THE UNIVERSITY OF ALABAMA AT BIRMINGHAM

Radiosurgery of multiple targets using single isocenter VMAT

Richard Popple

Disclosures

- Research support from Varian Medical Systems
- Intellectual property licensed to Varian Medical Systems through UAB
- Product evaluation agreements with Standard Imaging and Sun Nuclear

Outline

- Plan quality
  - Conformality
  - Gradient index
  - Low dose spill to normal brain
- Treatment planning
  - Planning techniques
  - Semi-automated planning
  - Comparison to multiple isocenters
- Rotational uncertainty
- QA
  - Mechanical
  - Patient specific
- Treatment delivery efficiency
- Clinical Outcomes

FEASIBILITY OF SINGLE-ISOCENTER VOLUMETRIC MODULATED ARC RADIOSURGERY FOR TREATMENT OF MULTIPLE BRAIN METASTASES

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Purpose: To evaluate the relative plan quality of single-isocenter vs. multi-isocenter volumetric modulated arc therapy (VMAT) for radiosurgical treatment of multiple central nervous system metastases.

Methods and Materials: VMAT plans were created using RapidArc technology for treatment of simulated patients with three brain metastases. The plans consisted of single-arc/single-isocenter, triple-arc (noncoplanar)/single-isocenter, and triple-arc (coplanar)/triple-isocenter configurations. All VMAT plans were normalized to deliver 100% of the 20-Gy prescription dose to all lesions. The plans were evaluated by calculation of Paddick and Radiation Therapy Oncology Group conformity index scores, Paddick gradient index scores, and 12-Gy isodose volumes.

Results: All plans were judged clinically acceptable, but differences were observed in the dosimetric parameters, with the use of multiple noncoplanar arcs showing small improvements in the conformity indexes compared with the single-arc/single-isocenter and triple-arc (coplanar)/triple-isocenter plans. Multiple arc plans (triple-arc [noncoplanar]/single-isocenter and triple-arc [coplanar]/triple-isocenter) showed smaller 12-Gy isodose volumes in scenarios involving three metastases spaced closely together, with only small differences noted among all plans involving lesions spaced further apart.

Conclusion: Our initial results suggest that single-isocenter VMAT plans can be used to deliver conformity equivalent to that of multiple isocenter VMAT techniques. For targets that are closely spaced, multiple noncoplanar single-isocenter arcs might be required. VMAT radiosurgery for multiple targets using a single isocenter can be efficiently delivered, requiring less than one-half the beam time required for multiple isocenter set ups. VMAT radiosurgery will likely replace multi-isocenter techniques for linear accelerator-based treatment of multiple targets.

Brain, metastases, volumetric modulated arc therapy, VMAT, radiosurgery, RapidArc.

INITIAL EXPERIENCE WITH VOLUMETRIC IMRT (RAPIDARC) FOR INTRACRANIAL STEREOTACTIC RADIOSURGERY

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Purpose: Initial experience with delivering frameless stereotactic radiotherapy (SRT) using volumetric intensity-modulated radiation therapy (IMRT) delivered with RapidArc is presented.
Methods and Materials: Treatment details for 12 patients (14 targets) with a mean clinical target volume (CTV) of 12.8 ± 4.0 cm^3 were examined. Dosimetric indices for conformality, homogeneity, and dose gradient were calculated and compared with published results for other frameless, intracranial SRT techniques, including CyberKnife, TomoTherapy, and static-beam IMRT. Statistics on setup and treatment times and per patient dose validations were examined.
Results: Dose indices compared favorably with other techniques. Mean conformality, gradient, and homogeneity index values were 1.10 ± 0.11, 64.9 ± 14.1, 1.083 ± 0.026, respectively. Median treatment times were 4.8 ± 1.7 min.
Conclusion: SRT using volumetric IMRT is a viable alternative to other techniques and enables short treatment times. This is anticipated to have a positive impact on radiobiological effect and for facilitating wider use of SRT.

RapidArc, Radiosurgery, Treatment time.

Intensity-modulated radiosurgery with rapidarc for multiple brain metastases and comparison with static approach

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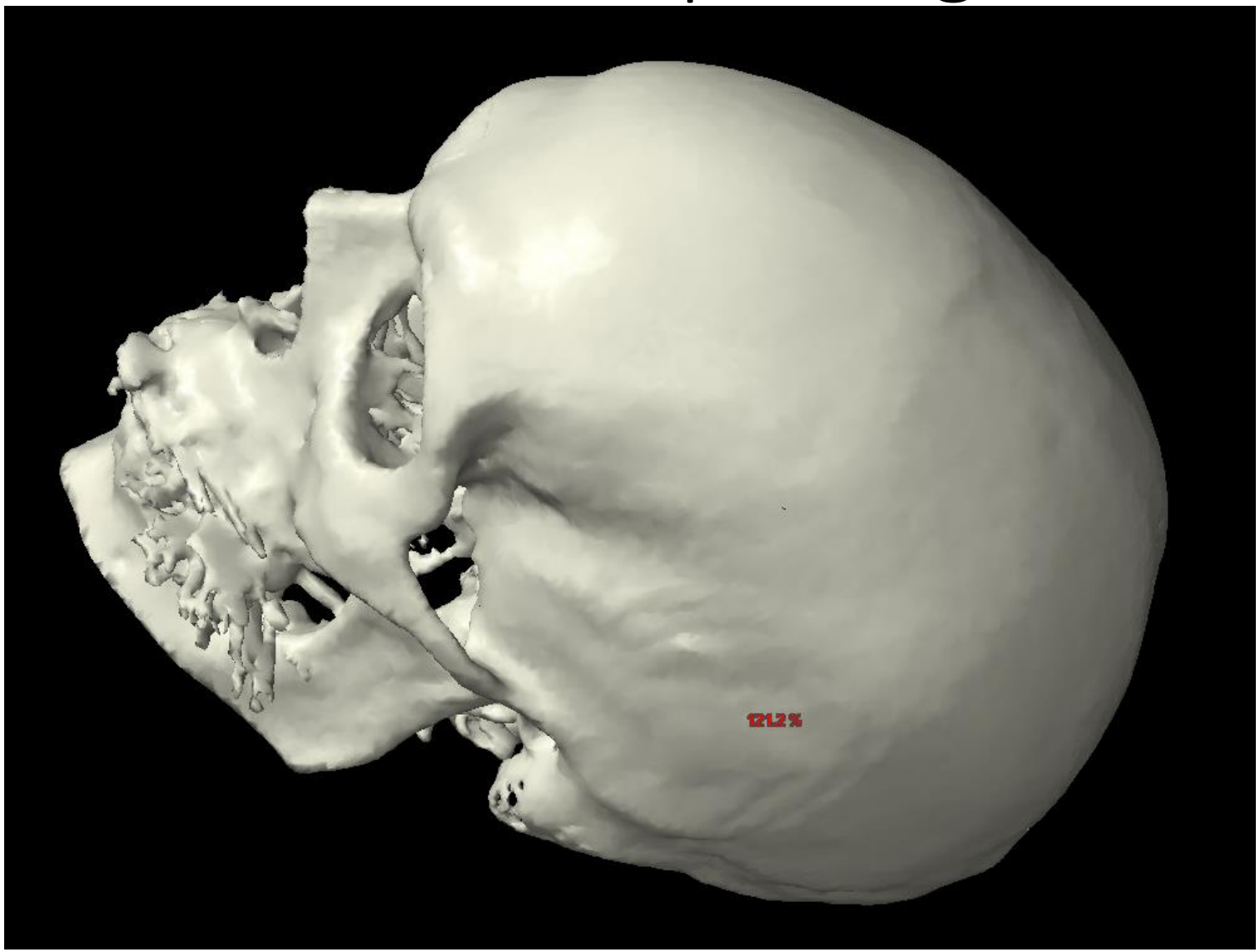
ABSTRACT

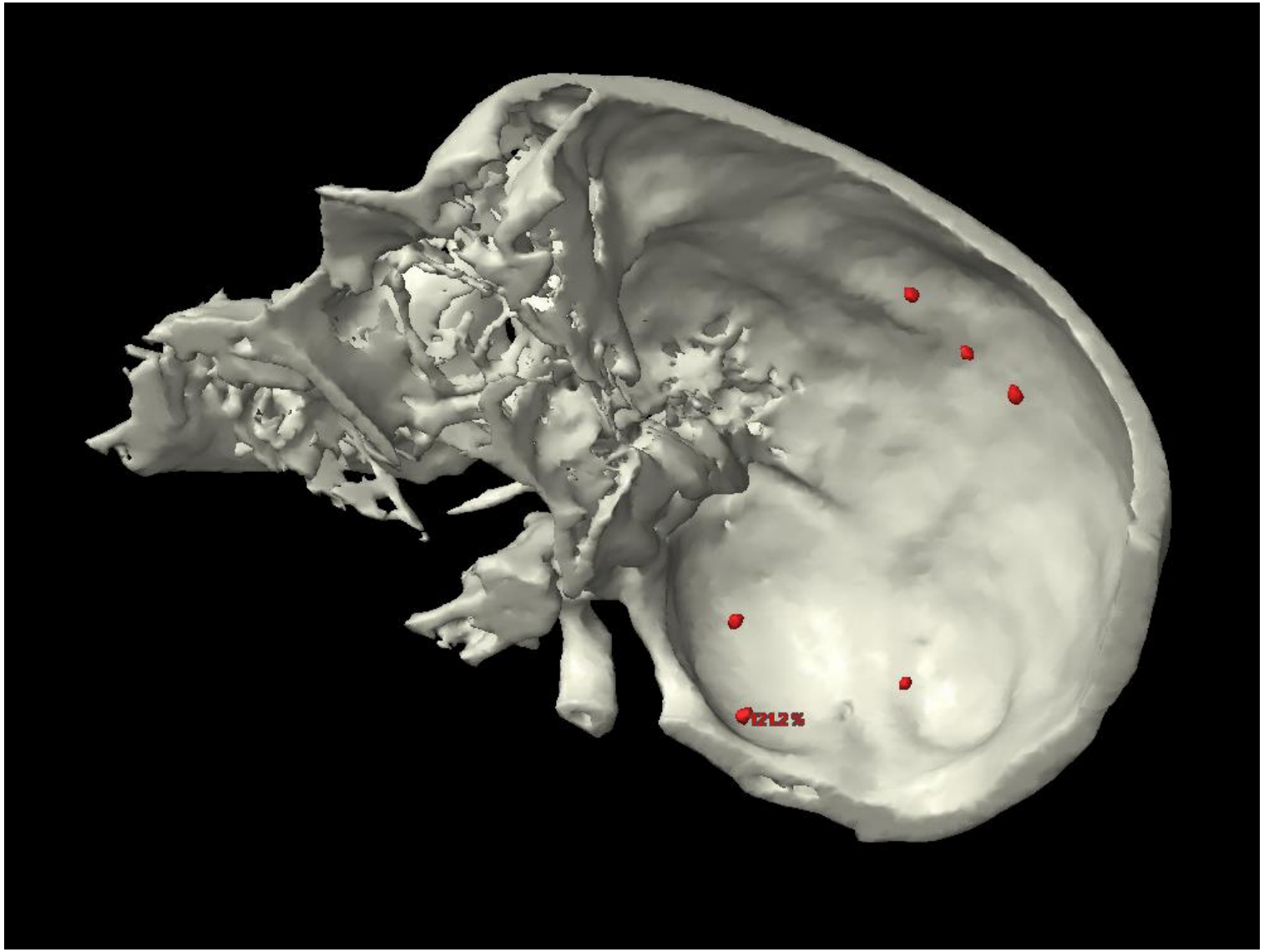
Rotational RapidArc (RA) and static intensity-modulated radiosurgery (IMRS) have been used for brain radiosurgery. This study compares the 2 techniques from beam delivery parameters and dosimetry aspects for multiple brain metastases. Twelve patients with 2–12 brain lesions treated with IMRS were replanned using RA. For each patient, an optimal 2-arc RA plan from several trials was chosen for comparison with IMRS. Homogeneity, conformity, and gradient indexes have been calculated. The mean dose to normal brain and maximal dose to other critical organs were evaluated. It was found that monitor unit (MU) reduction by RA is more pronounced for cases with larger number of brain lesions. The MU-ratio of RA and IMRS is reduced from 104% to 39% when lesions increase from 2 to 12. The dose homogeneities are comparable in both techniques and the conformity and gradient indexes and critical organ doses are higher in RA. Treatment time is greatly reduced by RA in intracranial radiosurgery, because RA uses fewer MUs, fewer beams, and fewer couch angles.

Efficiency vs Static Beams

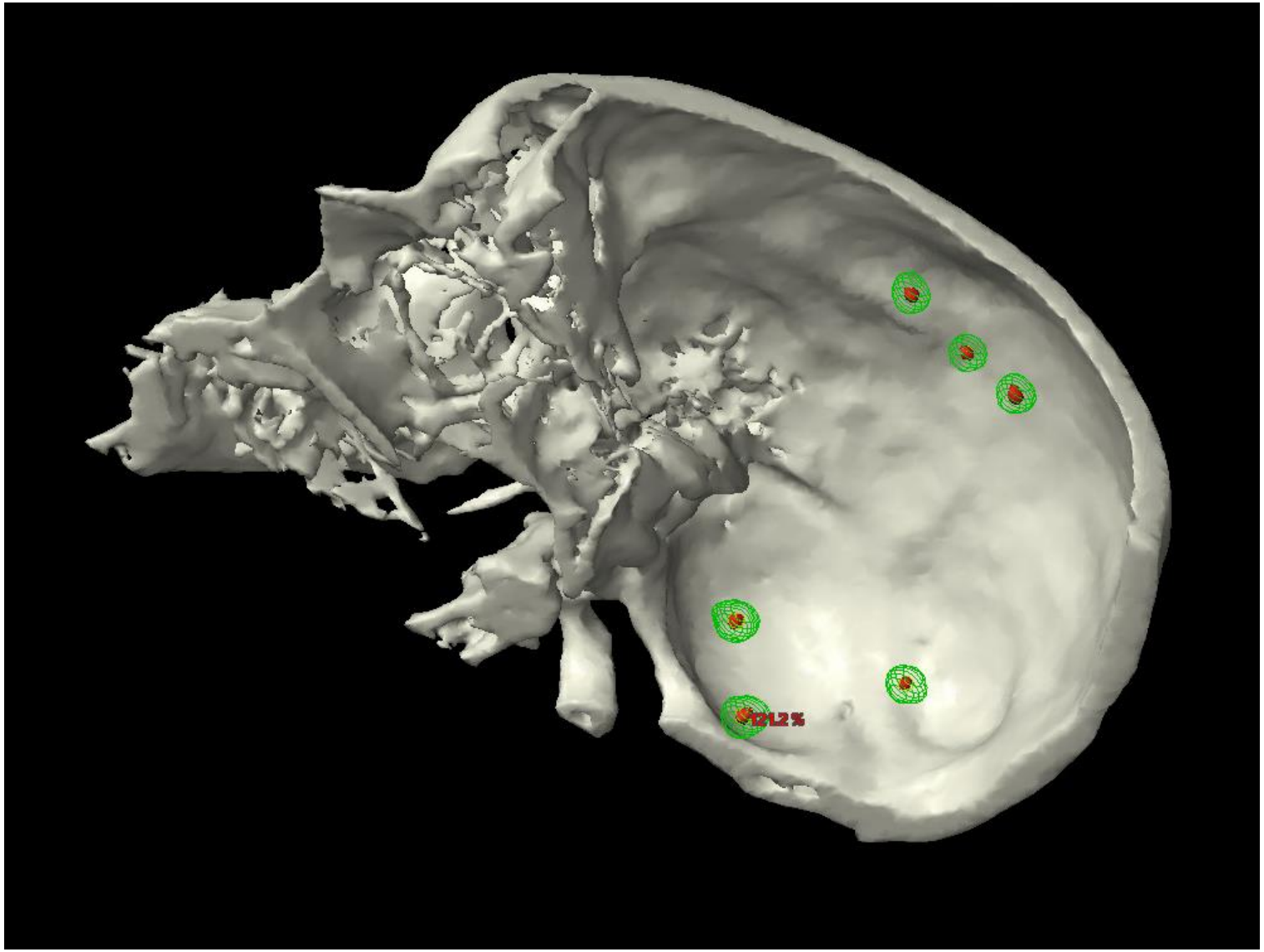
Plan evaluation – multiple targets



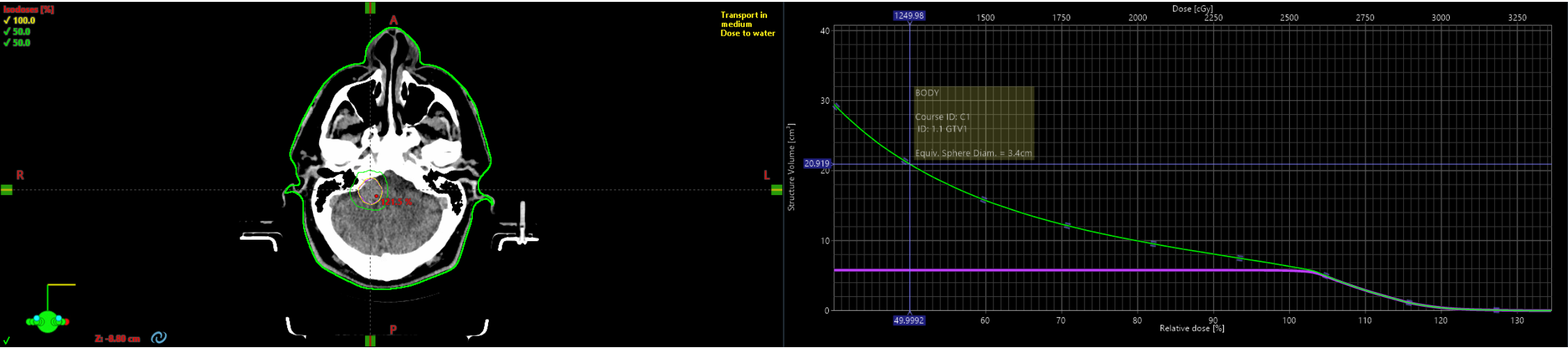
Plan evaluation – multiple targets



Plan evaluation – multiple targets

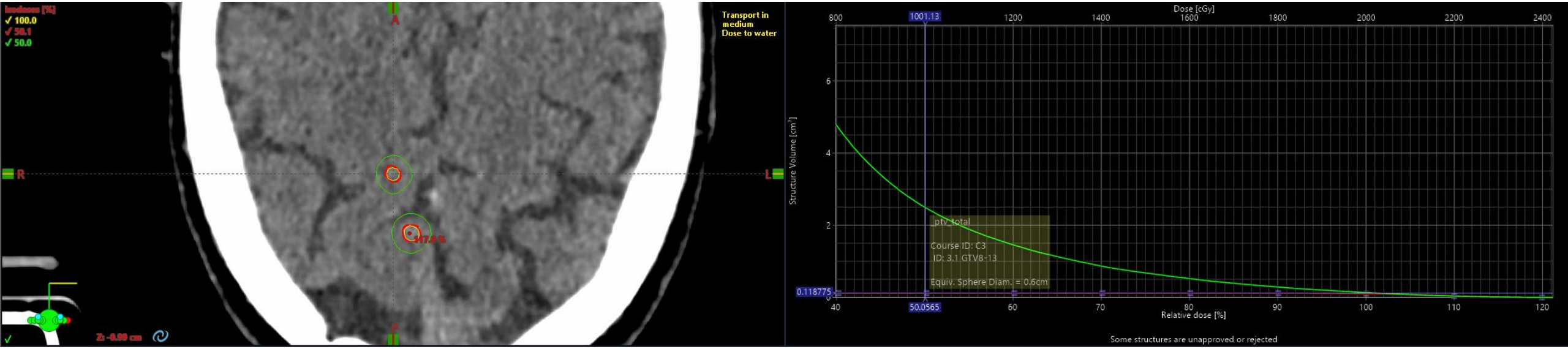


Plan evaluation



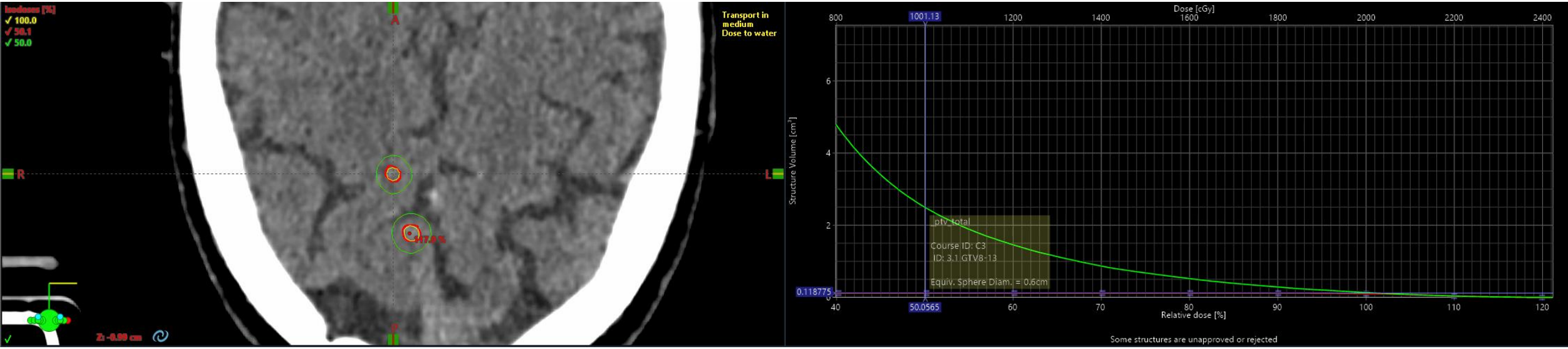
- TV = target volume
- PIV = prescription isodose volume
- V50% = volume receiving at least 50% of the prescription dose

Plan evaluation – multiple targets



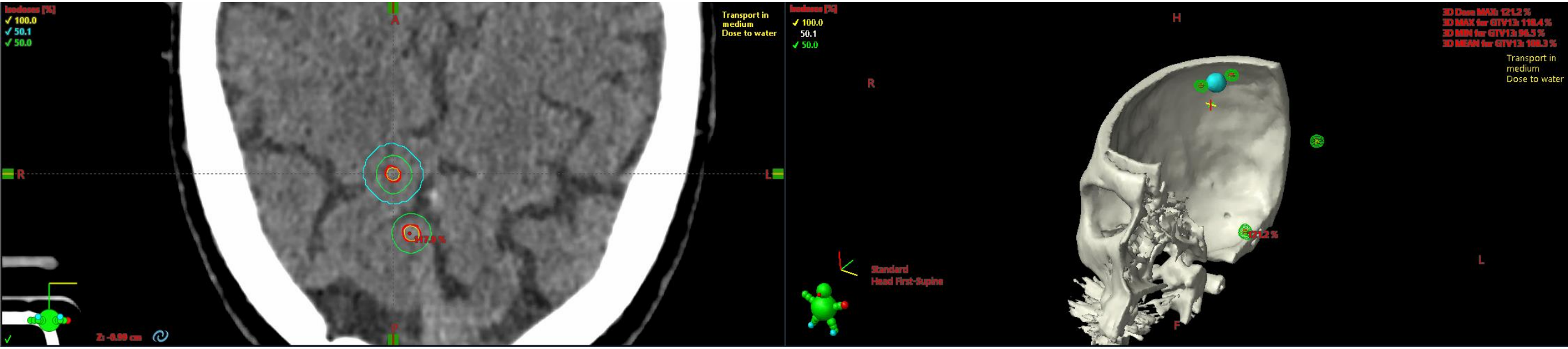
- Composite RTOG conformity index = PIV / ΣTV
  - 1.1 for case shown

Plan evaluation – multiple targets



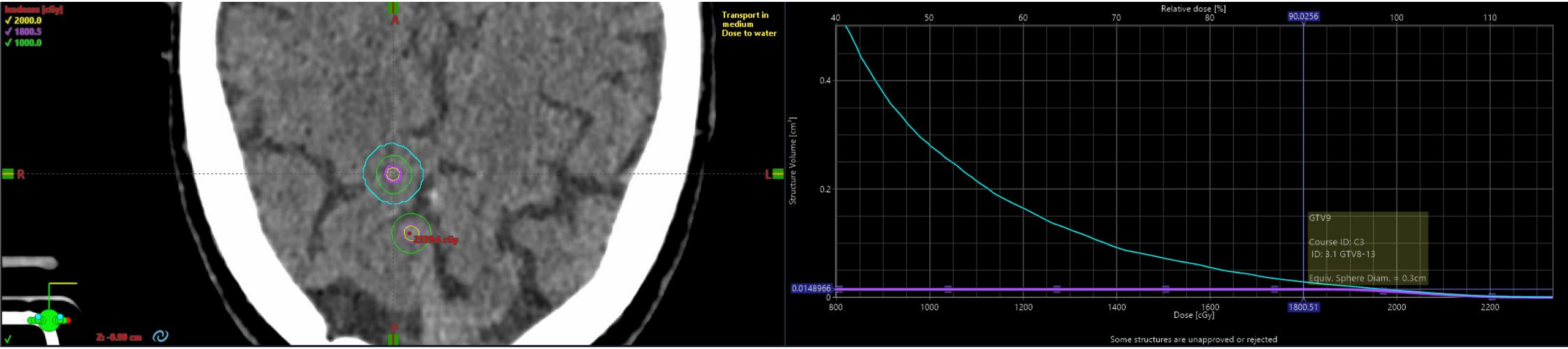
- Composite Paddick gradient index = V50% / PIV
  - 18.5 for case shown
- Composite indices do not account for different prescriptions

Plan evaluation – multiple targets



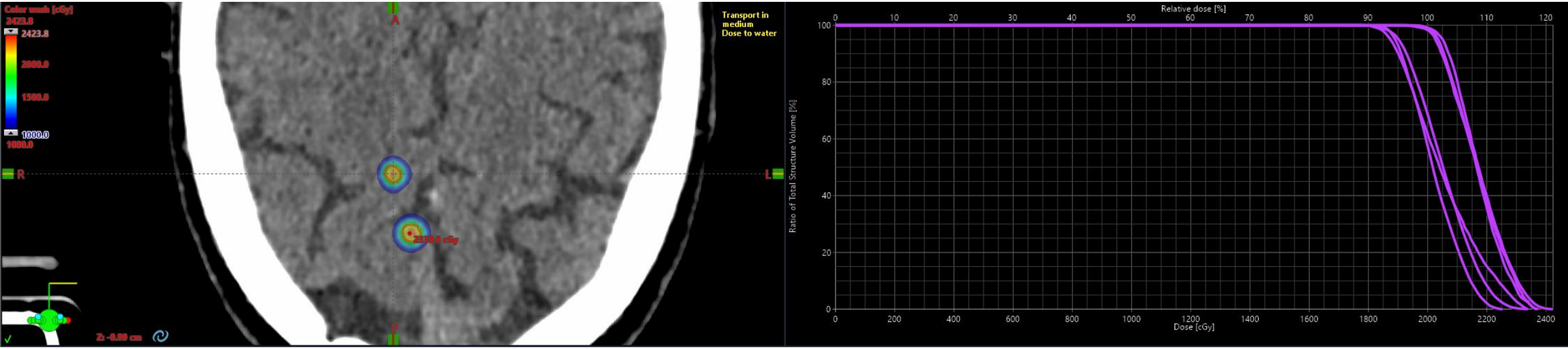
- Individual conformity and gradient indices requires constructing a shell around each target
- Shell must enclose the “local” 50% isodose volume
  - Targets in close proximity might be enclosed by a common 50% isodose volume – “bridging”

Plan evaluation – multiple targets



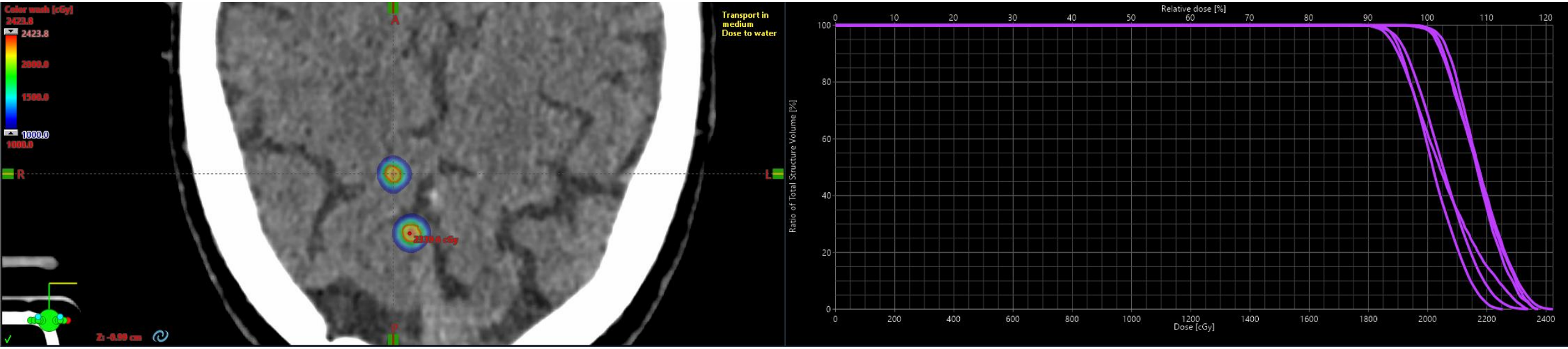
- Target shown
  - RTOG conformity index 1.9
  - Paddick gradient index 13.2

Plan evaluation – multiple targets



- Computing individual indices is tedious
- Use composite indices
- Review individual target DVHs
- Inspect 50% isodose volume

Plan evaluation – multiple targets



- Some planning systems provide target specific metrics

Show DVH	Structure	Dose Level [cGy]	RTOG CI	Paddick CI	GI
✔	GTV8	1800.0	1.49	0.56	14.65
✔	GTV9	1800.0	1.50	0.61	12.57
✔	GTV10	1800.0	1.34	0.68	9.85
✔	GTV11	2000.0	1.42	0.65	17.95
✔	GTV12	2000.0	1.20	0.64	15.06
✔	GTV13	2000.0	1.52	0.58	17.29

Plan evaluation – V12Gy

- V12Gy has been found to correlate with radionecrosis

● *Clinical Original Contribution*

RADIOSURGERY AND BRAIN TOLERANCE: AN ANALYSIS OF NEURODIAGNOSTIC IMAGING CHANGES AFTER GAMMA KNIFE RADIOSURGERY FOR ARTERIOVENOUS MALFORMATIONS

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CLINICAL INVESTIGATION **Brain**

12 GY GAMMA KNIFE RADIOSURGICAL VOLUME IS A PREDICTOR FOR RADIATION NECROSIS IN NON-AVM INTRACRANIAL TUMORS

TIMOTHY KORYTKO, M.D.,* TOMAS RADIVOYEVITCH, PH.D.,† VALDIR COLUSSI, PH.D.,* BARRY W. WESSELS, PH.D.,* KUNJAN PILLAI, M.S.,* ROBERT J. MACIUNAS, M.D., M.P.H.,*‡ AND DOUGLAS B. EINSTEIN, M.D., PH.D.*

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CLINICAL INVESTIGATION **Brain**

IRRADIATED VOLUME AS A PREDICTOR OF BRAIN RADIONECROSIS AFTER LINEAR ACCELERATOR STEREOTACTIC RADIOSURGERY

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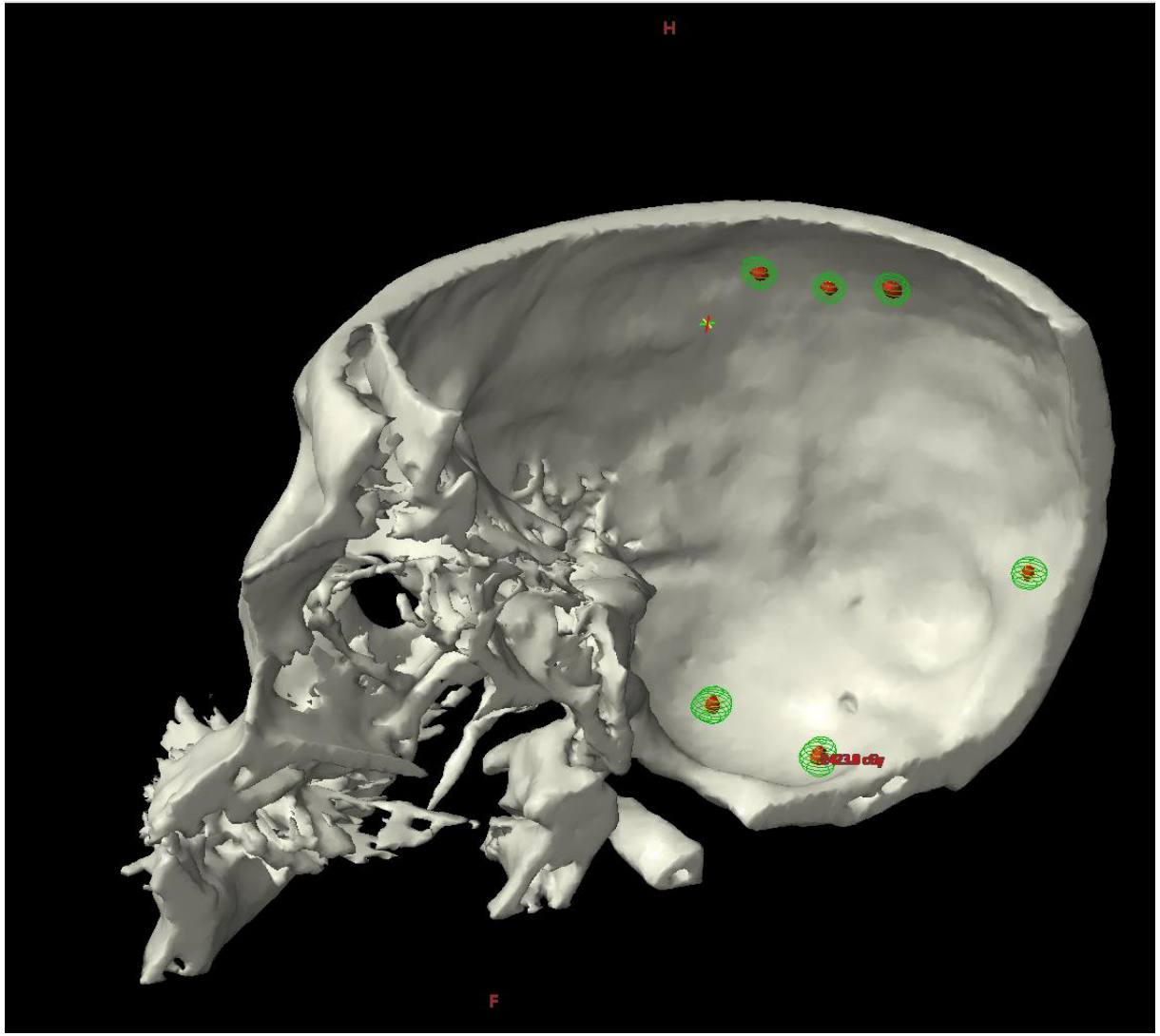
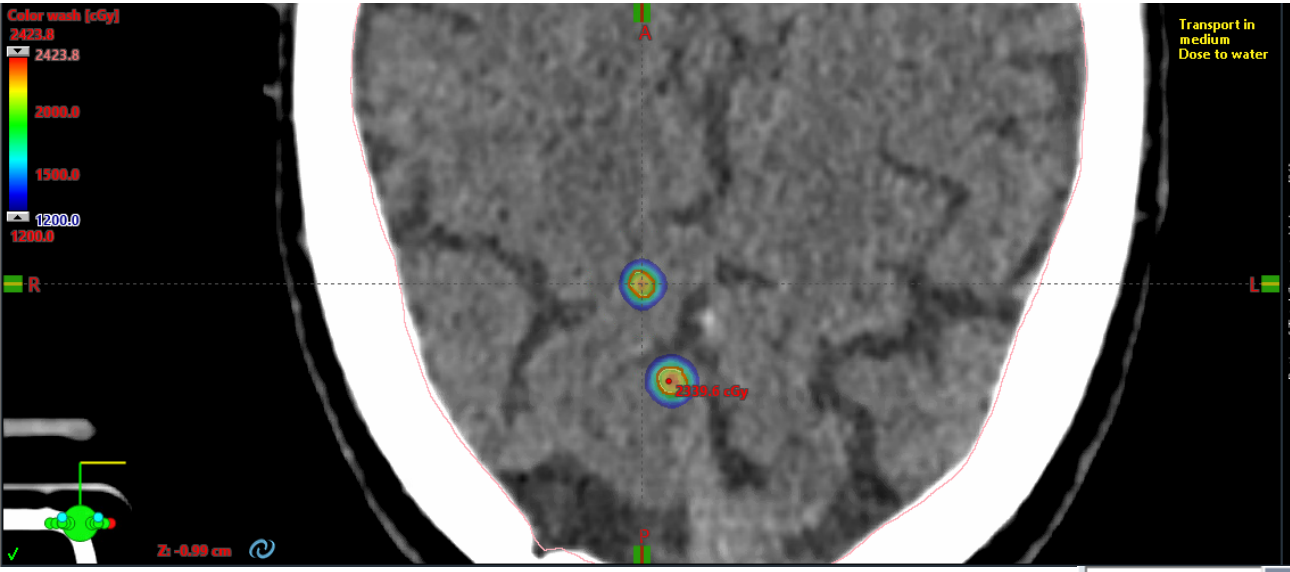
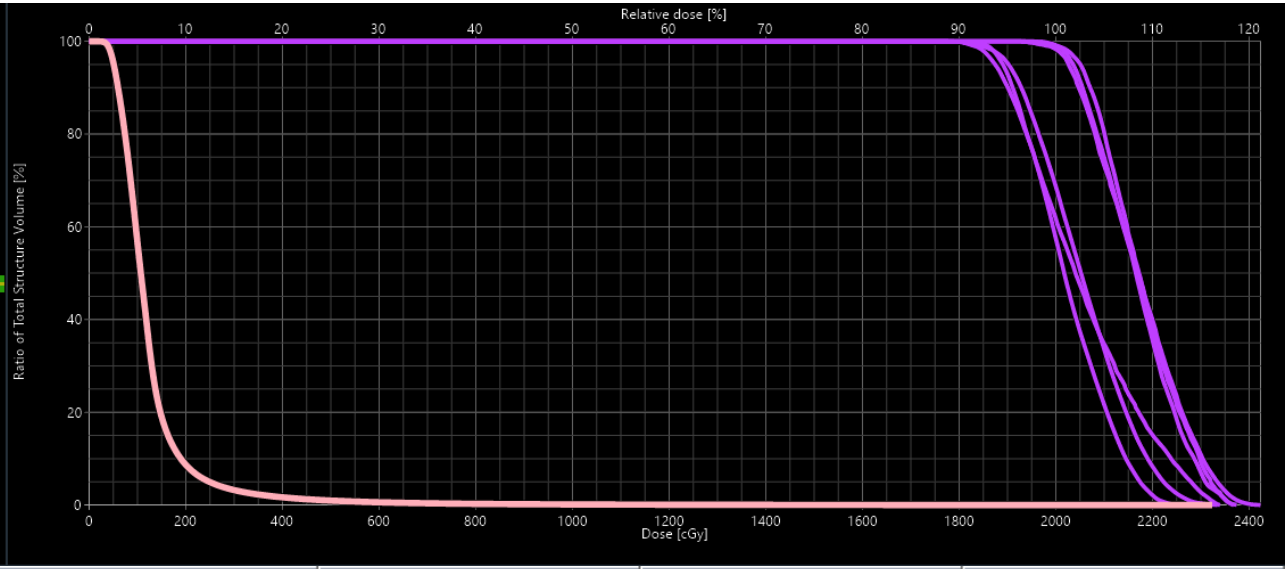
Plan evaluation – V12

- V12-based models of toxicity are based on single target treatments.
- Radiation necrosis estimates from V12 for multiple lesions should not be extrapolated from single target models.



Plan evaluation – Mean brain dose





Show DVH	Structure	Min Dose [cGy]	Max Dose [cGy]	Mean Dose [cGy]
☑	Brain-GTV	13.5	2325.3	123.8

Single Isocenter Radiosurgery – Multiple Target Class Solution

Practical Radiation Oncology (2012) 2, 306–313

pro

www.practicalradonc.org

Original Report

Plan quality and treatment planning technique for single isocenter cranial radiosurgery with volumetric modulated arc therapy

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[a]Department of Radiation Oncology, University of Alabama at Birmingham, Comprehensive Cancer Center, Birmingham, Alabama
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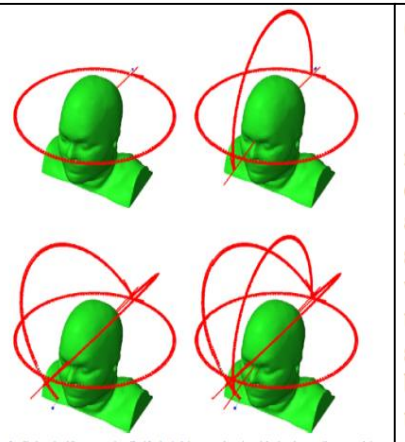


Figure 2 Single- and multibeam geometries utilized for the single isocenter volumetric modulated arc therapy radiosurgery technique.

Conclusions

The results of this report show that the single isocenter VMAT radiosurgery technique for the treatment of 1 or more brain metastases produces plans of high clinical quality, including favorable values for both conformity and dose gradient indices. We have outlined a practical, systematic approach that treatment planners may utilize when creating plans using this treatment platform. Given the high plan quality and extreme clinical efficiency, single isocenter VMAT approaches will continue to become more prevalent for linac-based radiosurgical treatment of 1 or more intracranial targets.

The Recipe
(in the appendix)

APPENDIX 1 - Systematic Treatment Planning Technique for Single Isocenter VMAT Radiosurgery

1.0 Contouring
- 1.1 Contour all normal structures, including brain, optic nerves, and brainstem
- 1.2 Contour each GTV and label as GTV1, GTV2, GTV3, etc
- 1.3 Using Boolean operations, create a GTV_total; for example, for 3 targets "GTV_total" = "GTV1" AND ("GTV2" AND "GTV3")
- 1.4 Create control structures as volumetric rings surrounding the target. In a stepwise fashion, create structures as follows:
  - 1.4.1 "inner control" = GTV_total + 0.5 cm
  - 1.4.2 "middle control" = GTV_total + 1.0 cm
  - 1.4.3 "outer control" = GTV_total + 3.0 cm
  - 1.4.4 Boolean operation: "outer control" = "outer control" SUB "middle control"
  - 1.4.5 Boolean operation: "middle control" = "middle control" SUB "inner control"
  - 1.4.6 Boolean operation: "inner control" = "inner control" SUB "GTV_total"
  - 1.4.7 Crop any control structures outside the body using Boolean operations
- 1.5 Create evaluation structures for DVH calculation of conformity indices: "GTV1_eval" = GTV1 + 1.5 cm, "GTV2_eval" = GTV2 + 1.5cm, etc.

2.0 Isocenter and Field geometry
- 2.1 Place isocenter at the geometric center of GTV_total
- 2.2 Consider arc geometries as follows:
  - 2.2.1 Single Arc: arc clockwise from 181° to 179°, couch angle 0°
  - 2.2.2 Two Arcs:
    - Arc 1 = clockwise from 181° to 179°, couch angle 0°
    - Arc 2 = counterclockwise from 181° to 10°, couch angle 90°
  - 2.2.3 Three Arcs:
    - Arc 1 = clockwise from 181° to 179°, couch angle 0°
    - Arc 2 = counterclockwise from 179° to 350°, couch angle 315°
    - Arc 3 = counterclockwise from 10° to 181°, couch angle 45°
  - 2.2.4 Four Arcs:
    - Arc 1 = clockwise from 181° to 179°, couch angle 0°
    - Arc 2 = counterclockwise from 179° to 350°, couch angle 315°
    - Arc 3 = counterclockwise from 10° to 181°, couch angle 45°
    - Arc 4 = clockwise from 181° to 10°, couch angle 90°
- 2.3 Visualize beams-eye-view arc rotations and adjust each field size (jaws of collimator) to ensure it encompasses the entirety of GTV_total for the entire length of all degrees of rotation, leaving at least 1 cm of margin between field edge and target at all angles

3.0 Optimization Objectives
- 3.1 Each individual GTV (not the composite) = 100% of the target to receive 102% of the prescription dose; priority = 100
- 3.2 Inner Control = 0% of the structure to receive 98% of the prescription dose; priority = 150.
- 3.3 Middle Control = 0% of the structure to receive 50% of the prescription dose; priority = 100
- 3.4 Outer Control = 0% of the structure to receive 40% of the prescription dose; priority = 80
- 3.5 Additional dose constraint objectives may be needed if sensitive adjacent normal structures are nearby (brainstem, optic nerves, chiasm, etc); If not nearby, control structures will adequately serve as constraints on limiting dose to these organs.

4.0 Plan Normalization and Evaluation
- 4.1 Normalize plan to deliver 100% of the prescription to 99-100% of the GTV_total
- 4.2 Calculate the conformity index (CI) of each target by using the evaluation structures
  - 4.2.1 Ensure that 100% isodose line is not extending outside of evaluation structures
  - 4.2.2 CI = 100% isodose line of eval structure divided by the target volume; for example: CI for GTV1 = 100% isodose line for "GTV1_eval" divided by the volume of GTV1
  - 4.2.3 CI can also be calculated by the Eclipse treatment planning software
- 4.3 Calculate the gradient index (GI) of the plan
  - 4.3.1 GI = volume of 50% isodose line divided by the volume of the 100% isodose line.
  - 4.3.2 Note that Eclipse will calculate a gradient measure which is a different definition than the above calculated GI

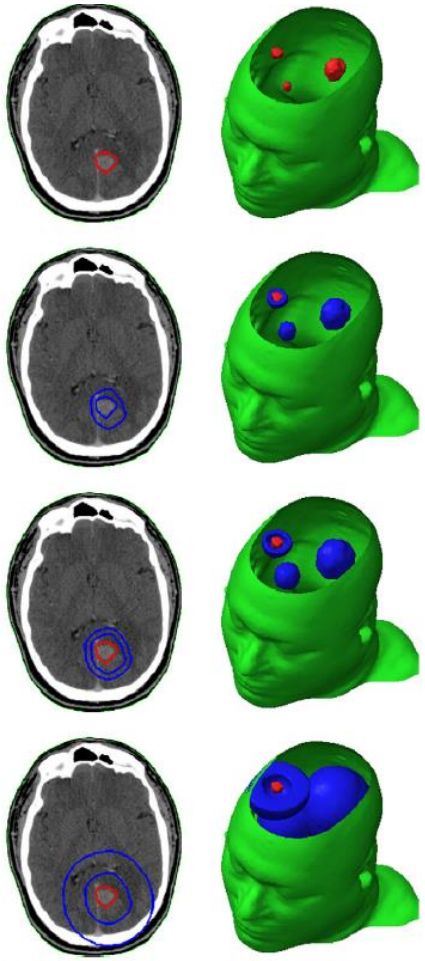
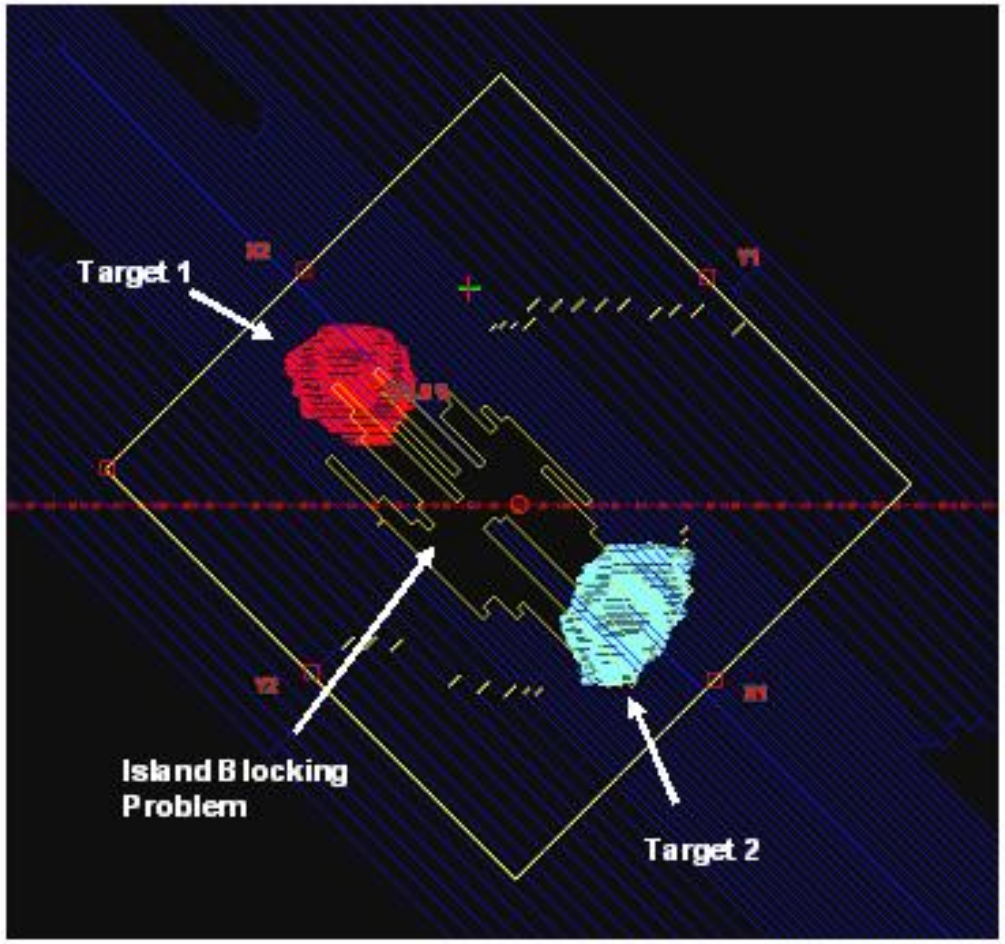


Figure 1 Dose control tuning structures utilized for dose optimization. Left side = 2-dimensional visualization for a single target patient. Right side = 3-dimensional visualization for a multitarget patient. From top to bottom (both sides): target(s) (red), inner control tuning structure (blue), middle control tuning structure (blue), and outer control tuning structure (blue).

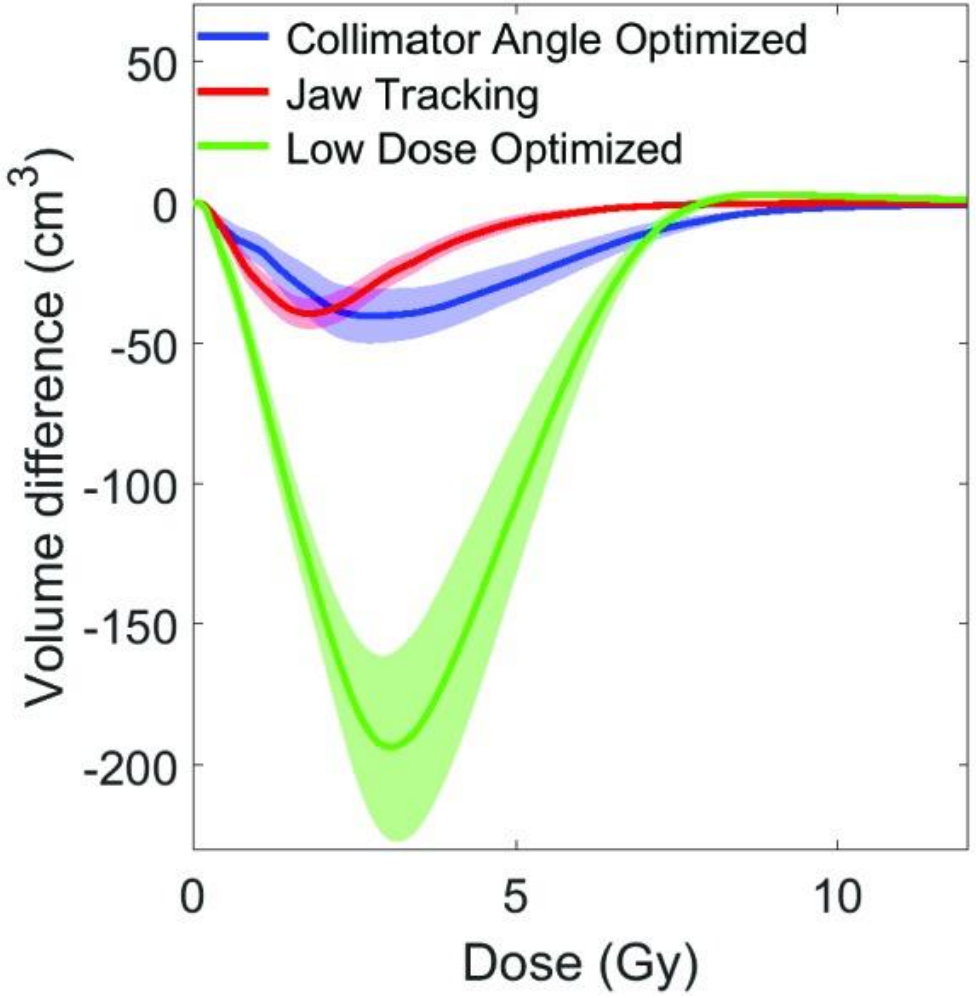
Clark GM, Popple RA, Prendergast BM, et al. Plan quality and treatment planning technique for single isocenter cranial radiosurgery with volumetric modulated arc therapy. *Pract Radiat Oncol*. 2012;2(4):306-313. doi:10.1016/j.prro.2011.12.003

Island blocking



- Collimator angle and table angle optimization (Kang (Hopkins); Med Physics; 37: 4146-4154)
- Include dose to normal brain in objective function
- Multiple arcs limiting MLCs to individual tumors

Island blocking



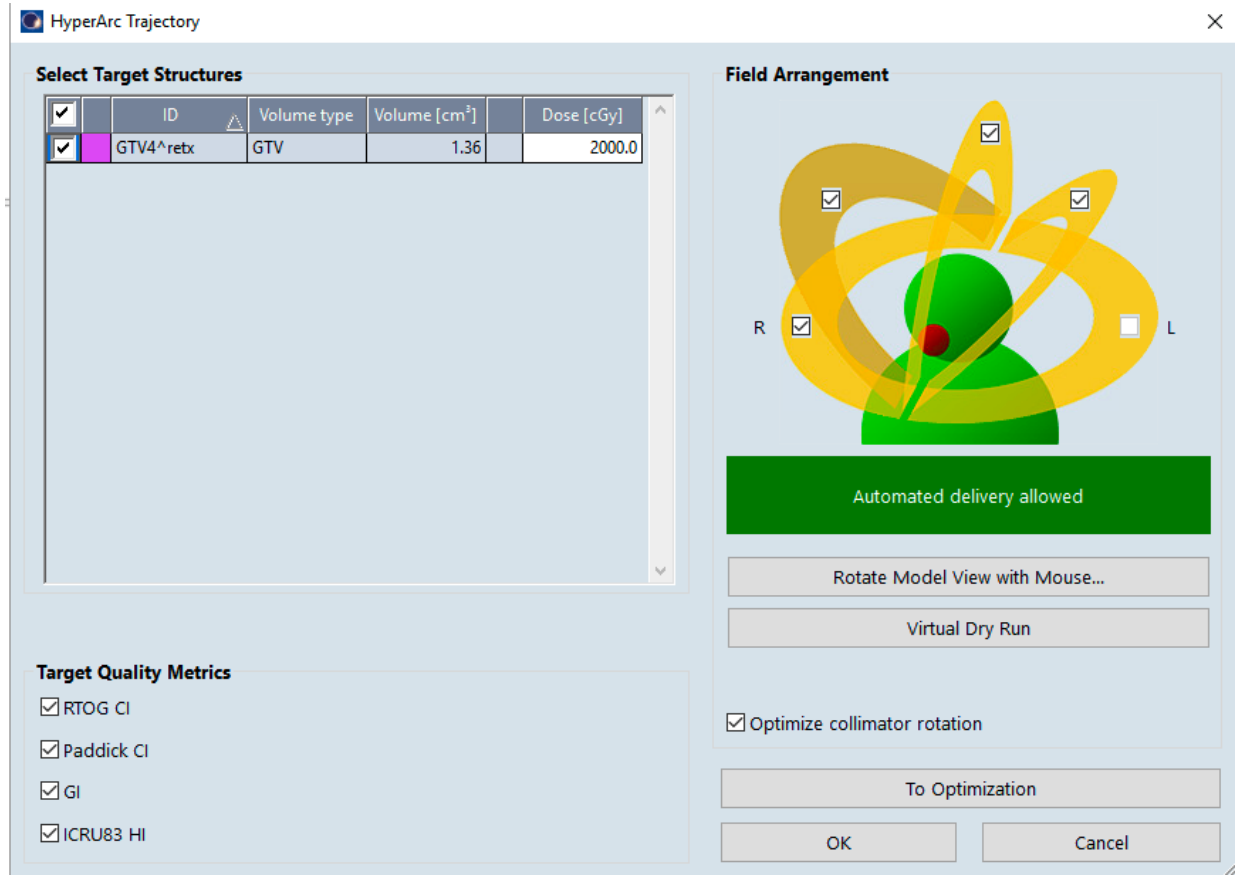
SAM ALERT

"To reduce low dose spill into normal brain for single isocenter VMAT radiosurgery of multiple targets, it is important to incorporate a limit on low dose spill into the objective function."

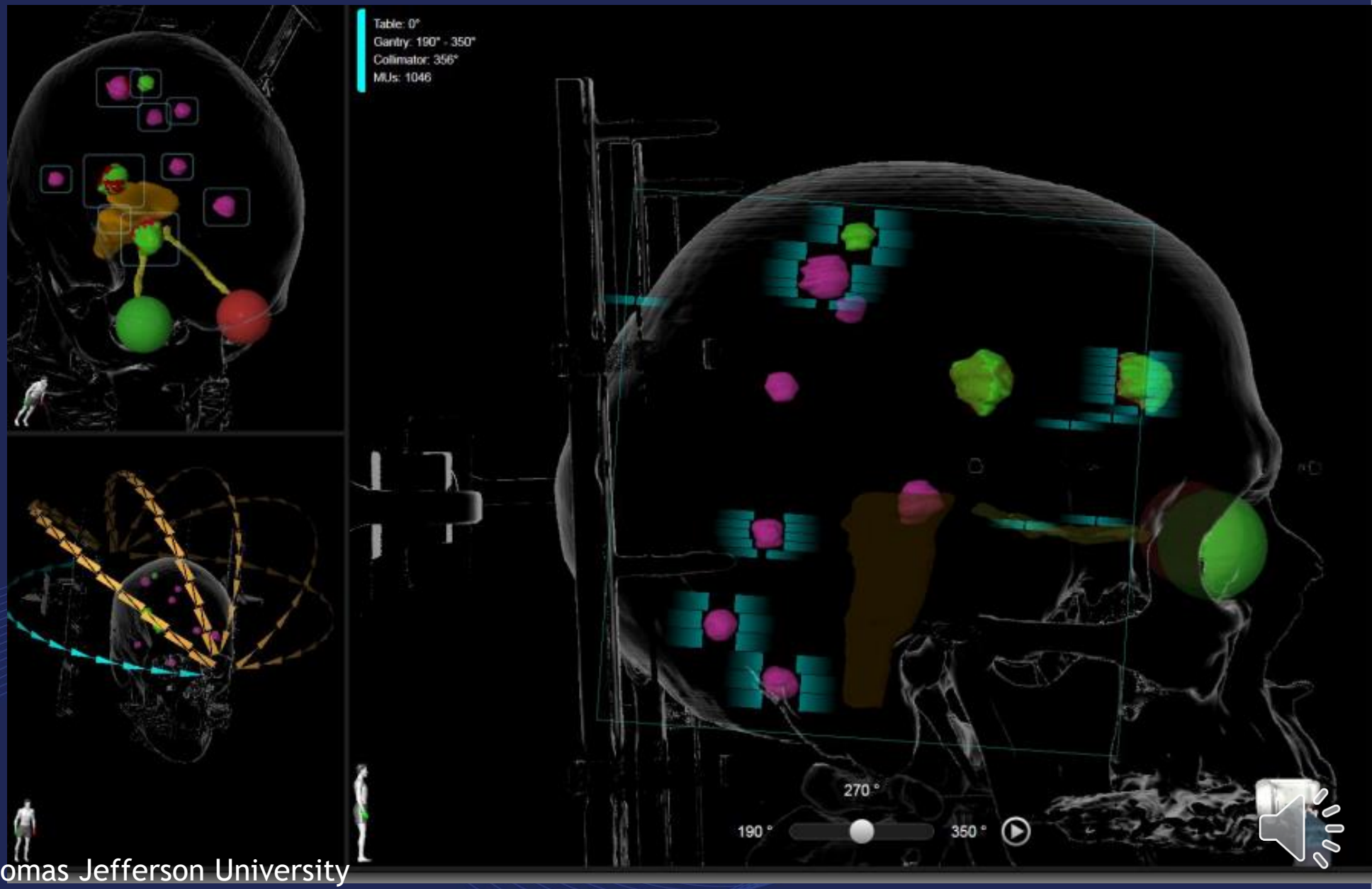
Yuan Y et al. Evaluation of multiple factors affecting normal brain dose in single-isocenter multiple target radiosurgery. J Radiosurg SBRT. 2018;5(2):131-144. PMID: 29657894; PMCID: PMC5893454.

Semi-automated planning - HyperArc

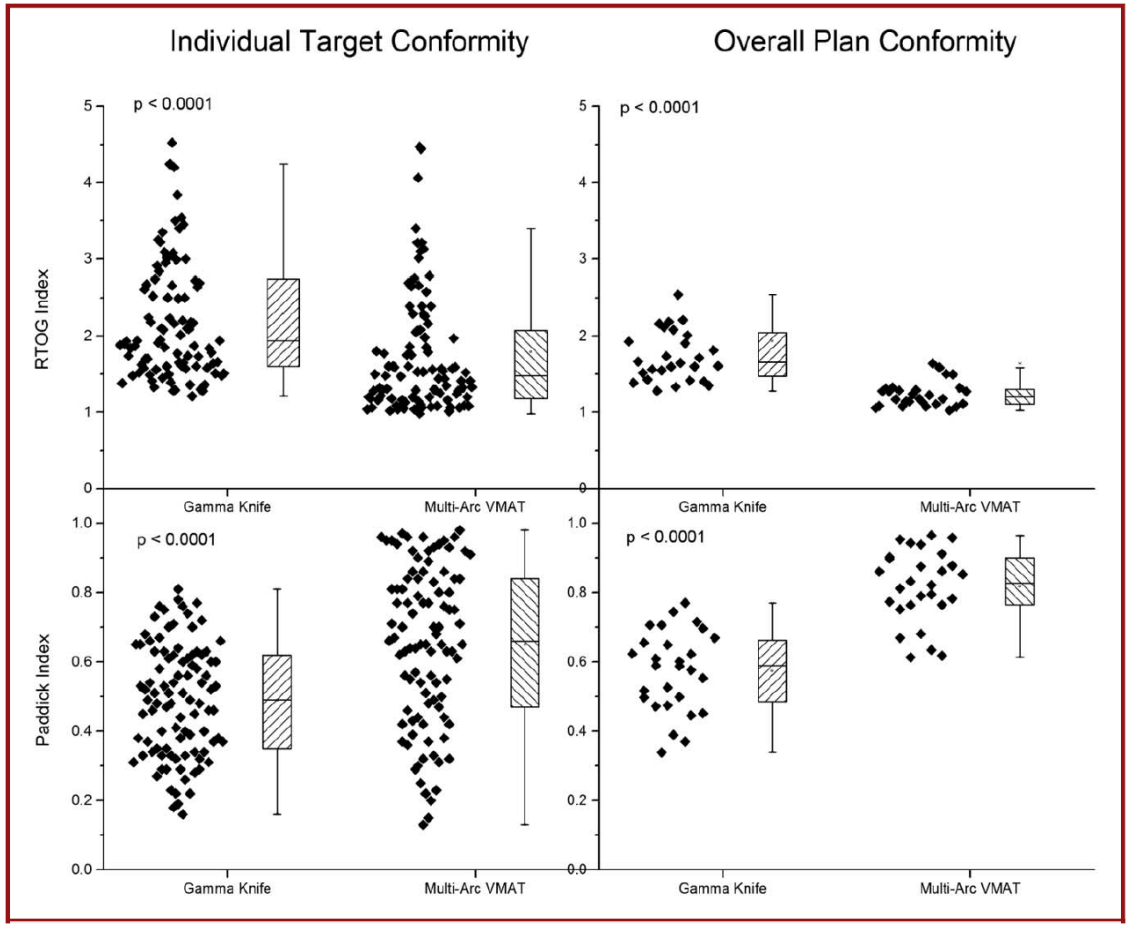
- No ring structures → SRS specific normal tissue objective
- Simplified planning workflow
- Field geometry template designed to meet planning goals for nearly all cases
- Reduction in SRS treatment planning time
- Systematic SRS treatment planning results



Multimets Element (MME) Plan: Pre-templated arc geometry



Courtesy Haisong Liu, Ph.D., Thomas Jefferson University



SAM ALERT

TABLE 2. Descriptive Conformity Index Statistics[a]

		Multiarc VMAT			Gamma Knife		
		Range	Median	Mean	Range	Median	Mean
Overall plan	RTOG	1.04-1.69	1.14	1.20	1.28-7.39	1.65	1.93
	Paddick	0.58-0.94	0.86	0.83	0.34-0.77	0.59	0.57
Individual target	RTOG	0.99-4.31	1.29	1.51	1.21-6.10	1.94	2.30
	Paddick	0.23-0.99	0.75	0.72	0.16-0.81	0.49	0.49

[a]RTOG, Radiation Therapy Oncology Group; VMAT, volumetric modulated arc therapy.

"Conformity was more favorable in multiarc VMAT plans than GK."

Thomas EM, et al. Comparison of plan quality and delivery time between volumetric arc therapy (RapidArc) and Gamma Knife radiosurgery for multiple cranial metastases. Neurosurgery. 2014 Oct;75(4):409-17; discussion 417-8. doi: 10.1227/NEU.0000000000000448. PMID: 24871143; PMCID: PMC4203364.

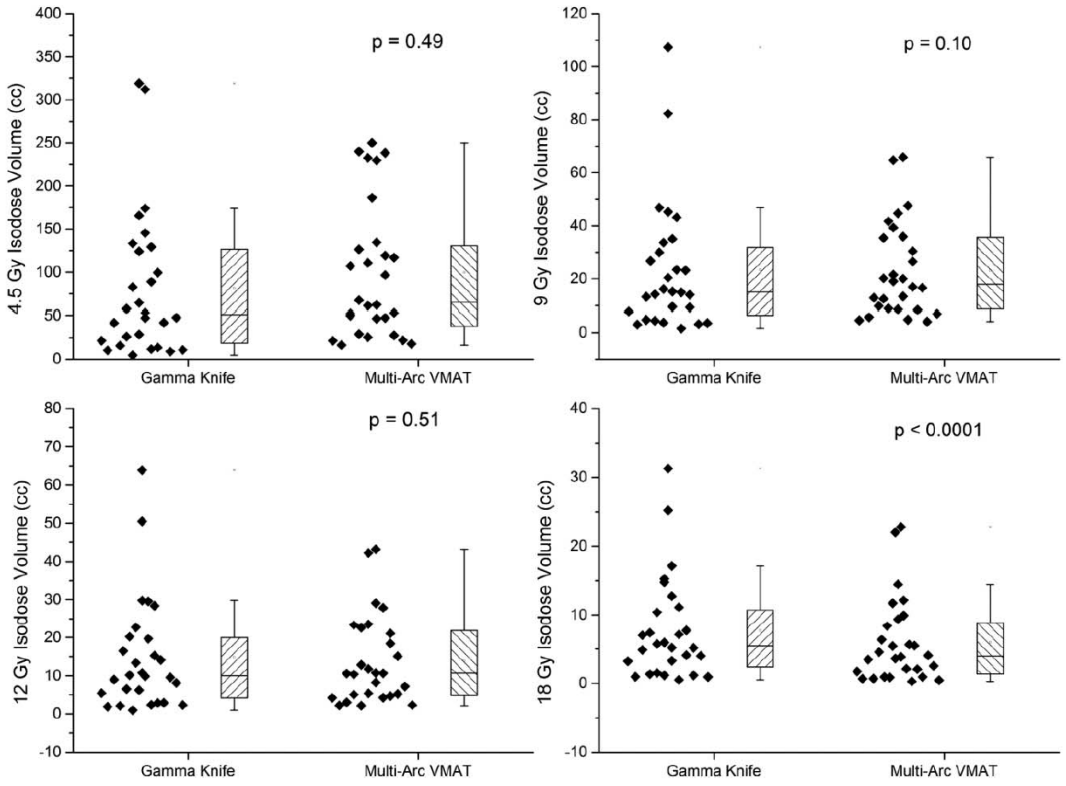


FIGURE 3. *Distributions of V4.5, V9, V12, and V18 levels for Gamma Knife and multiarc VMAT. VMAT, volumetric modulated arc therapy.*

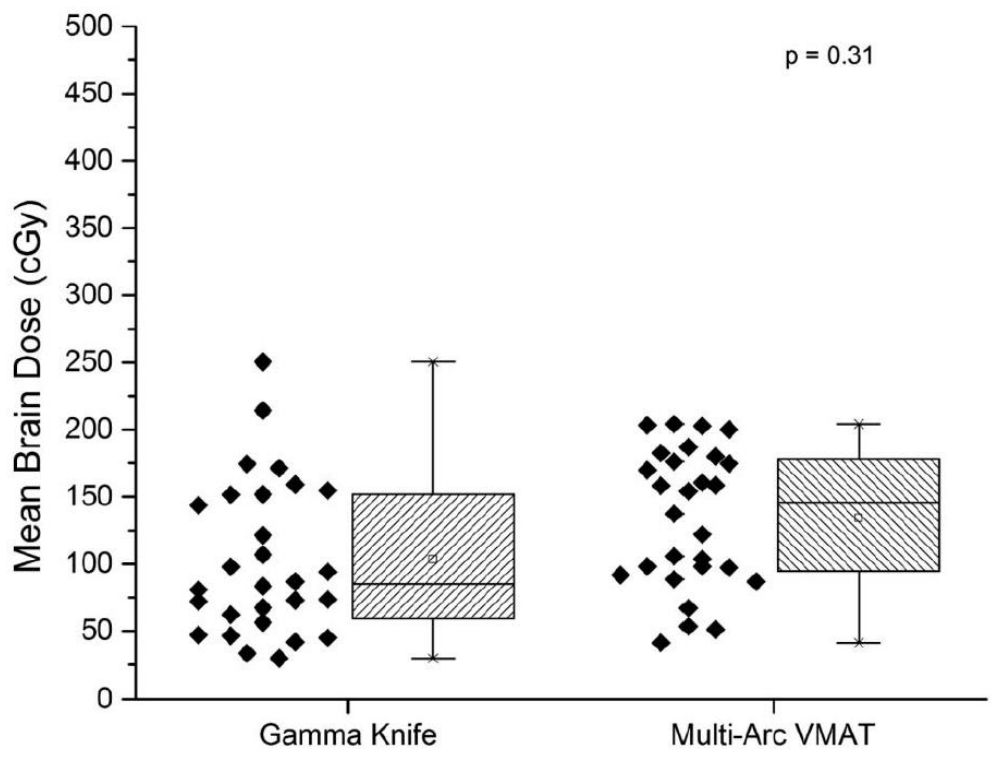
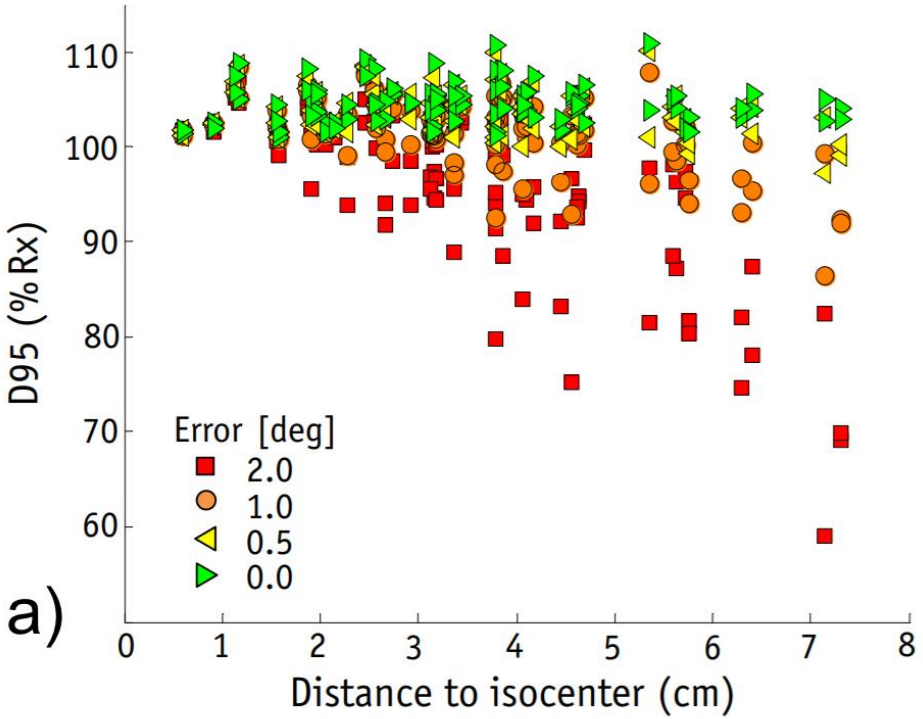
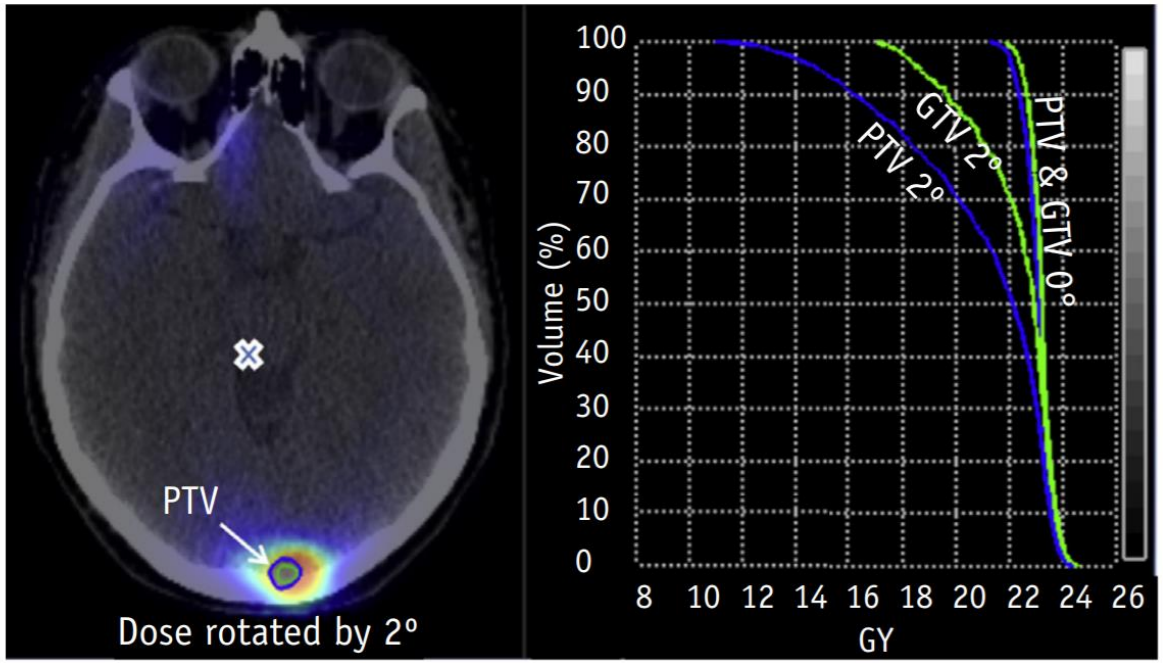


FIGURE 4. *Distribution of mean brain doses for Gamma Knife and multiarc VMAT. VMAT, volumetric modulated arc therapy.*

Thomas EM, et al. Comparison of plan quality and delivery time between volumetric arc therapy (RapidArc) and Gamma Knife radiosurgery for multiple cranial metastases. Neurosurgery. 2014 Oct;75(4):409-17; discussion 417-8. doi: 10.1227/NEU.0000000000000448. PMID: 24871143; PMCID: PMC4203364.

Managing rotational error

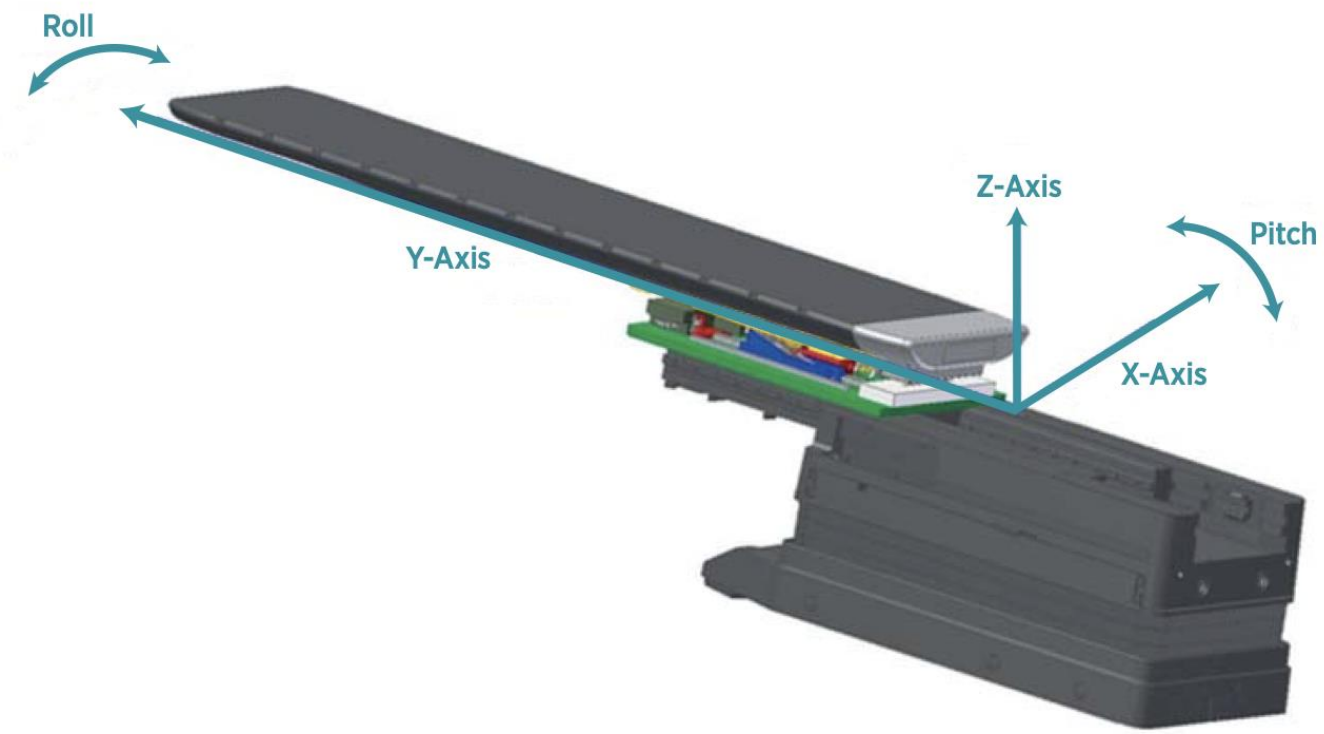




Roper et al, IJROBP 2015;93(3):540-6

Managing rotational error

- Single isocenter treatment requires rotational error correction

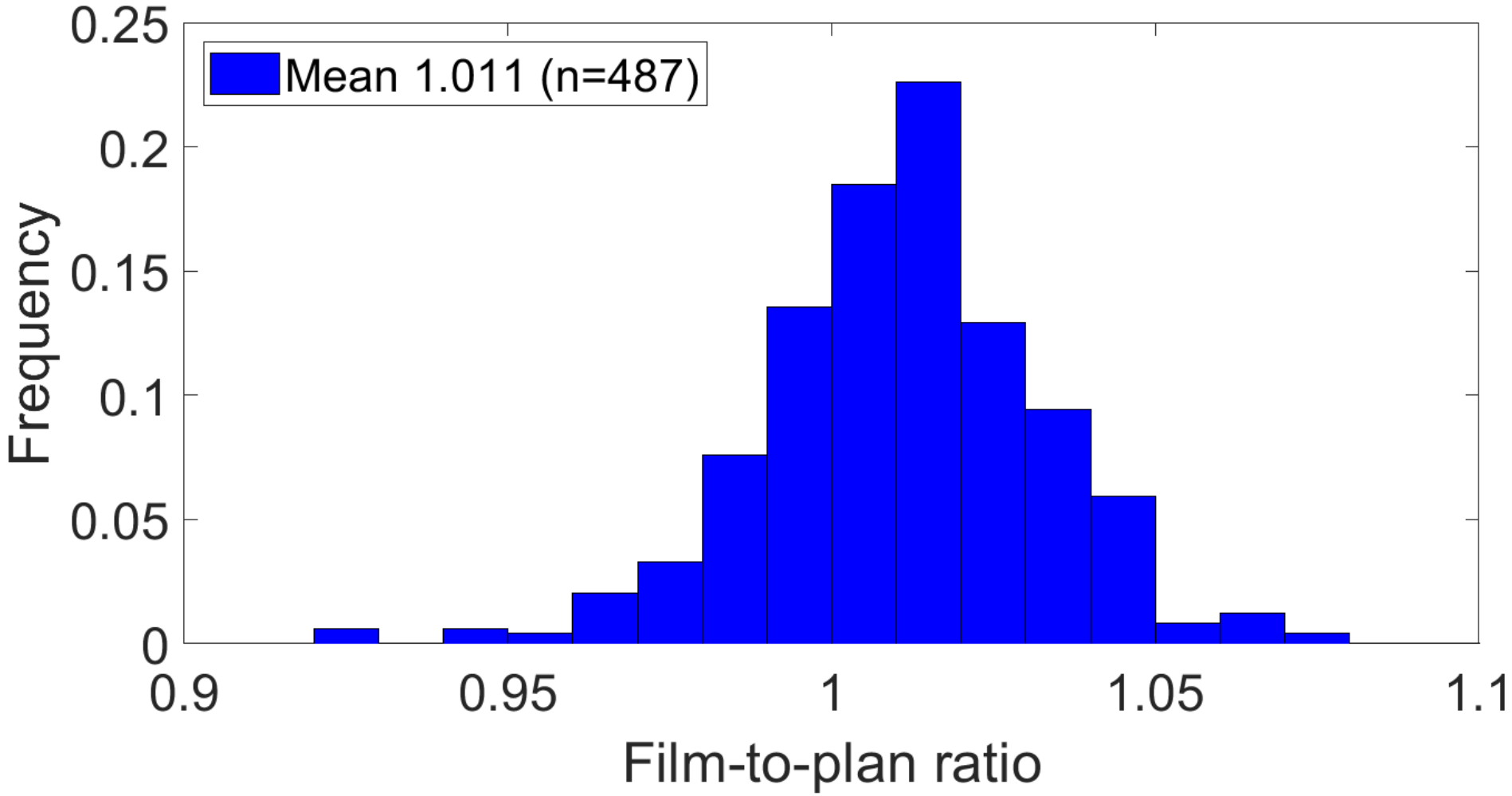


Machine QA - AAPM TG-142

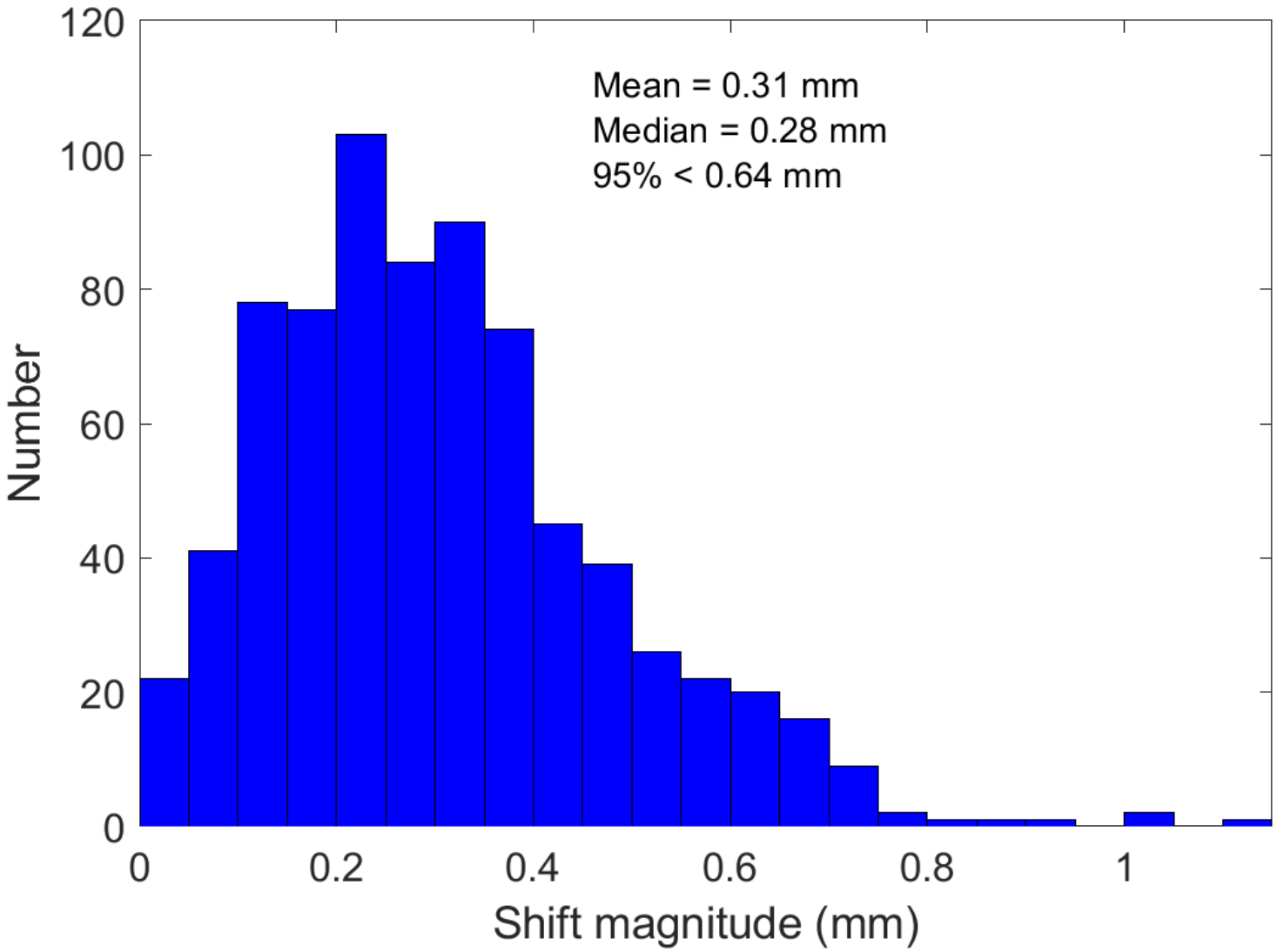
TABLE VI. Imaging.

Procedure	Application-type tolerance	
	non-SRS/SBRT	SRS/SBRT
Daily[a]		
Planar kV and MV (EPID) imaging		
Collision interlocks	Functional	Functional
Positioning/repositioning	≤2 mm	≤1 mm
Imaging and treatment coordinate coincidence (single gantry angle)	≤2 mm	≤1 mm
Cone-beam CT (kV and MV)		
Collision interlocks	Functional	Functional
Imaging and treatment coordinate coincidence	≤2 mm	≤1 mm
Positioning/repositioning	≤1 mm	≤1 mm

Patient-specific QA – Radiochromic film



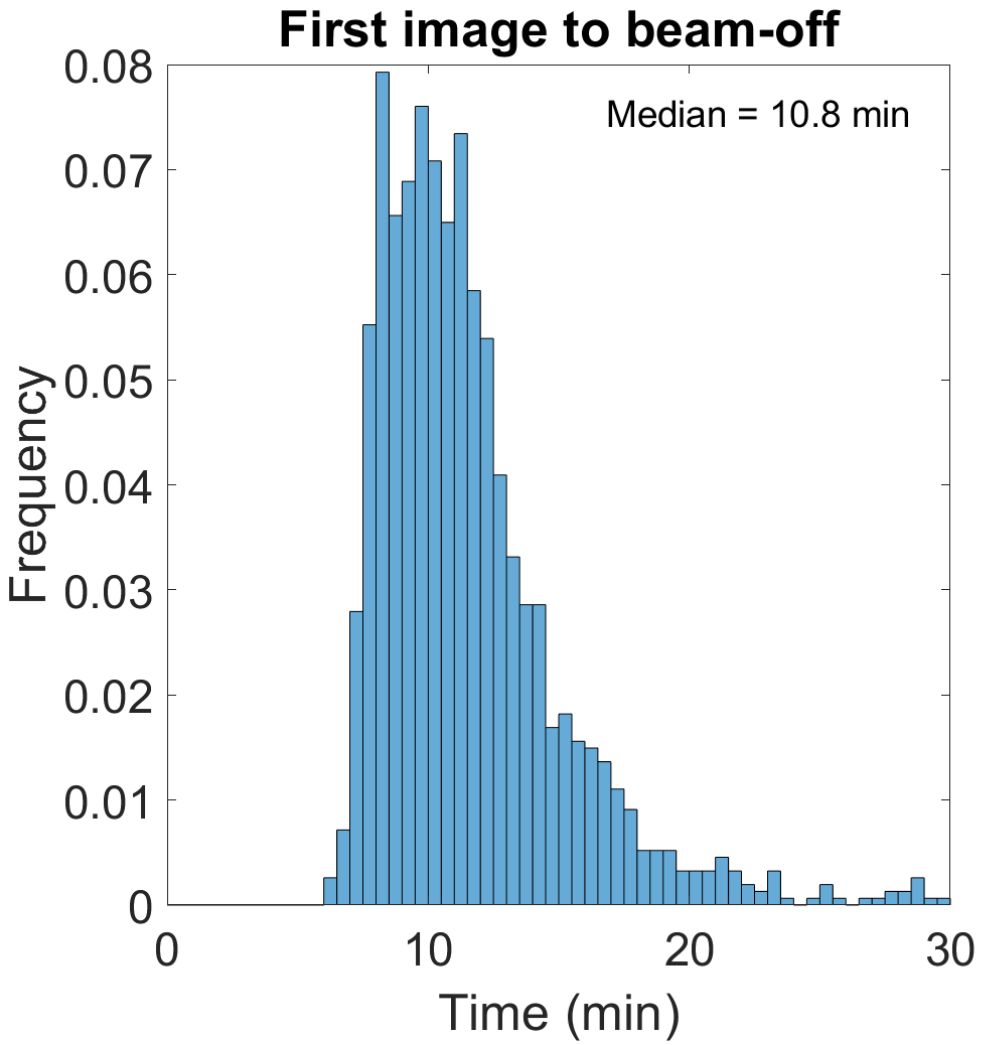
Patient-specific QA – Radiochromic film

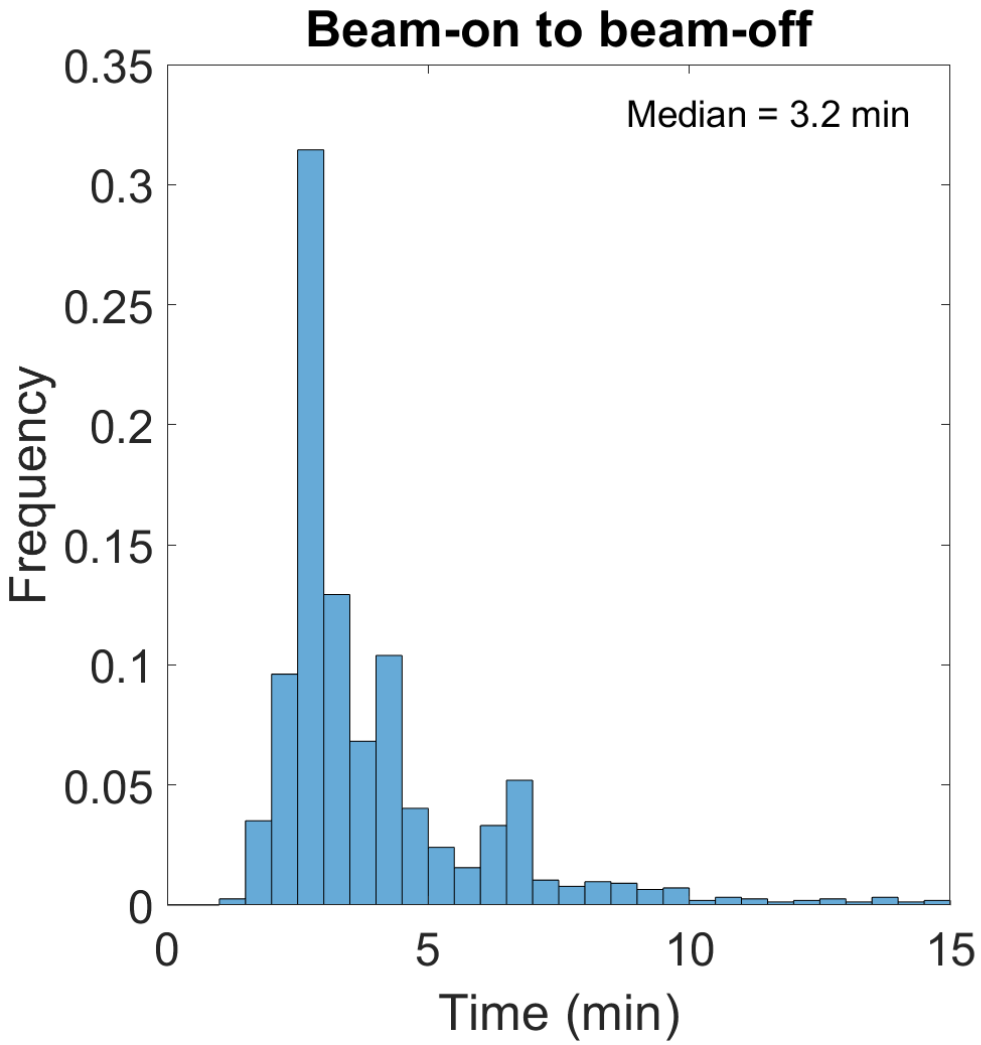


Patient-specific QA

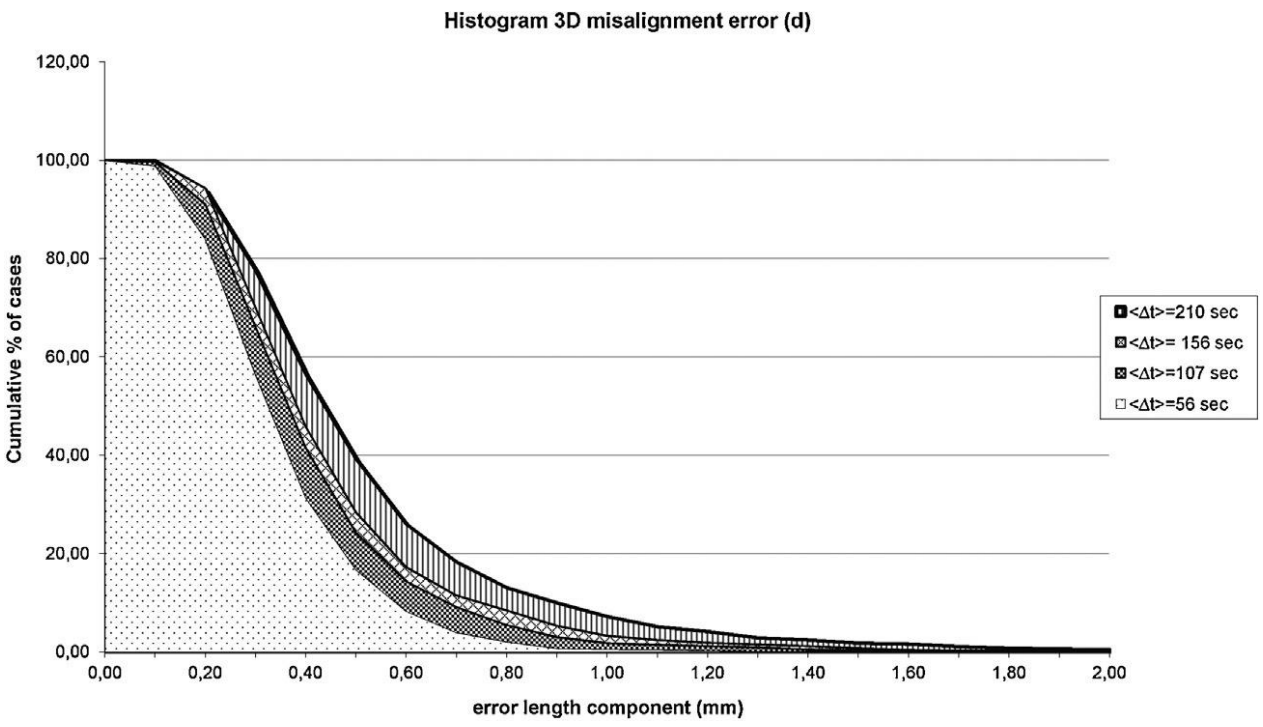
- More commercial tools are becoming available
- Plastic scintillator detector
- 2D diode array
- Others…

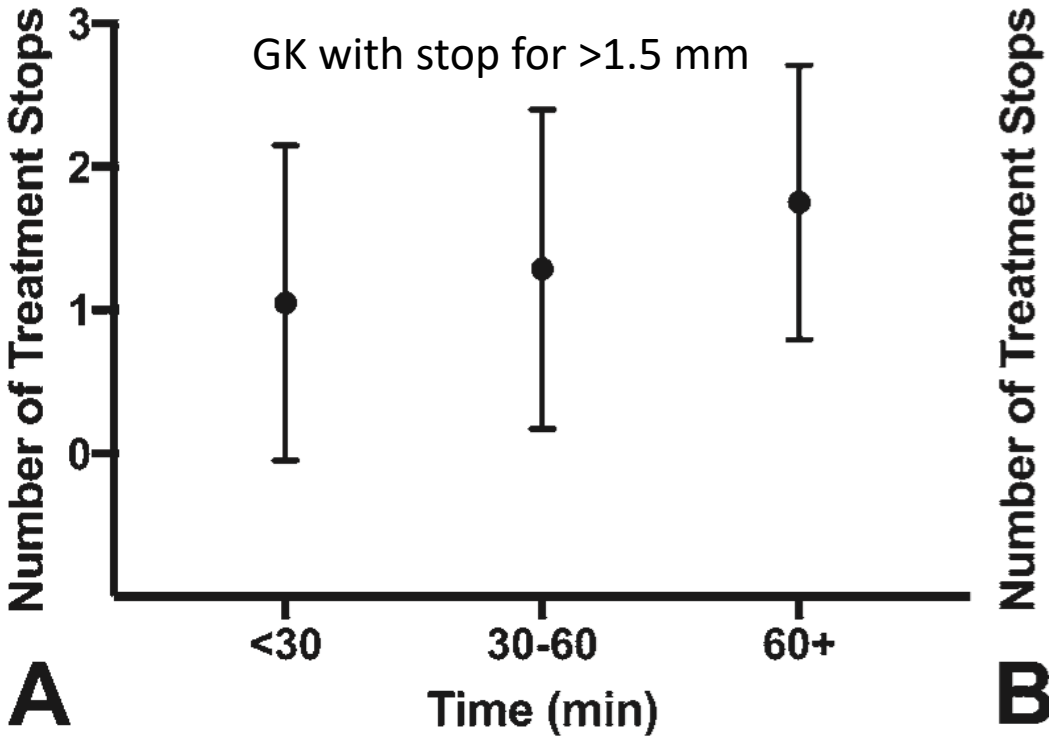
Treatment time





Fast Treatment Decreases Intrafraction Motion





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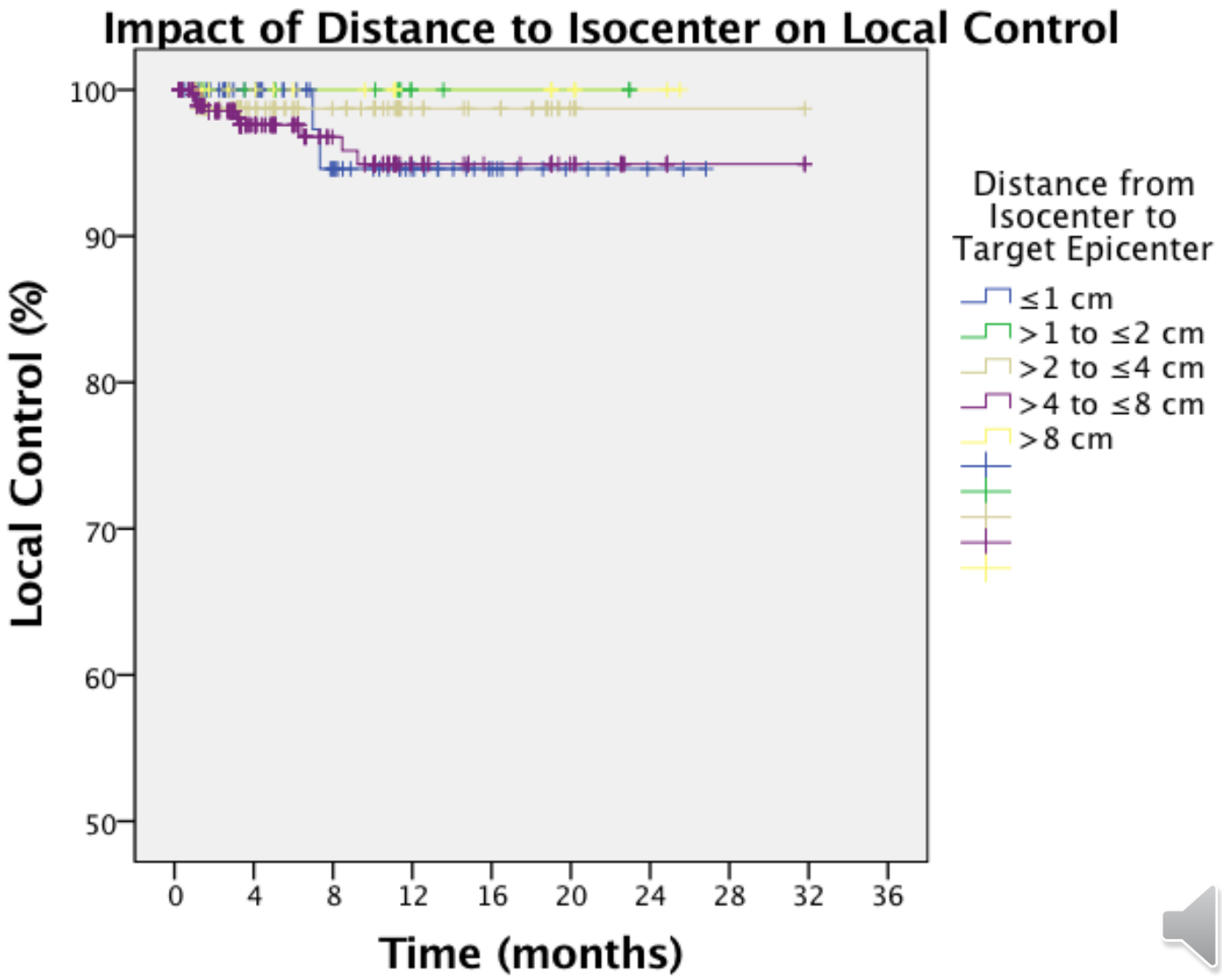
Fliorano et al, Reports of practical oncology and radiotherapy 1 8 (2 0 1 3) 173–178

Carminucci et al, J Neurosurg (Suppl) 129:133–139, 2018

Local Tumor Control is Independent of Distance from Isocenter

- 532 tumors single fraction SRS
- Frameless
- No margins
- Single Isocenter



Marcrom et al, ASTRO 2018, abstract MO_8_267

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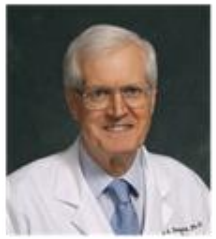

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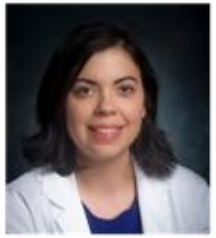

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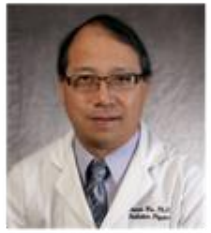

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