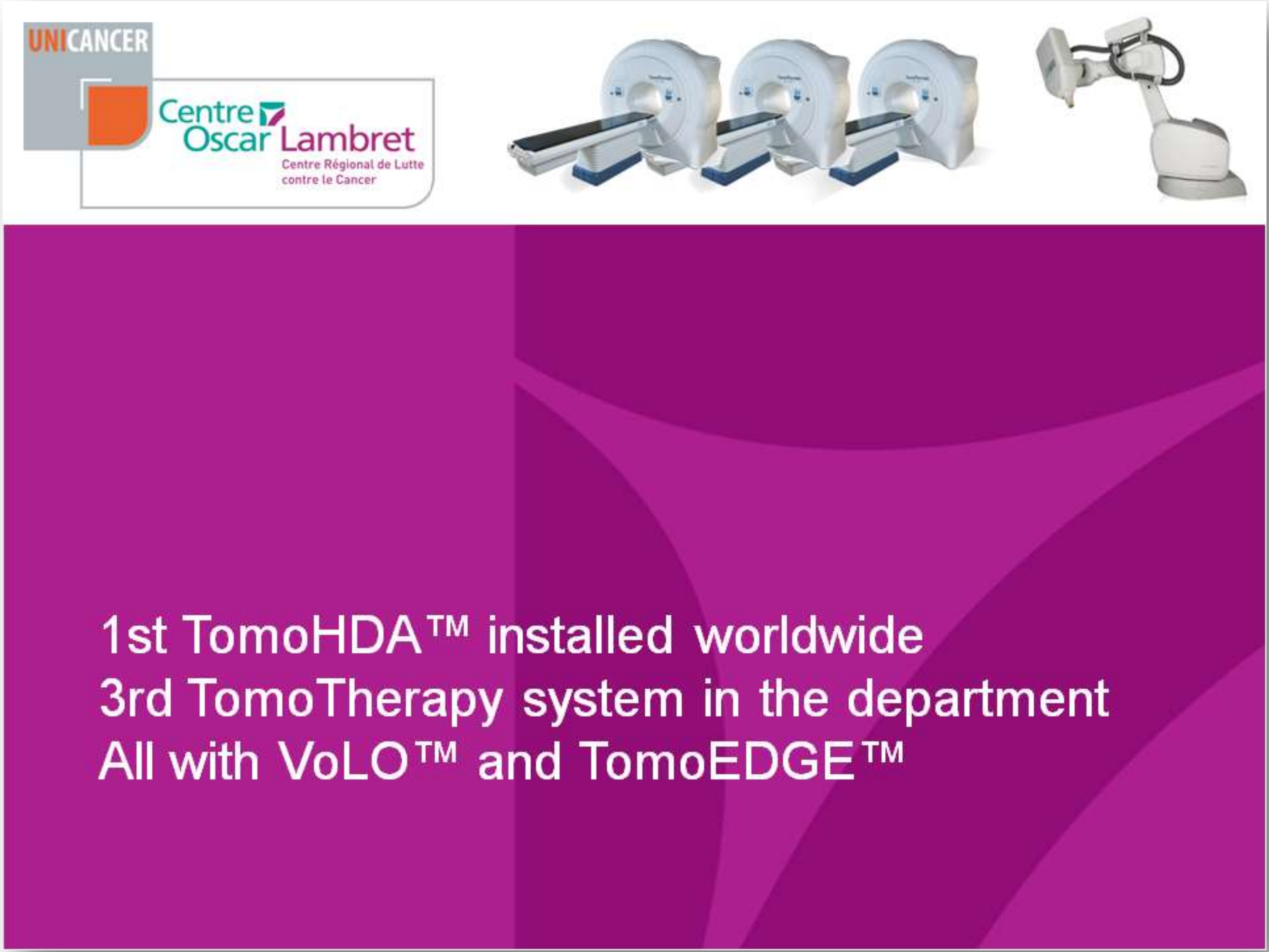
Beam-on 6 min

Courtesy of PD Dr. Med. Florian Sterzing, Heidelgerg, Germany

UNICANCER

Centre Oscar Lambret

Centre Régional de Lutte contre le Cancer



Courtesy of Prof. Eric Lartigau, Lille, France

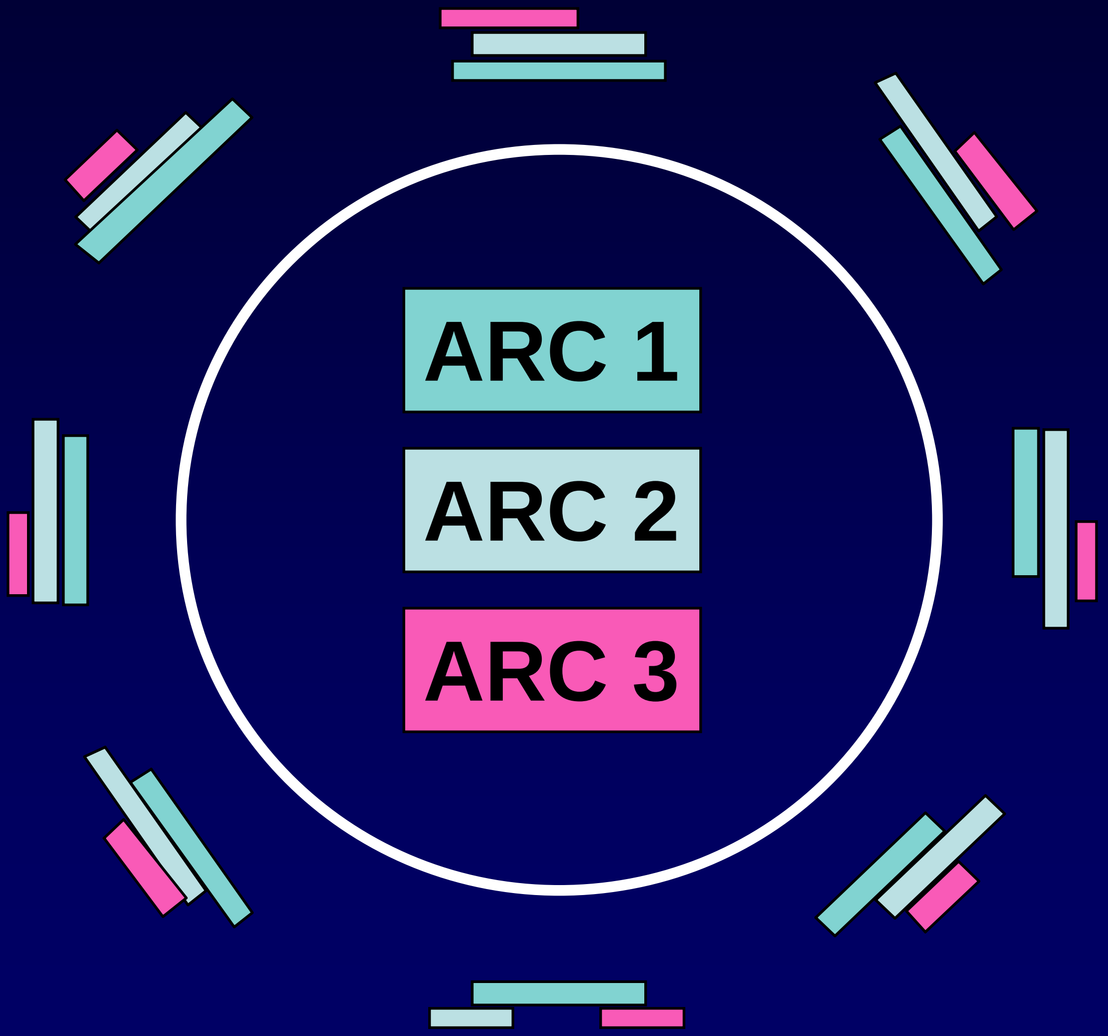
Centre Oscar Lambret TomoTherapy's activity

- ✓ 1st patient on the 23rd of April
  - ✓ first patient was a breast cancer patient
- ✓ 32 patients per day
- ✓ Called and coloured pink as this unit is mainly intended to treat breast cancer patients.

Courtesy of Prof. Eric Lartigau, Lille, France

Courtesy of Prof. Eric Lartigau, Lille, France

IMAT Delivery



From Cedric Yu

Int. J. Radiation Oncology Biol. Phys., Vol. ■, No. ■, pp. 1–8, 2009

0360-3016/09/$–see front matter

ELSEVIER

doi:10.1016/j.ijrobp.2009.07.1686

PHYSICS CONTRIBUTIONS

DYNAMIC JAWS AND DYNAMIC COUCH IN HELICAL TOMOTHERAPY

Florian Sterzing, M.D.,* Matthias Uhl, M.D.,* Henrik Hauswald, M.D.,* Kai Schubert, Ph.D.,* Gabriele Sroka-Perez, Ph.D.,* Yu Chen, Ph.D.,† Weiguo Lu, Ph.D.,† Rock Mackie, Ph.D.,† Jürgen Debus, M.D., Ph.D.,* Klaus Herfarth, M.D.,* and Gustavo Oliveira, Ph.D.†

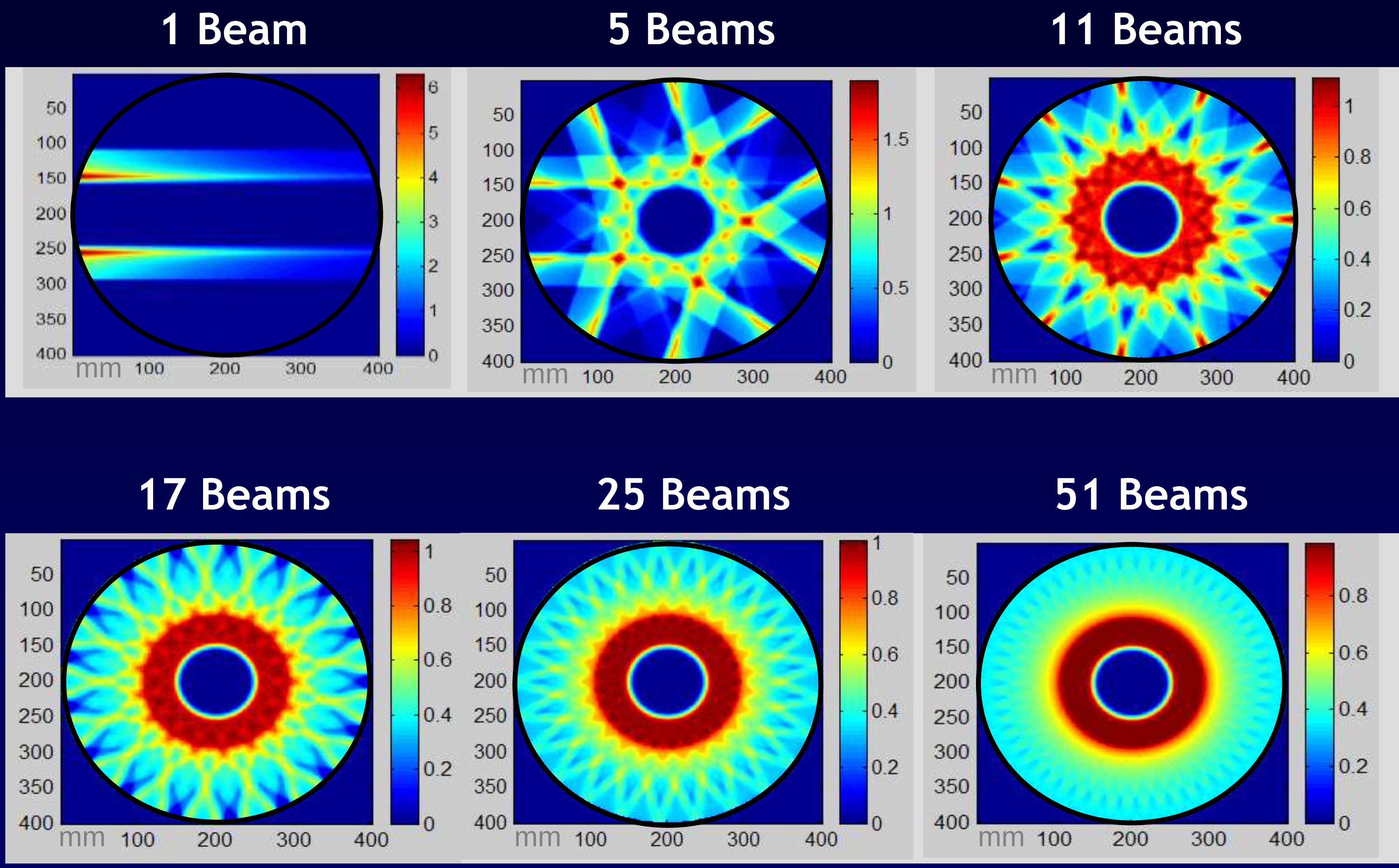
*Department of Radiation Oncology, University of Heidelberg, Germany; and †Tomotherapy Incorporated, Madison, Wisconsin

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

IMAT – Initial Experience

- 50 patients were treated in this trial: central nervous system (17 patients), head and neck (25 patients) and prostate (8 patients).
- Average treatment time was 7.5 minutes.
- Demonstrated IMAT can be delivered safely an accurately on a conventional linac.

Why rotational delivery?

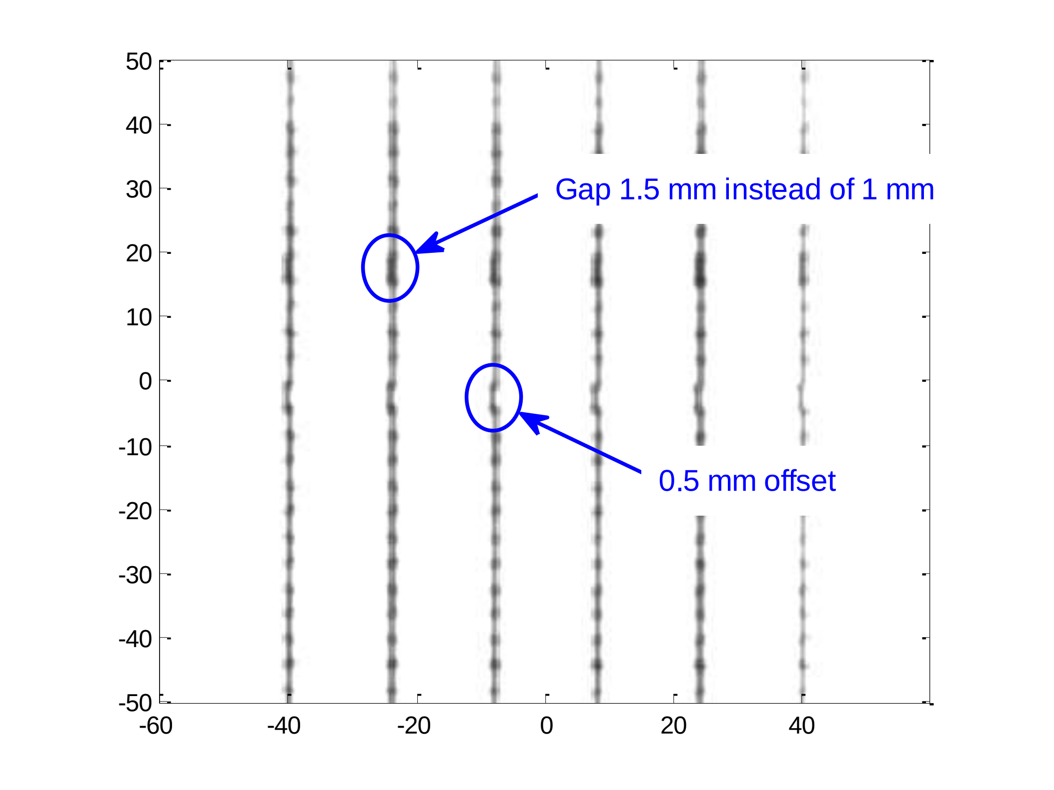


Courtesy of Accuray Inc.

C-shaped Target Simulations

# Angles	Obj. Funct. Value	Std. Dev. in target dose	d_{95}	Mean dose to RAR	Total integral dose
3	0.665	0.124	0.747	0.488	2732.5
5	0.318	0.090	0.814	0.215	2563.3
7	0.242	0.064	0.867	0.206	2596.8
9	0.222	0.064	0.855	0.192	2598.3
11	0.202	0.058	0.879	0.186	2570.2
15	0.187	0.053	0.908	0.180	2542.9
21	0.176	0.049	0.912	0.171	2545.1
33	0.151	0.038	0.933	0.155	2543.5

Picket fence test with simulated error



Courtesy Richard Popple

Int. J. Radiation Oncology Biol. Phys., Vol. 80, No. 4, pp. 1248–1255, 2011

0360-3016/$ - see front matter

ELSEVIER

doi:10.1016/j.ijrobp.2010.08.007

PHYSICS CONTRIBUTION

SMARTARC-BASED VOLUMETRIC MODULATED ARC THERAPY FOR OROPHARYNGEAL CANCER: A DOSIMETRIC COMPARISON WITH BOTH INTENSITY-MODULATED RADIATION THERAPY AND HELICAL TOMOTHERAPY

Stefania Clemente, Ph.D.,*† BinBin Wu, Ph.D.,* Giuseppe Sanguineti, M.D.,* Vincenzo Fusco, M.D.,† Francesco Ricchetti, M.D.,* John Wong, Ph.D.,* and Todd McNutt, Ph.D.*

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Purpose: To investigate the roles of volumetric modulated arc therapy with SmartArc (VMAT-S), intensity-modulated radiation therapy (IMRT), and helical tomotherapy (HT) for oropharyngeal cancer using a simultaneous integrated boost (SIB) approach.
Methods and Materials: Eight patients treated with IMRT were selected at random. Plans were computed for both IMRT and VMAT-S (using Pinnacle TPS for an Elekta Infinity linac) along with HT. A three-dose level prescription was used to deliver 70 Gy, 63 Gy, and 58.1 Gy to regions of macroscopic, microscopic high-risk, and microscopic low-risk disease, respectively. All doses were given in 35 fractions. Comparisons were performed on dose–volume histogram data, monitor units per fraction (MU/fx), and delivery time.
Results: VMAT-S target coverage was close to that achieved by IMRT, but inferior to HT. The conformity and homogeneity within the PTV were improved for HT over all strategies. Sparing of the organs at risk (OAR) was achieved with all modalities. VMAT-S (along with HT) shortened delivery time (mean, −38%) and reduced MU/fx (mean, −28%) compared with IMRT.
Conclusion: VMAT-S represents an attractive solution because of the shorter delivery time and the lower number of MU/fx compared with IMRT. However, in this complex clinical setting, current VMAT-S does not appear to provide any distinct advantage compared with helical tomotherapy.

IMRT, HT, VMAT SmartArc, Oropharyngeal cancer.

Int. J. Radiation Oncology Biol. Phys., Vol. 81, No. 1, pp. 284–296, 2011

0360-3016/$ - see front matter

ELSEVIER

doi:10.1016/j.ijrobp.2010.10.059

PHYSICS CONTRIBUTION

HELICAL TOMOTHERAPY VERSUS SINGLE-ARC INTENSITY-MODULATED ARC THERAPY: A COLLABORATIVE DOSIMETRIC COMPARISON BETWEEN TWO INSTITUTIONS

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*Department of Human Oncology and Medical Physics, University of Wisconsin-Madison, WI, Madison; †University of Wisconsin Cancer Center Riverview, Wisconsin Rapids, WI; and ‡Department of Radiation Oncology, University of Maryland School of Medicine, Baltimore, MD

Purpose: Both helical tomotherapy (HT) and single-arc intensity-modulated arc therapy (IMAT) deliver radiation using rotational beams with multileaf collimators. We report a dual-institution study comparing dosimetric aspects of these two modalities.
Methods and Materials: Eight patients each were selected from the University of Maryland (UMM) and the University of Wisconsin Cancer Center Riverview (UWR), for a total of 16 cases. Four cancer sites including brain, head and neck (HN), lung, and prostate were selected. Single-arc IMAT plans were generated at UMM using Varian RapidArc (RA), and HT plans were generated at UWR using Hi-Art II TomoTherapy. All 16 cases were planned based on the identical anatomic contours, prescriptions, and planning objectives. All plans were swapped for analysis at the same time after final approval. Dose indices for targets and critical organs were compared based on dose–volume histograms, the beam-on time, monitor units, and estimated leakage dose. After the disclosure of comparison results, replanning was done for both techniques to minimize diversity in optimization focus from different operators.
Results: For the 16 cases compared, the average beam-on time was 1.4 minutes for RA and 4.8 minutes for HT plans. HT provided better target dose homogeneity (7.6% for RA and 4.2% for HT) with a lower maximum dose (110% for RA and 105% for HT). Dose conformation numbers were comparable, with RA being superior to HT (0.67 vs. 0.60). The doses to normal tissues using these two techniques were comparable, with HT showing lower doses for more critical structures. After planning comparison results were exchanged, both techniques demonstrated improvements in dose distributions or treatment delivery times.
Conclusions: Both techniques created highly conformal plans that met or exceeded the planning goals. The delivery time and total monitor units were lower in RA than in HT plans, whereas HT provided higher target dose uniformity. © 2011 Elsevier Inc.

Helical tomotherapy, Single-arc intensity-modulated arc therapy, Dynamic multileaf collimator, Dose–volume histogram, Intensity-modulated radiotherapy.

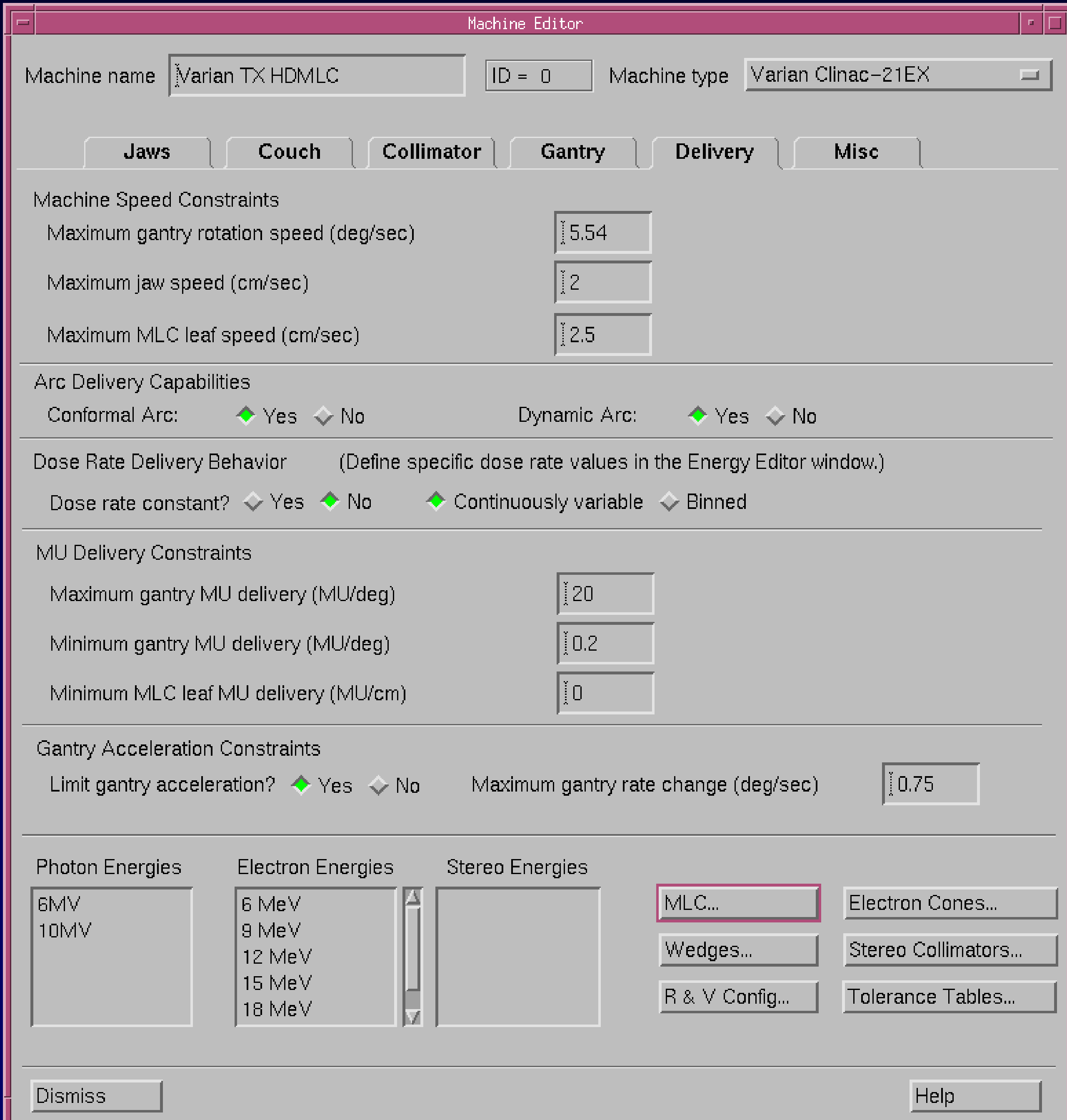
IMRT Delivery Techniques

- Compensators
- Step-and-shoot
- Sliding Window
- Tomotherapy
- IMAT

Fixed field (Compensators, Step-and-shoot, Sliding Window)

Rotational (Tomotherapy, IMAT)

SWEDISH

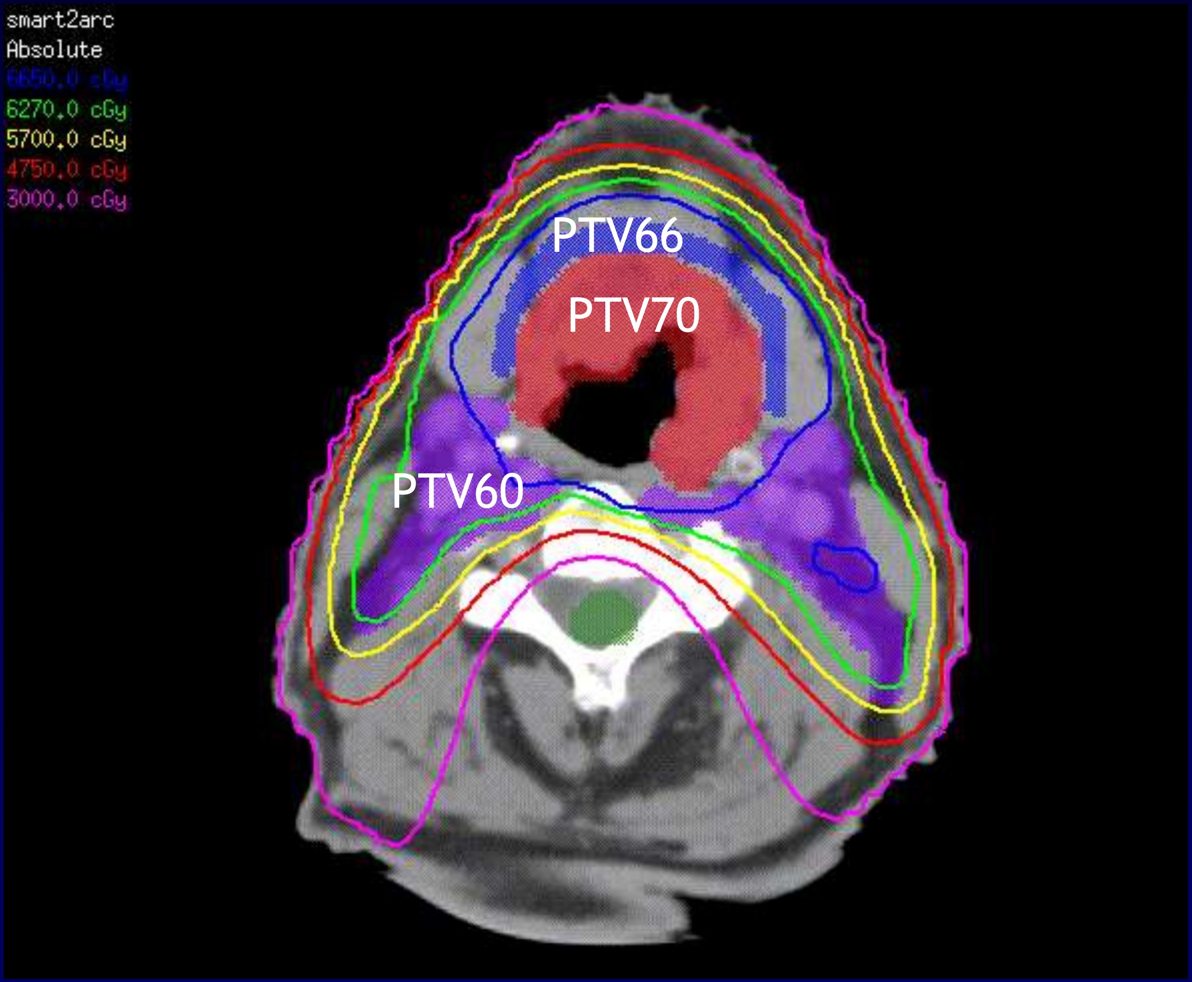


SmartArc delivery parameters are specified in one Physics window

IMAT – Forward Planning

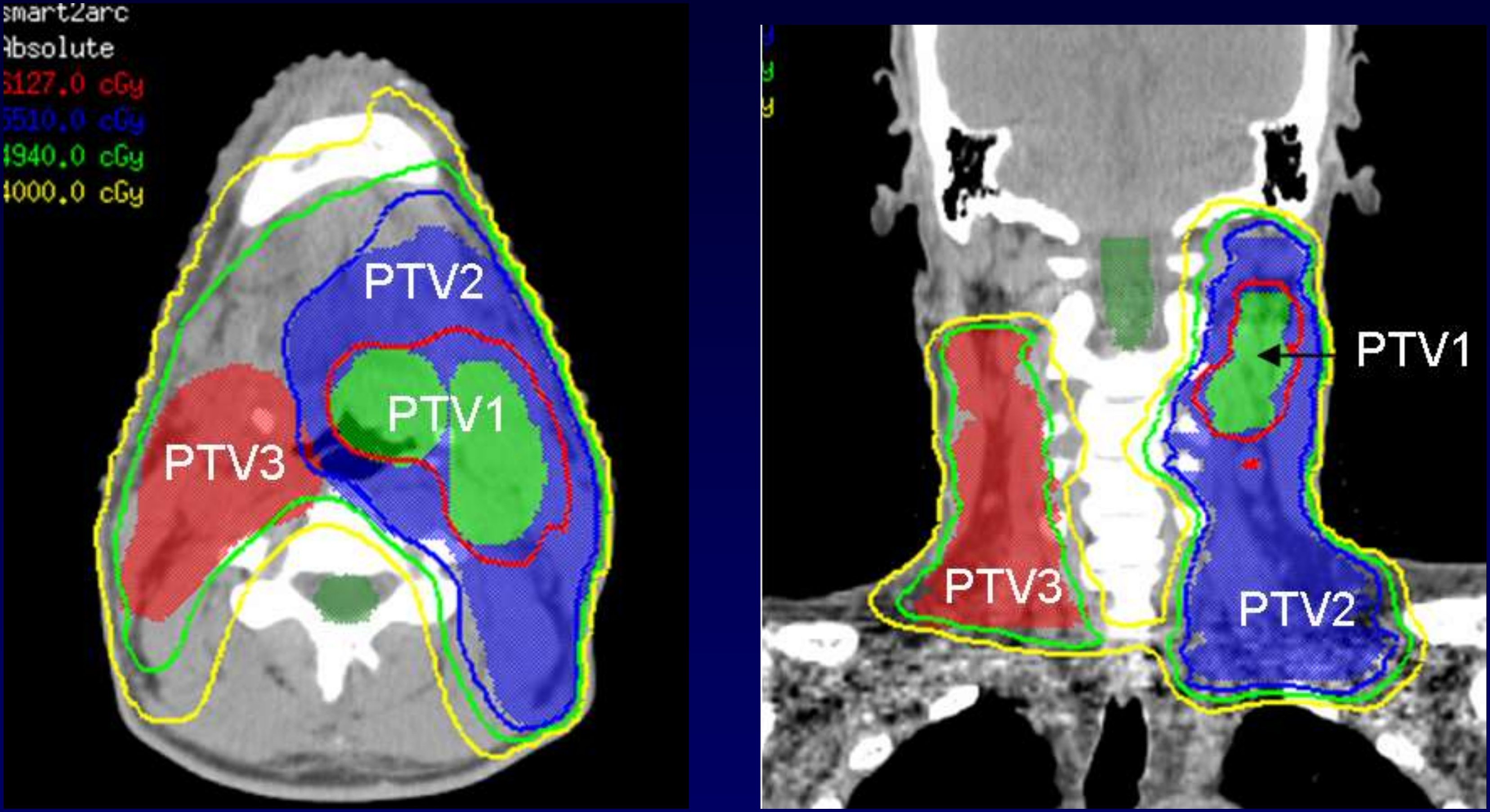
- Dosimetrists used iterative trial-and-error approach to determine starting and stopping angles, the beam shapes, and beam weights.
- Planning was time consuming.
- No guarantee that a plan was close to optimal.

H&N Example #2

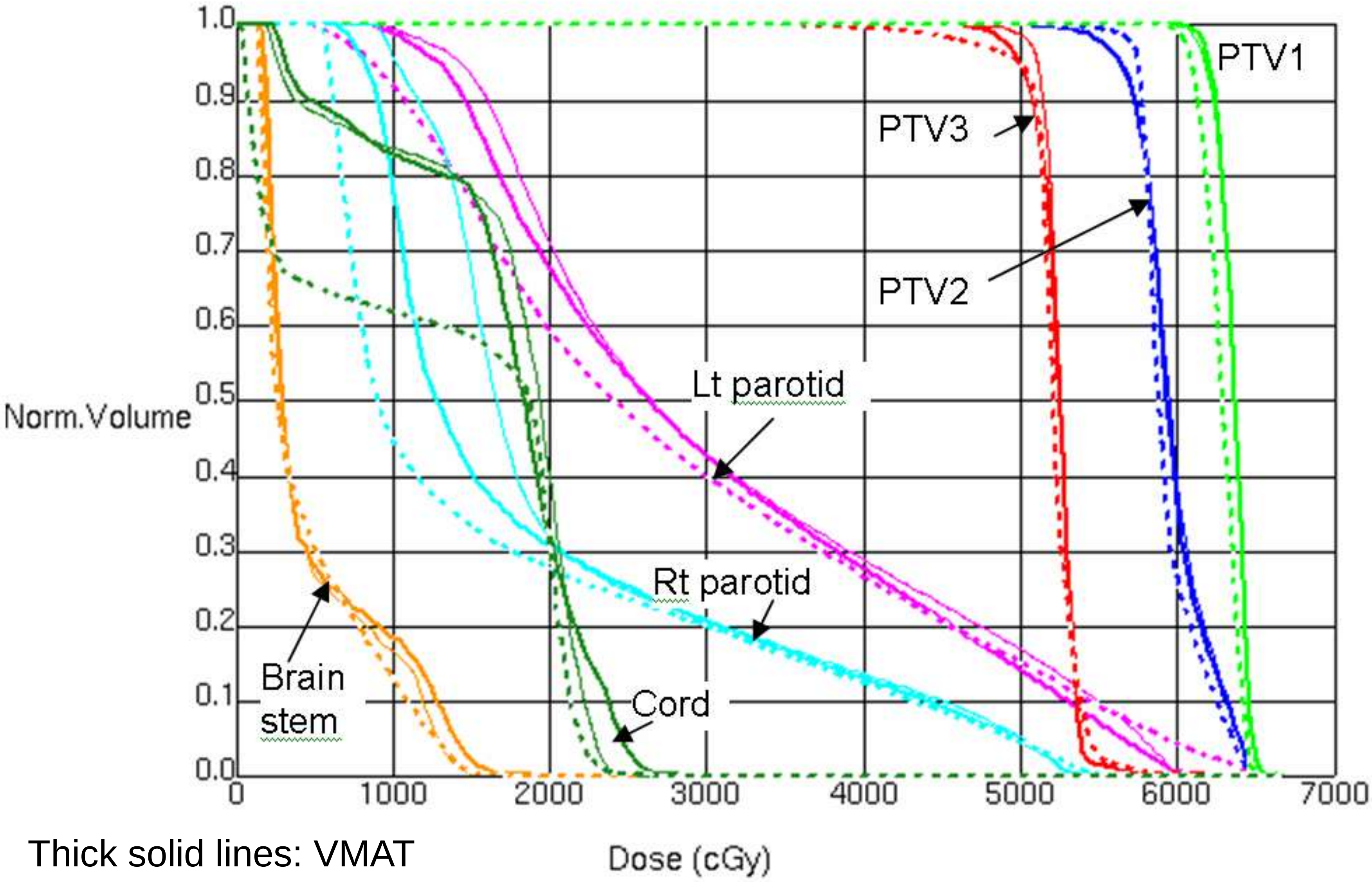


- 2 arcs, 512 monitor units
- Deliver time = 4 minutes 7 seconds

H&N Example #3

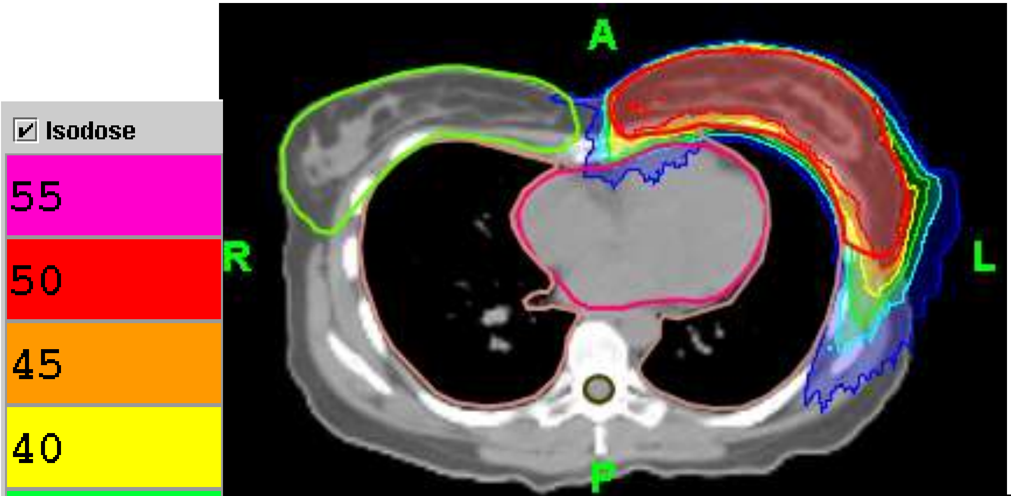


VMAT Plan

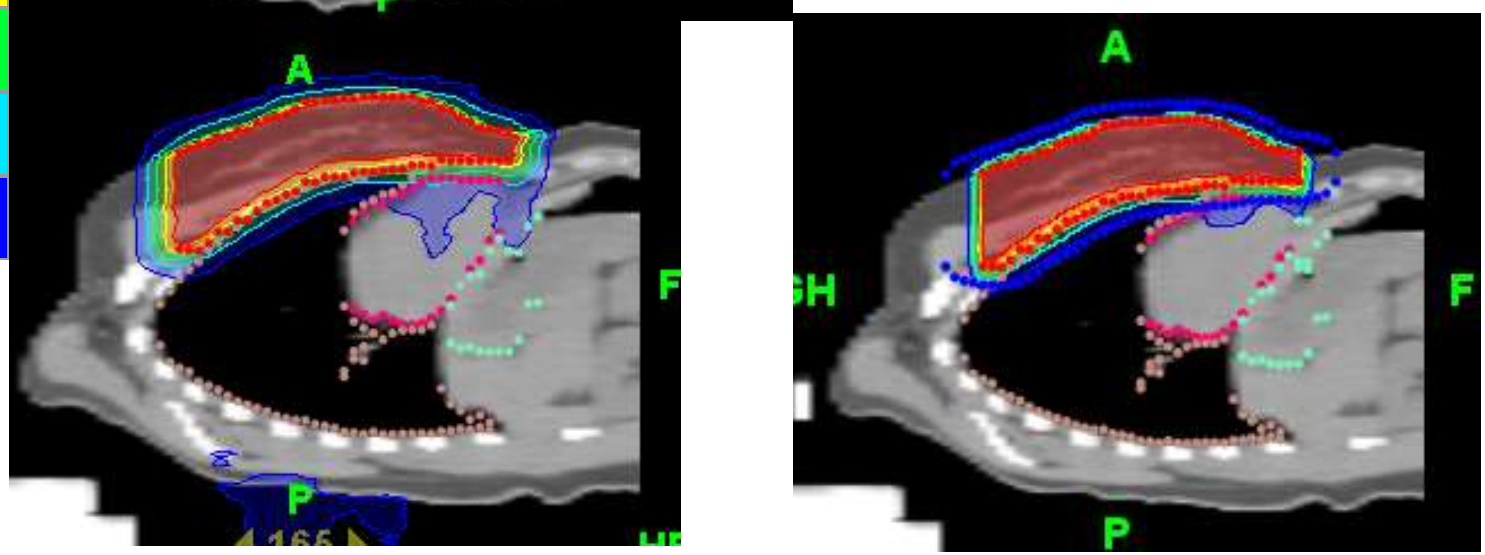


Thick solid lines: VMAT
Dashed lines: Tomo
Thin solid: 9 Field IMRT

Breast Cancer and Funnel Chest

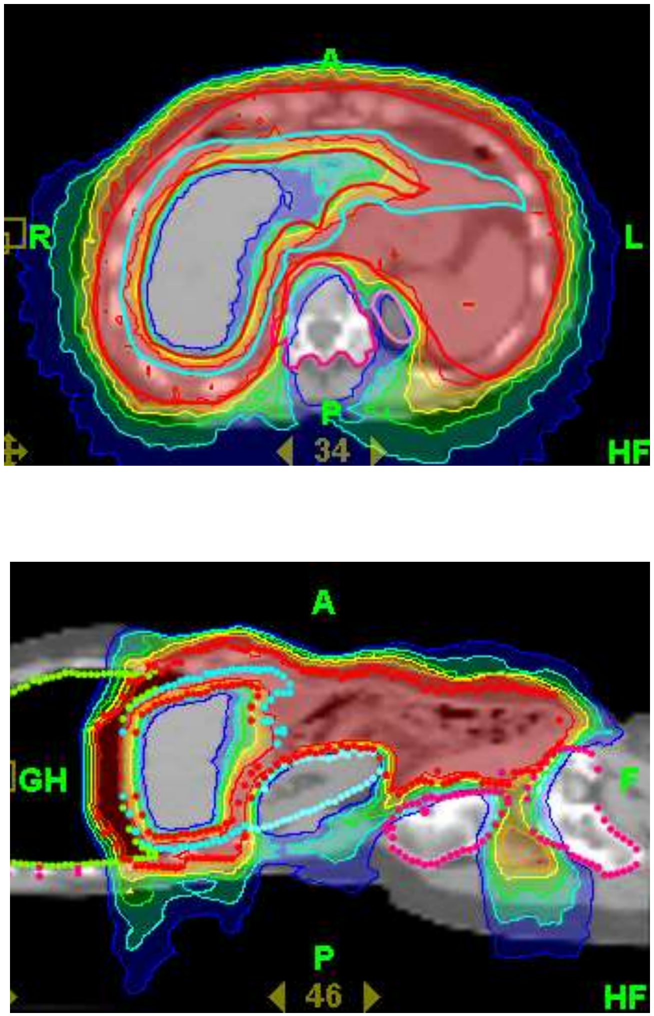


Courtesy of Dr. Florian Sterzing,
Heidelberg University



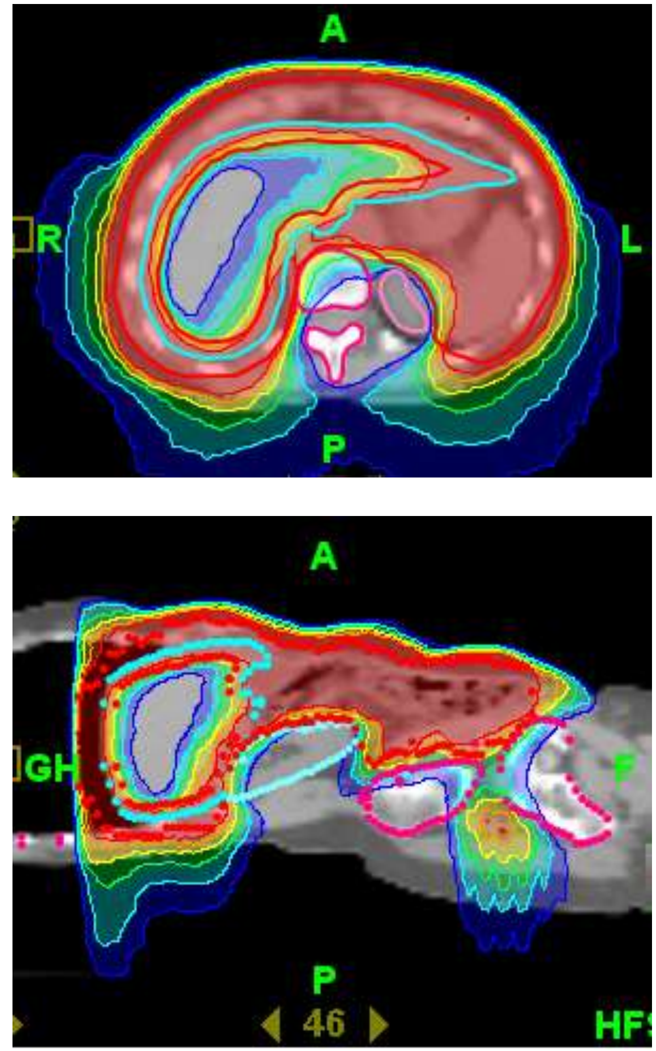
treatment time **regular 2.5** → **Djdc 5**: 3.5 minutes
12 minutes

Whole Abdominal Irradiation



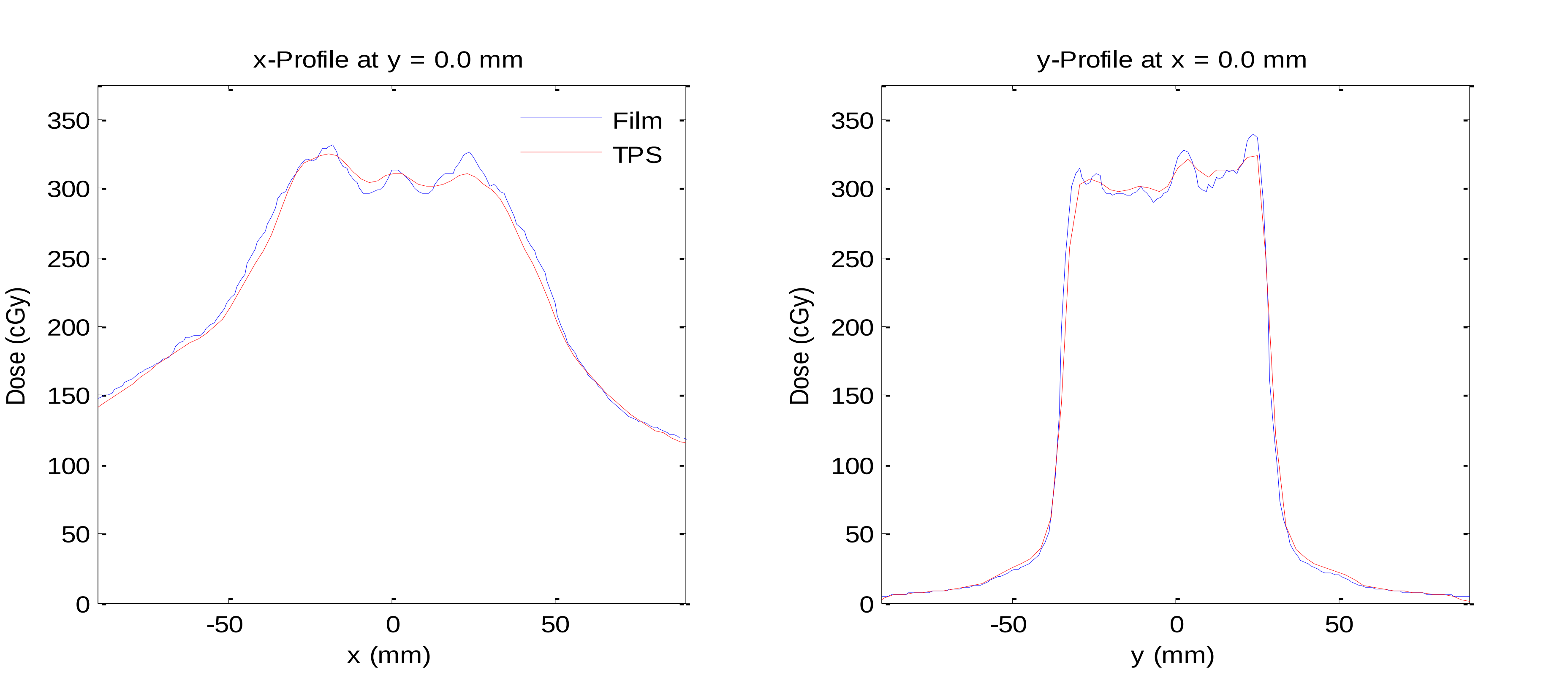
treatment time **regular 2.5cm**
17 minutes

→



Dynamic jaw Dynamic Couch 5cm: 5.5 minutes

End-to-end test: Prostate - coronal



Courtesy Richard Popple

VMAT – Commercial TPS Solutions

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

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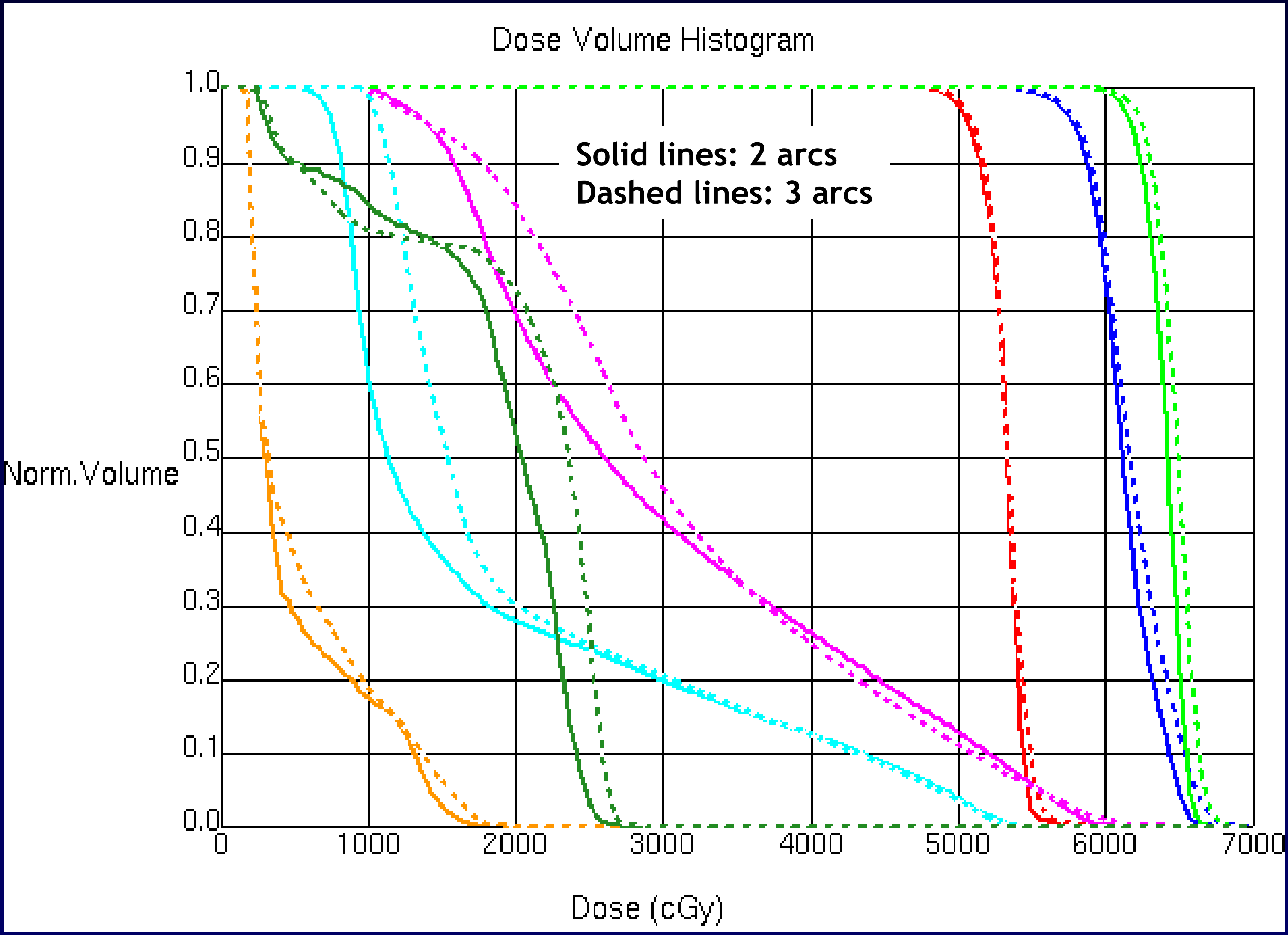
2 arcs vs. 3 arcs



Delivery time: 2 arcs = 181 sec, 3 arcs: 293 sec

Leaf motion

Leaf motion (mm/deg)	1	3	5	10
Estimated delivery time (sec)	303	315	325	376
Actual delivery time (sec)	218	250	300	427
QA passing rate (%)	98.3	99.0	98.7	98.1

Linac-Based IMRT/VMAT Commissioning and QA Program Development

Grace Gwe-Ya Kim, Ph.D., DABR

AAPM 54th Annual Meeting, July 30 2012