UC San Diego Health

Single Isocenter Treatment Technique for Multiple Cranial Targets - RapidArc and HyperArc

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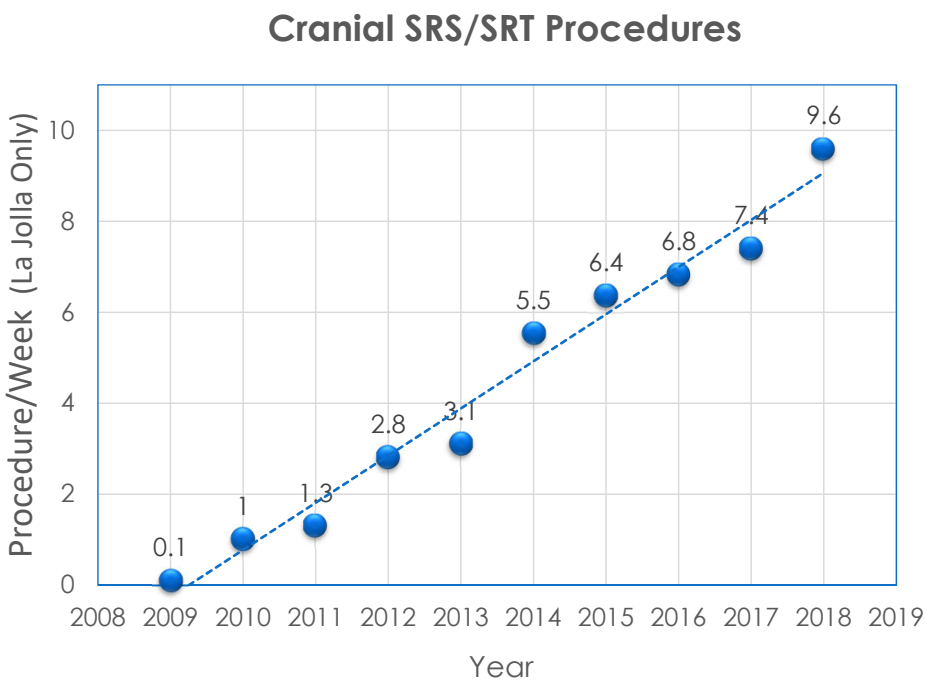
LEARNING OBJECTIVES

- Summarize the published data on SRS alone for multiple brain metastases
- Review new techniques of planning and delivery system and quality assurance
- Learn about the treatment planning strategy and dose tolerance of critical structure and understand challenges of multiple metastases planning.
- Interactive clinical case planning and evaluation of the plan quality metrics.

DISCLOSURE

- Consulting agreement with Varian Medical Systems

UC SAN DIEGO RADIOSURGERY PROGRAM



- Metastases
- Resection Cavity
- Benign Tumors
- AVM
- Trigeminal Neuralgia
- Malignant Tumors

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MLC BASED LINAC SRS

- Better conformity for irregular target
- Improved dose homogeneity inside the target
- Comparable dose fall-off outside the target
- Less time-consuming treatment planning
- Shorter treatment time
- Linac is not limited for cranial treatment

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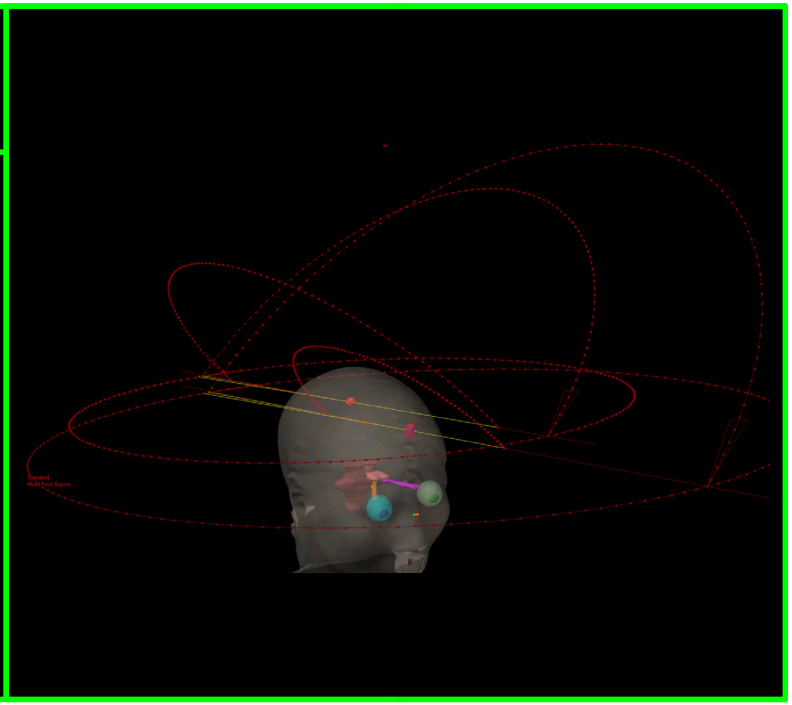
Multi-met Planning Strategy

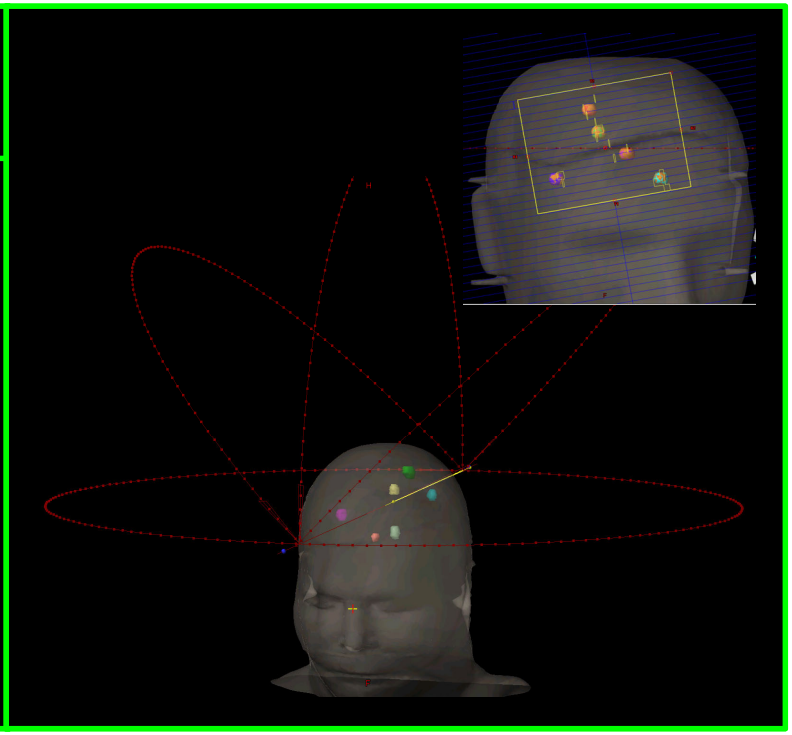
Multi-iso approach
• Relatively easier to achieve good plan quality • Less influenced by setup uncertainty • Hard to control sum dose



Multi-met Planning Strategy

Single-iso approach

- Need better understanding of planning tools
- Requires accurate patient positioning / monitoring method



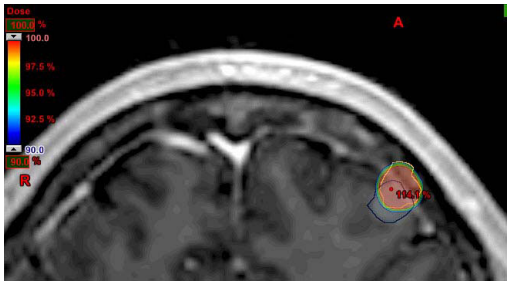
MR DISTORTION

TG-54

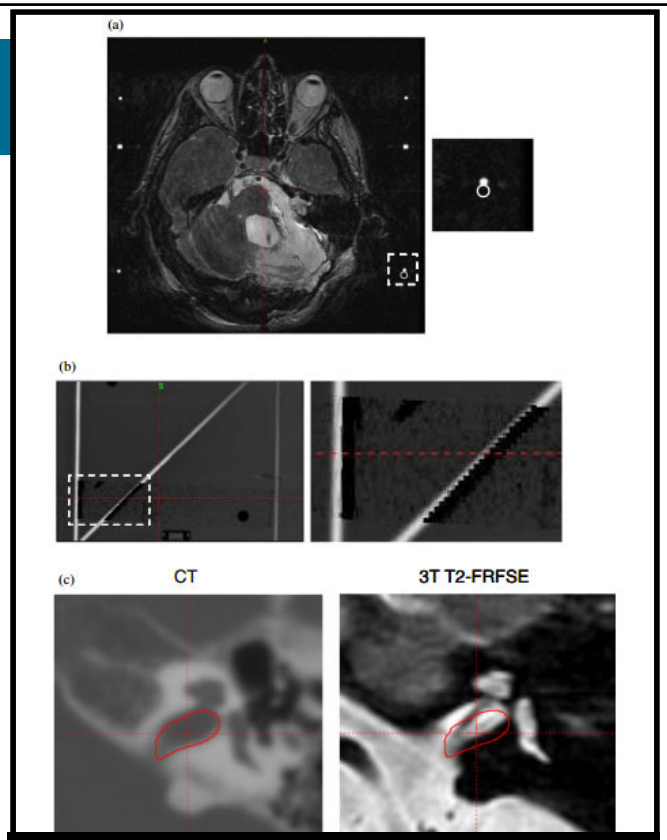
"MRI contains distortions which impede direct correlation with CT data at the level required for SRS"

TG-117

Use of MRI data in Treatment Planning and Stereotactic Procedures – Spatial Accuracy and Quality Control Procedures



Gradient nonlinearity distortion, Siebert et al, PRO 2016



B Zhang et al., Phys. Med. Biol. 55 (2010) 6601-6615

Figure 2. Clinical impact of geometric distortion of stereotactic references. (a) Stereotactic reference deviation in MR. (b) Stereotactic reference deviation in sagittal view (subtraction between CT and MR). (c) Displacement of the internal auditory canal (red contour) between CT and MR as a result of stereotactic reference deviation in MR.

CCTG CE.07 PHASE III TRIAL

- STEREOTACTIC RADIOSURGERY COMPARED WITH WHOLE BRAIN RADIOTHERAPY (WBRT) FOR **5-15 BRAIN METASTASES**
  - The largest target < 2.5 cm dia.
  - Total Volume ≤ 30 cm^3

Brain Metastasis volume	Dose Prescribed to Tumour Margin
Lesions < 4 cc	22 Gy
Lesions 4-10 cc	18-20 Gy

Brainstem Metastasis volume	Dose Prescribed to Tumour Margin
Lesions 4-10 cc	14-16 Gy
Lesions 1- 4 cc	16-18 Gy
Lesions < 1 cc	18-20 Gy

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CCTG CE.07 PHASE III TRIAL – TARGET DEFINITIONS (ICRU50, 62)

- Gross Tumour Volume (**GTV**):
  - the contrast enhancing tumour on T1 with contrast scans.
  - Surrounding blood and edema will be excluded
  - Numbering GTV1, GTV2, GTV3 from the most cranial axial and from to back in same slice
- Clinical Target Volume (**CTV**): No additional margin
- Planning Target Volume (**PTV**):
  - 1 mm isotropic margin can be added when non-invasive immobilization is used for multiple-isocenter SRS for 6D setup. whereas 2 mm margins can be used with 3D setup correction.

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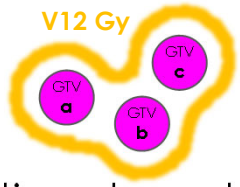
CCTG CE.07 PHASE III TRIAL – TARGET DEFINITIONS (ICRU50, 62)

- **Total Brain:** the brain minus the summed volume of the GTVs
  - V12 Gy < 30 cm^3 (30 cc).
  - Adjacent lesions: V12 Gy < 8.5 cc.

    If this volume is exceeded, the prescription doses to the adjacent metastases must be lowered until this constraint is met.
  - Median brain dose < 8 Gy.



- **Optic structures: The maximum point dose < 9-10 Gy**
- **Brainstem: V12 Gy < 1 cc** (the brainstem minus GTV)

VMAT OPTIMIZATION FOR MULTIPLE METASTASES

< Island blocking problem>

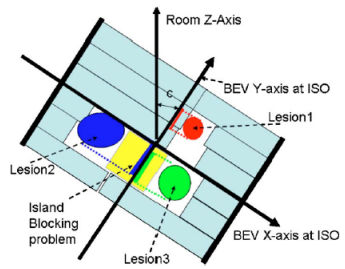


FIG. 1. Schematic beam-eye-view illustration of MLC blocking for an example case with three lesions. The lesions are projected onto the beam *Y*-axis vector. The MLC is unable to block the square region.

< Shadow>

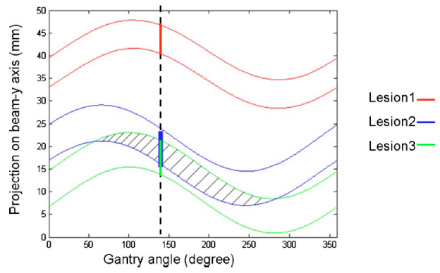
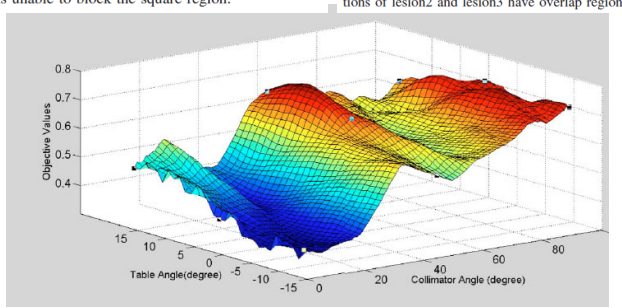
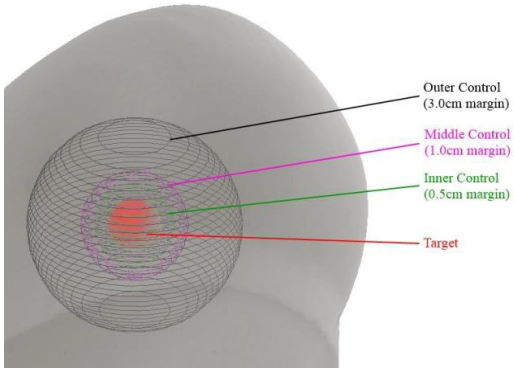


FIG. 2. The sinogram for the three-lesion case. The shadowed region shows the area where two lesions overlap and an island blocking problem is present. The dashed line represents the gantry angle 140°, where the projections of lesion2 and lesion3 have overlap region.



Tuning Structures

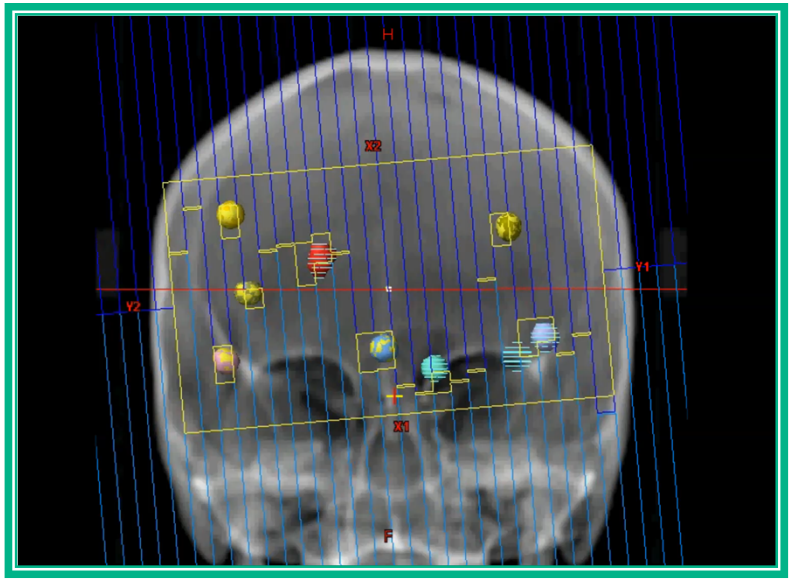


- **Inner control max dose** = 98% of Rx
- **Middle control max dose** = 50% of Rx
- **Outer control max dose** = 40% of Rx

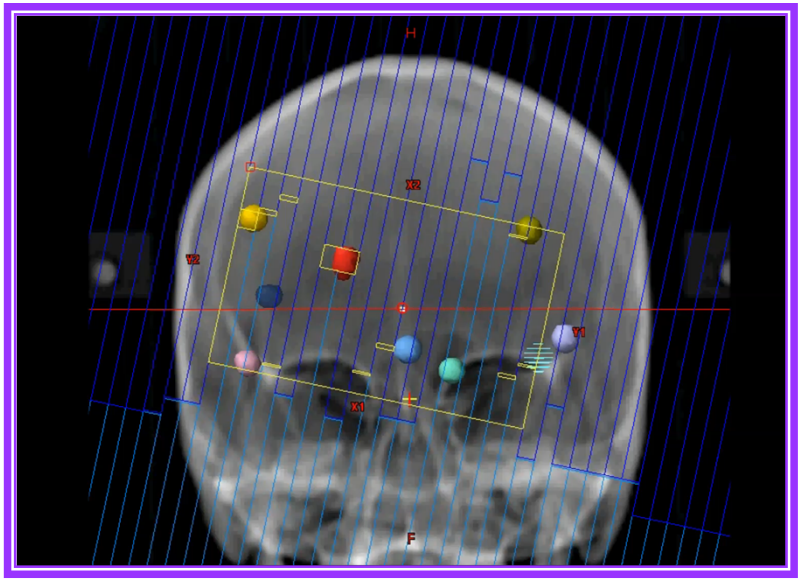
Kang J, Ford EC, Smith K et al., A method for optimizing LINAC treatment geometry for volumetric modulated arc therapy of multiple brain metastases Medical Physics, 2010;**37**(8): 4146-4154.

Clark G, Popple R, Prendergast B et al., Plan quality and treatment planning technique for single isocenter cranial radiosurgery with volumetric modulated arc therapy, Practical Radiation Oncology. 2012;2:306–313.

BEV (FIXED JAWS VS. JAW TRACKING)

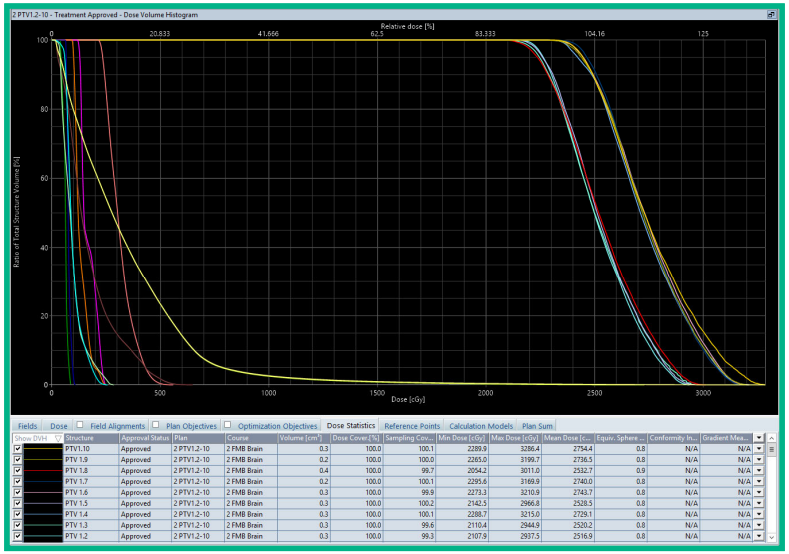


- Fixed Jaw setting
- Collimator rotation optimized manually

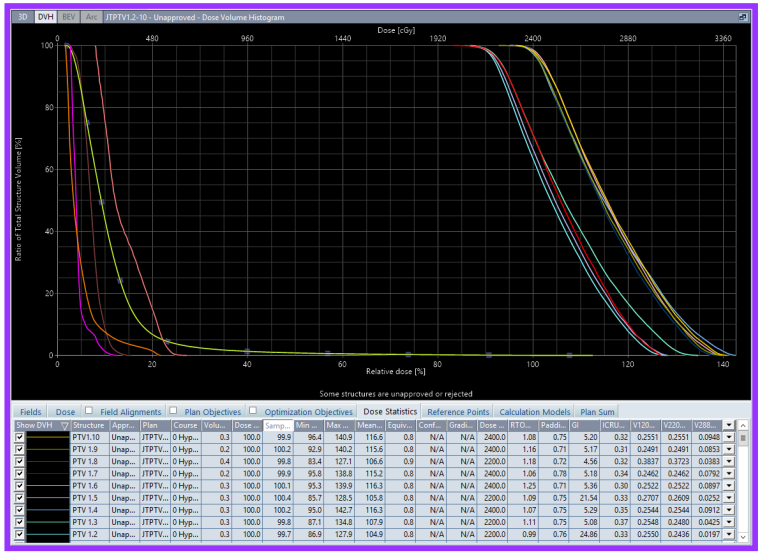


- Jaw tracking on
- HyperArc Collimator Angle Optimizer (CAO)

DVH (FIXED JAWS VS. JAW TRACKING)



- Total MU: 7,964, PTVs Dmax = 136.9%
- Brain-PTVs: V12 = 20.86 cm^3
- Brainstem Dmax = 651.5 cGy



- Total MU: 8,737, PTVs Dmax = 142.7%
- Brain-PTVs: V12 = 10.95 cm^3
- Brainstem Dmax = 374.5 cGy

Jour. of Radiosurgery and SBRT, Vol. 5, pp. 131-144

Evaluation of multiple factors affecting normal brain dose in single-isocenter multiple target radiosurgery

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- Ten cases (3-11 mets), 16 combinations
- 2 versus 4 arcs
- Collimator angle 45° versus selected per beam
- Fixed jaw versus jaw tracking
- 2 Gy mean dose objective versus no low dose objective.

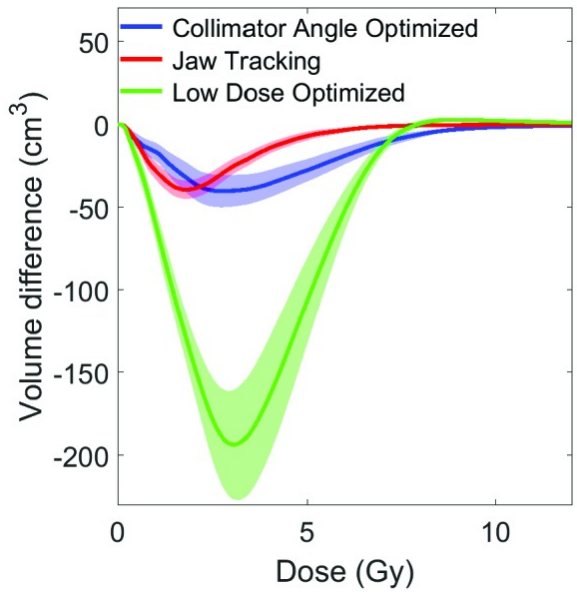


Figure 4. Mean difference between dose volume histograms for normal brain for each parameter. Negative numbers indicate that collimator angle optimization, jaw tracking, or a low dose objective reduces the volume of normal brain at the given dose. The bands indicate the 95% confidence intervals.

PLAN OPTIMIZATION - SRS

- Constraints (GTV, CTV, PTV, OARs)
- NTO or Tuning Structures
- MU constraint
- Optimization resolution
- Calc. grid size

CONSTRAINTS

- TG-101

Serial Tissue	Max vol. (cc)	One fraction		Three fraction		Five fraction		End point
		Threshold dose (Gy)	Max point dose (Gy)	Threshold dose (Gy)	Max point dose (Gy)	Threshold dose (Gy)	Max point dose (Gy)	
Optic pathway	<0.2	8	10	15.3	17.4	23	23	Neuritis
Cochlea			9		17.1		25	Hearing loss
Brainstem (not medulla)	<0.5	10	15	18	23.1	23	31	Cranial neuropathy
Spinal cord and medulla	<0.35 <1.2	10 7	14	18 12.3	21.9	23 14.5	30	Myelitis

- Normal Brain V10 < 12 cc or V12 < 10 cc (One fraction SRS)
- Cranial Nerves (fifth, seventh and eighth CN)12.5-15 Gy
  (Flicker et al., IJROBP 2004)

CONSTRAINTS

Table 6 Published dose constraints for SRS, with NTCP estimates[a]

Tissues	Dose (Gy)	Volume	Fraction	Endpoint	NTCP	Reference
Brain	14	5-10 cc	1	Necrosis	1–20%	This study
Brainstem	12.5	max	1	Neuropathy	< 5%	QUANTEC
Brainstem	10.0	0.5 cc	1	Neuropathy	Unknown	TG 101
Optic nerves	12.0	max	1	Neuritis	0.7%	QUANTEC
Optic nerves	8.0	0.2 cc	1	Neuritis	1.1%	TG 101
Cochlea	12.0	max	1	Hearing loss	11.8%	Timm. 2008
Spinal cord	14.0	max	1	Myelitis	1.6%	RTOG 0915

[a] Notes: (1) Dose constraints from the listed references [3, 61, 63, 65]. (2) Volume effect limits and more details are available [5–7]. (3) NTCP results from Seminars in Radiation Oncology, April 2016 [4–7] or QUANTEC [3]. (4) NTCP depends on the exact circumstances of each dataset [4–7]

Table 7 Published dose constraints for SBRT, with NTCP estimates[a]

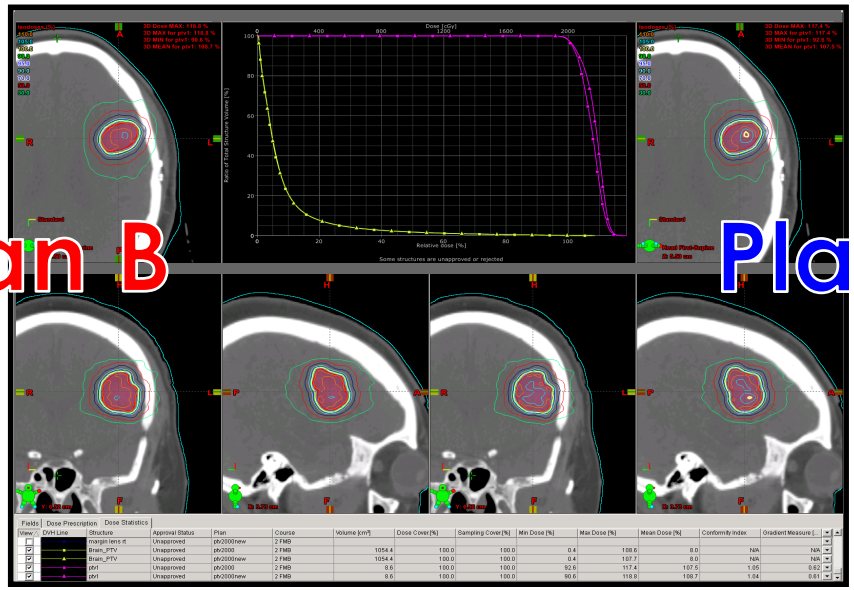
Tissues	Dose (Gy)	Volume	Fraction	Endpoint	NTCP	Reference
Brain	28.8	5–10 cc	5	Necrosis	1–20%	This study
Brainstem	31.0	max	5	Neuropathy	Unknown	TG 101
Brainstem	23.0	0.5 cc	5	Neuropathy	Unknown	TG 101
Optic nerves	25.0	max	5	Neuritis	0.8%	TG 101
Optic nerves	20.0	0.2 cc	5	Neuritis	1.7%	Timm. 2008
Cochlea	25.0	max	5	Hearing loss	13.8%	TG 101
Spinal cord	30.0	max	5	Myelitis	2.6%	RTOG 0813

*Notes: (1) Dose constraints from the listed references [61, 63, 64]. (2) Volume effect limits and more details are available [5–7]. (3) NTCP results from Seminars in Radiation Oncology, April 2016 [4–7]. (4) NTCP depends on the exact circumstances of each dataset [4–7]

Jinyu Xue et al., Clinical evidence for dose tolerance of the central nervous system in hypofractionated radiotherapy, Journal of Radiation Oncology, Dec. 2018

PLAN OPTIMIZATION – MU

Plan B

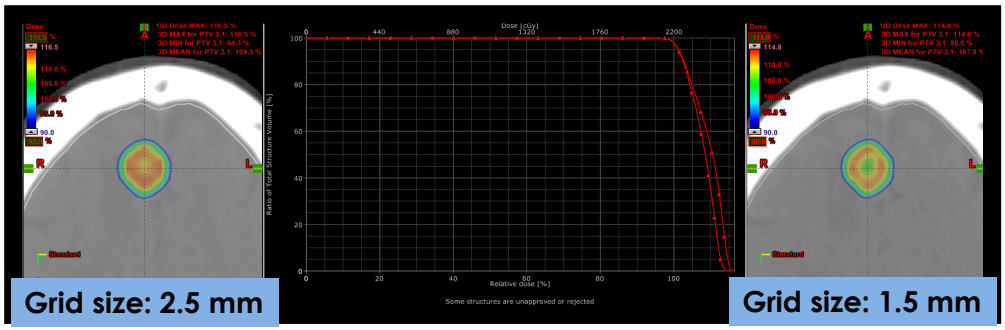


Plan A

Field	Arc 1	Arc 2	Arc 3
Plan A	4116	2105	2105
Plan B	3488 (18% ↓)	1794 (17% ↓)	1794 (17% ↓)

CALCULATION GRID SIZE

- Expected effects for SRS case



- Calculation accuracy
- Max dose
- Conformity Index
- Gradient
- DVH

MECHANICAL ACCURACY

Re-examining TG-142 recommendations in light of modern techniques for linear accelerator based radiosurgery

Med. Phys. 43 (10), October 2016

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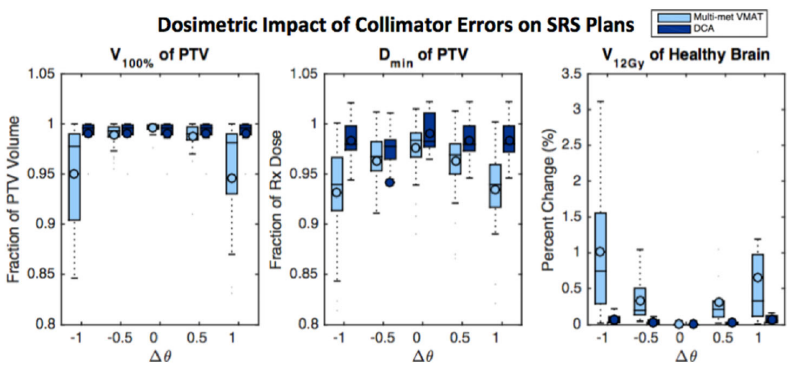
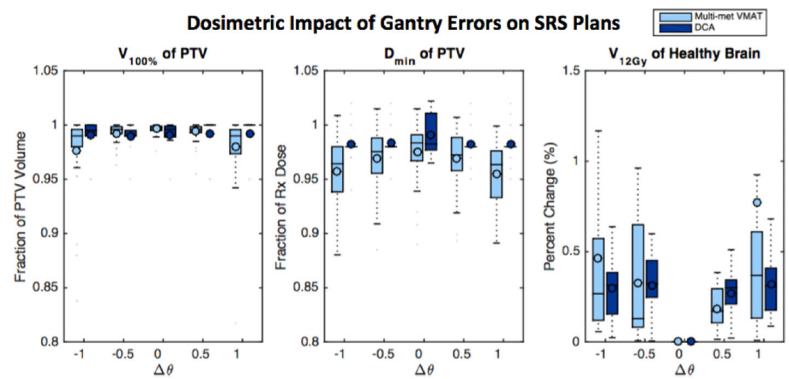
(Received 8 June 2016; revised 14 July 2016; accepted for publication 24 August 2016; published 13 September 2016)





4D VS. 6D COUCH

Table 2 Required margins calculated from Eq. (4) to account for initial (before 6D correction) and intraoperational rotational uncertainties

		Margins for initial uncertainties (when no 6D correction is applied) (cm)			Margins for intraoperational uncertainties (cm)		
P	d (cm)	Pitch	Roll	Yaw	Pitch	Roll	Yaw
.90	5.00	0.11	0.14	0.15	0.03	0.04	0.04
.95	5.00	0.13	0.17	0.17	0.03	0.05	0.05
.98	5.00	0.15	0.19	0.20	0.04	0.06	0.06
.90	10.00	0.21	0.28	0.29	0.06	0.09	0.09
.95	**10.00**	**0.26**	**0.34**	**0.35**	**0.07**	**0.10**	**0.10**
.98	10.00	0.29	0.39	0.40	0.08	0.12	0.12
.90	15.00	0.32	0.42	0.44	0.08	0.13	0.13
.95	15.00	0.38	0.51	0.52	0.10	0.16	0.15
.98	15.00	0.44	0.58	0.59	0.11	0.18	0.18

6D, 6 degrees of freedom. A 1-mm margin accounts for 95% of intraoperational uncertainties at 10 cm (values shown in bold).

Practical Radiation Oncology (2016) 6, 207-213

practical radiation oncology pro
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Original Report

Physics considerations for single-isocenter, volumetric modulated arc radiosurgery for treatment of multiple intracranial targets

Carl Stanhope BS [a], Zheng Chang PhD [b], Zhiheng Wang PhD [b], Fang-Fang Yin PhD [b], Grace Kim MD, PhD [b], Joseph K. Salama MD [b], John Kirkpatrick MD, PhD [b], Justus Adamson PhD [b,*]

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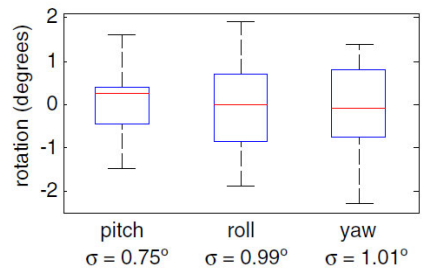


Figure 1 Box plot of initial rotational uncertainty for the U-frame thermoplastic mask system at setup when no rotational corrections are made; measured from 20-kV cone beam computed tomography scans. The central line indicates the median, the edges of the box are the 25th and 75th percentiles, and whiskers are the most extreme points that are not outliers. Uncertainty (σ) in the rotational correction before treatment is noted.

PATIENT-SPECIFIC QA

Received: 20 August 2018 | Revised: 19 December 2018 | Accepted: 11 March 2019

DOI: 10.1002/acm2.12578

TECHNICAL NOTE

WILEY

Assessing the feasibility of single target radiosurgery quality assurance with portal dosimetry

Elizabeth L. Covington | Jesse D. Snyder | Xingen Wu | Rex A. Cardan | Richard A. Popple

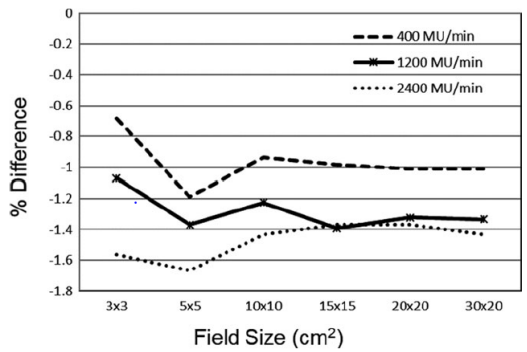


Fig. 4. The percent difference between the delivered and predicted portal image output at central axis for open fields at dose rates of 400, 1200, and 2400 MU/min.

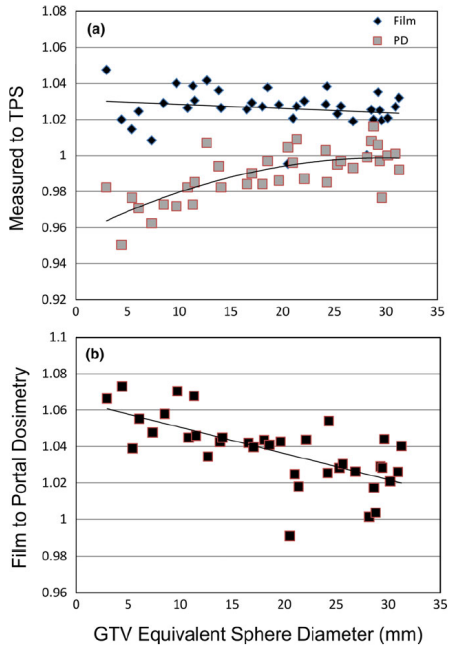
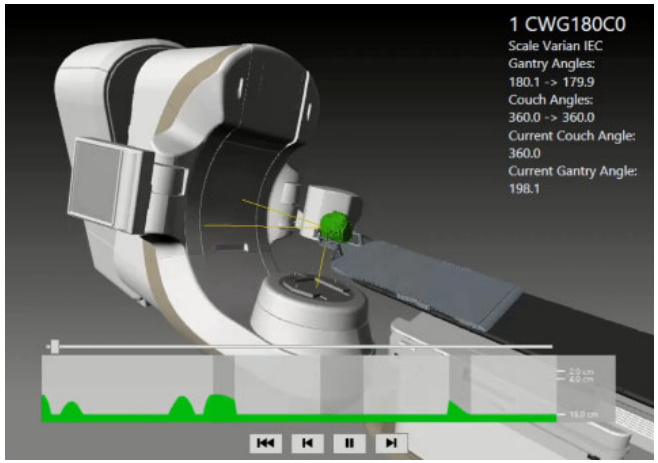


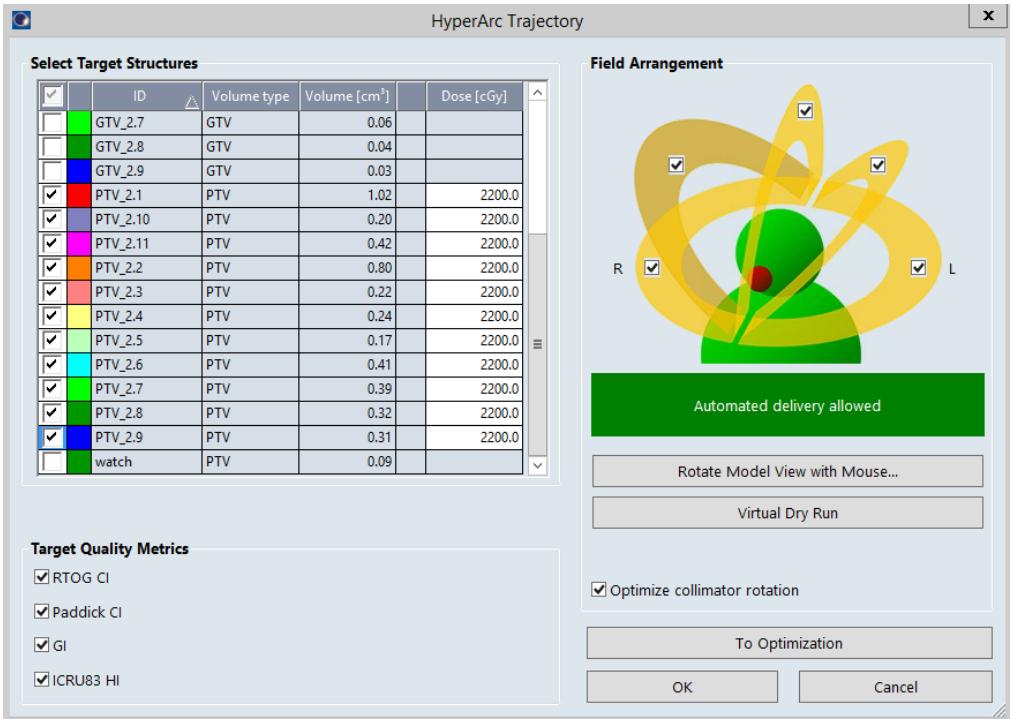
Fig. 3. (a) The measured to treatment planning system (TPS) dose in the >90% maximum dose region as a function of target size. While the film remains relatively flat across all target size, the portal dosimetry results are target size dependent. (b) The ratio of film to portal dosimetry measurements as a function of target size.

HYPERARC ™

- Fixed geometry: up to 4 arcs (1 coplanar and 3 non-coplanar)
- Achieve the optimal dose coverage, highest conformity, sparing of normal tissue with non-coplanar arcs
- Collision prevention, avoidance and detection
- Enable automatic tx. delivery: shorten the overall tx. time



HYPERARC TRAJECTORY

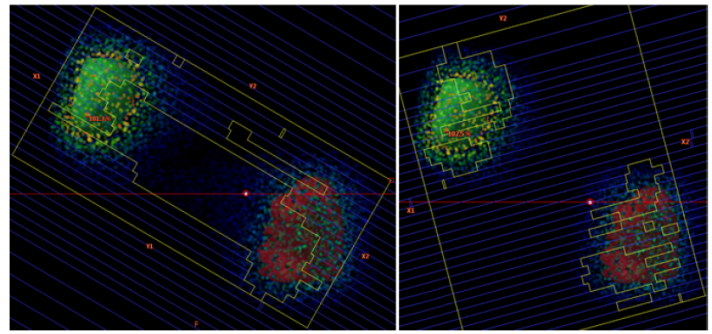


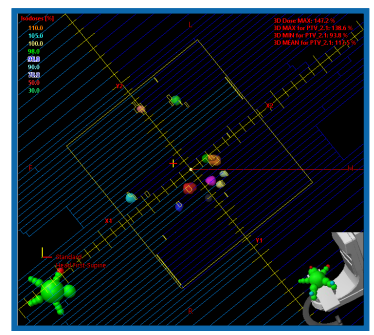
- Isocenter is automatically defined
- Optimization of collimator rotation
- Optimization of Jaw setting

COLLIMATOR ANGLE OPTIMIZER

- Max length of field opening: 17 cm
- Max leaf travel: 15 cm
- Max width of field opening: 40 cm if it's at most 40 cm
- Optimized the angle to avoid island blocking
- Optimized at the end of the fields generation (HyperArc Trajectory)

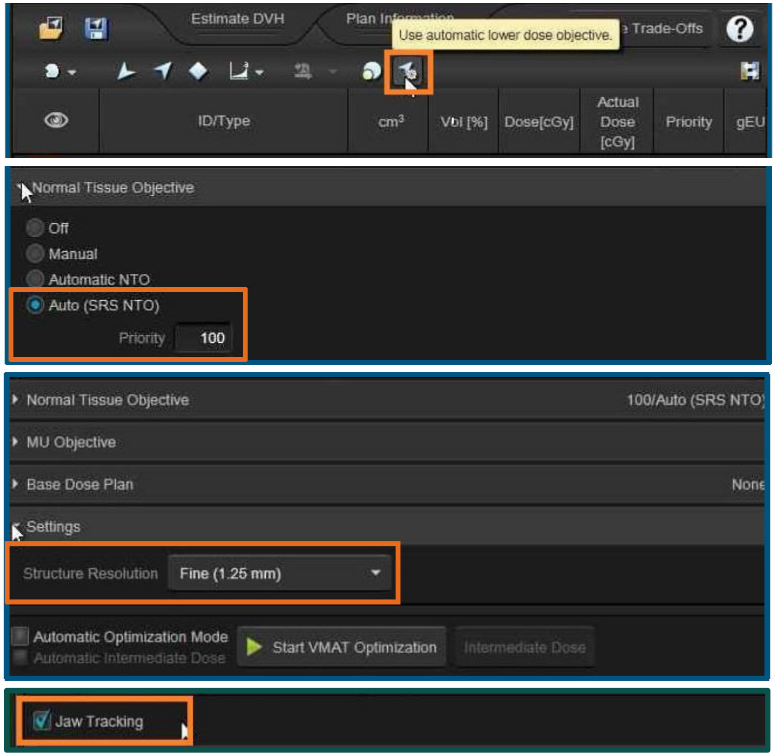
Pre and post CAO





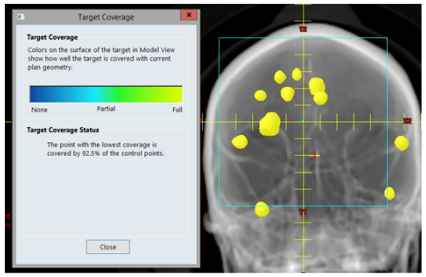
HYPERARC OPTIMIZATION

- Automatic Lower Dose Objective (ALDO)
- VMAT optimization: PO15.5 or above
- Warning if the target is not converted as a hi-resolution structure
- Use SRS NTO
- Use hi-resolution optimization by default
- Aperture shaper off
- Use cal. grid to 1.25 mm by default

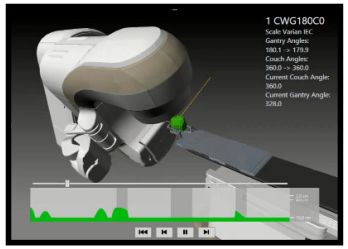


PLAN EVALUATION - HYPERARC

- Target coverage
  - DVH evaluation
  - Location of hot and cold spots
- Dose to Organ at Risk (OAR)
  - DVH evaluation
- Conformity, Gradient, Homogeneity
- Normal tissue irradiated
- Delivery efficiency
- Number of MU
- Collision

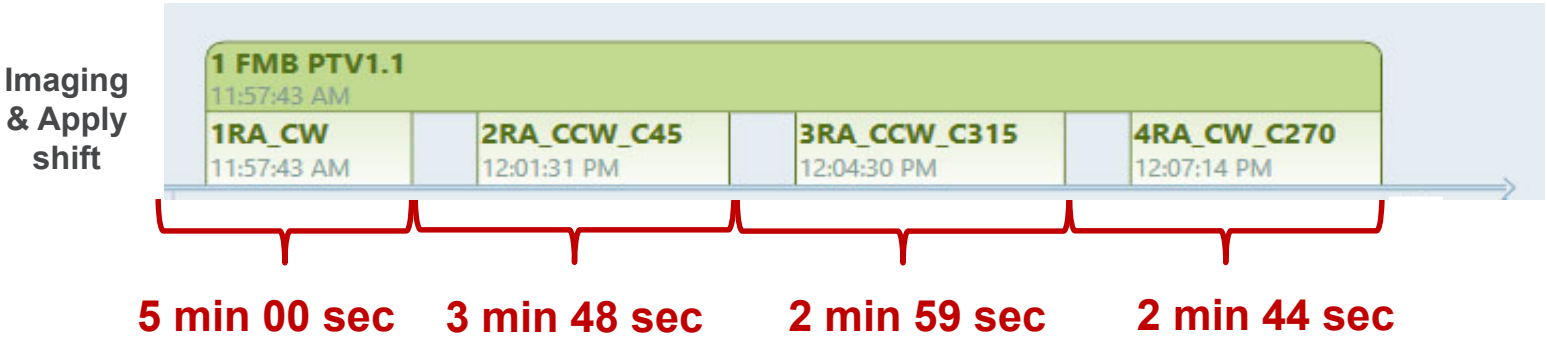


Eclipse Conformity Index	Eclipse Gradient Measurement	RTOG Conformity Index
The volume closed by the prescription isodose surface divided by the target volume	Difference between the equivalent sphere radius of the prescription and half-prescription isodoses	$CI_X(T) \equiv \frac{V(I_X(T))}{V(T)}$
Paddick Conformity Index	Gradient Index	ICRU83 Homogeneity Index
$PCI_X(T) \equiv \frac{V^2(T \cap I_X)}{V(T)\ V(I_X(T))}$	$GI(T) \equiv \frac{V(I_{X/2}(T))}{V(I_X(T))}$	$HI_X(T) \equiv \frac{D_{100-X}(T) - D_X(T)}{D_{50}(T)}$



TREATMENT DELIVERY - AUTOMATION AND EFFICIENCY

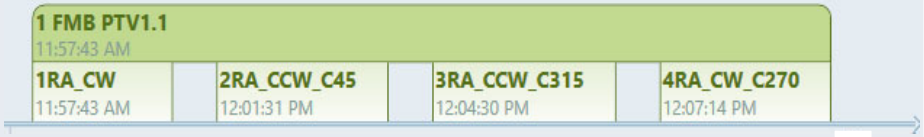
Example RA SRS case: Rx = 22 Gy, Total MU = 6922 MU



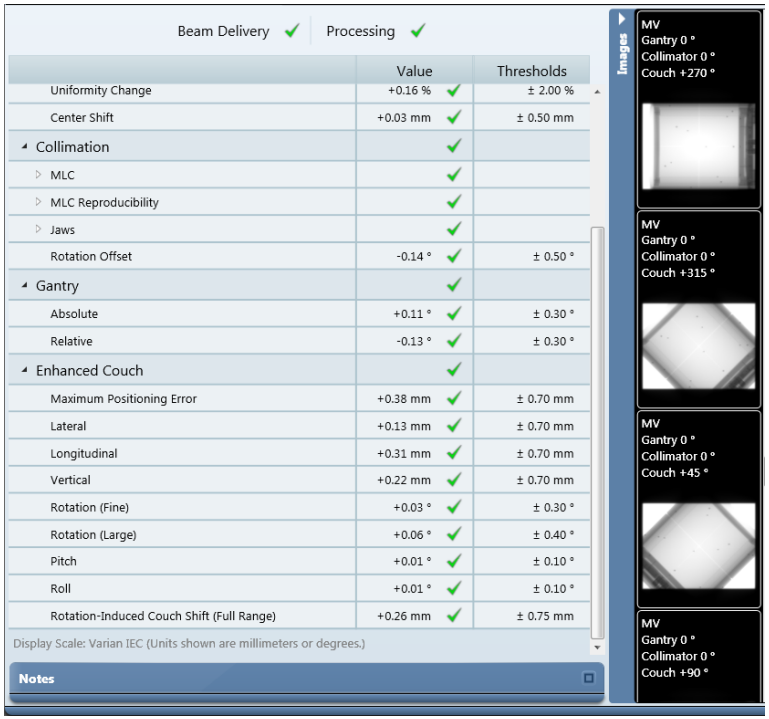
5 min 00 sec **3 min 48 sec** **2 min 59 sec** **2 min 44 sec**

- Total delivery time 4 arcs: 14 min 31 sec
- Total beam beam-on time: 5 min 22 sec
- G/C Motion + in/out time: 9 min 09 sec

TREATMENT DELIVERY - COMPARISON

HyperArc	8:40	22 Gy (7555MU)	
RapidArc	14:31	22 Gy (6922MU)	

MPC – ENHANCED COUCH



Beam Delivery ✓ Processing ✓

	Value		Thresholds
Uniformity Change	+0.16 %	✓	± 2.00 %
Center Shift	+0.03 mm	✓	± 0.50 mm
Collimation		✓	
MLC		✓	
MLC Reproducibility		✓	
Jaws		✓	
Rotation Offset	-0.14 °	✓	± 0.50 °
Gantry		✓	
Absolute	+0.11 °	✓	± 0.30 °
Relative	-0.13 °	✓	± 0.30 °
Enhanced Couch		✓	
Maximum Positioning Error	+0.38 mm	✓	± 0.70 mm
Lateral	+0.13 mm	✓	± 0.70 mm
Longitudinal	+0.31 mm	✓	± 0.70 mm
Vertical	+0.22 mm	✓	± 0.70 mm
Rotation (Fine)	+0.03 °	✓	± 0.30 °
Rotation (Large)	+0.06 °	✓	± 0.40 °
Pitch	+0.01 °	✓	± 0.10 °
Roll	+0.01 °	✓	± 0.10 °
Rotation-Induced Couch Shift (Full Range)	+0.26 mm	✓	± 0.75 mm

Display Scale: Varian IEC (Units shown are millimeters or degrees.)

Notes

Images

- **Collimation rotation Offset**: the max. dev. of the nominal versus the actual collimator rotation (5 coll. rotation angles)
- **Gantry rotation**
  Use eight representative gantry angles (0, 45, 90, 135, 180, 225, 270, 315)°
- **Enhanced Couch**
  The rotation-induced couch shift is the offset of this center of rotation from the treatment isocenter.

Test Position		Rotational Axes	
Linear Axes		6	Yaw +6 ° Pitch + 3 ° Roll – 3 °
1	Vrt. + 5 cm	7	Yaw - 6 ° Pitch - 3 ° Roll + 3 °
2	Lat. + 5 cm	8	Yaw – 45 °
3	Lng. + 5 cm	9	Yaw – 90 °
4	Vrt. + 5 cm, Lat. – 5 cm, Lng. + 5 cm	10	Yaw + 45 °
5	Vrt. - 5 cm, Lat. + 5 cm, Lng. - 5 cm	11	Yaw + 90 °

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SUMMARY

- Single isocenter for multiple brain metastases treatment is rapidly changing the practice of radiosurgery.
- QA needs to be carefully developed and performed to ensure the quality of treatment.
- HyperArc can enable to improved the plan quality as well as save significant planning time.
- Automatic delivery saves treatment time in the meantime, enforced safety features prevent potential adverse incident ahead of time.

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