SRT I: Comparison of SRT Techniques

Overview of MLC-based Linac Radiosurgery

Grace Gwe-Ya Kim, Ph.D. DABR

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
- Machine is not limited for cranial treatment

MLC based SRS + Frameless

- Patient comfort
- Ease of treatment / workflow
- Comparable positioning accuracy
- Hypofractionated treatments

SRS vs. SRT

- The prescribed dose and dose fractionation in stereotactic dose delivery depend upon:
  - Volume
  - Location
  - Disease

M Linskey et al. J Neurosurg (Suppl 3) 2000;93:90-95

SRS vs. SRT

- Risk factors to developing edema (Meningioma)
  - Dose
  - Volume
  - Location
  - Pre-existing edema etc.

Single-fraction SRS	
Prescribed dose, Gy	15 (11-18)
BED, Gy	83 (40-116)
Volume, mL	3.7 (0.1-47)
Fractionated SRS	
Prescribed dose, Gy	25 (9-40)
Fractionation distribution	
25 Gy in 5 fractions	56
30-35 Gy in 5 fractions	5
18-21 Gy in 3 fractions	6
Other	9
BED, Gy	63 (14-109)
Volume, mL	6.6 (0.6-232)

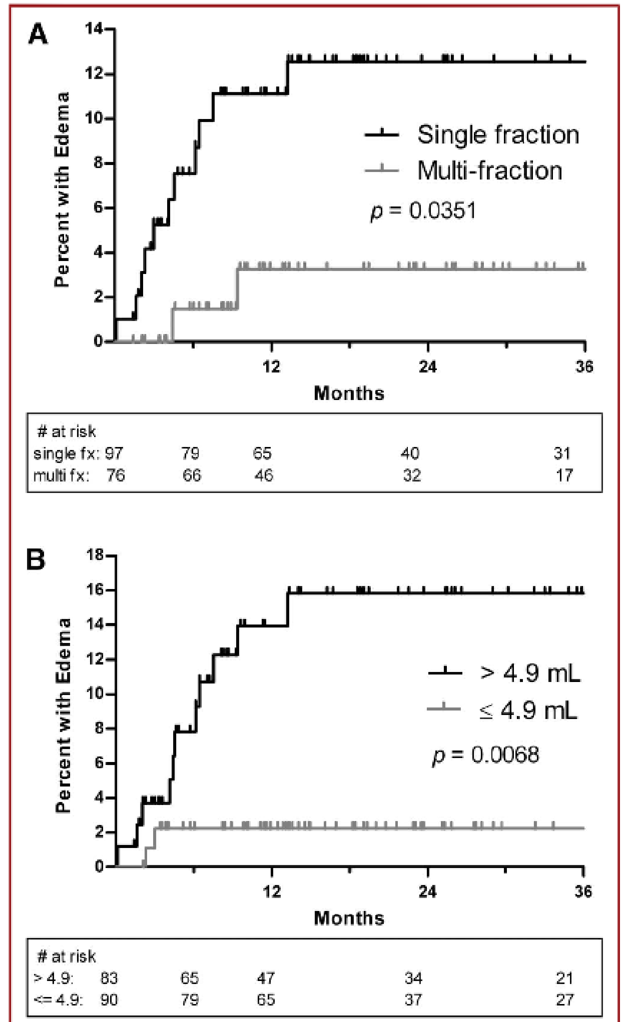

FIGURE 4. *Cumulative incidence of symptomatic posttreatment peritumoral ...ma following SRS with respect to single fraction vs fractionated treatment* (**A**) *...l tumor volume >4.9 mL vs ≤4.9 mL* (**B**).

Gagnon et al., Neurosurgery, (2012), 70 (3) 639-645

SRS vs. SRT

C Brennan et al., IJROBP, 88 (1) 130–136, (2014)

A Phase 2 Trial of Stereotactic Radiosurgery Boost After Surgical Resection for Brain Metastases

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- 49 patients
- SRS boost : Significant lower local failure
- Tumors ≥ 3 cm with superficial : higher risk of local failure

G Minniti et al., IJROBP, 86 (4) 623–629, (2013)

Multidose Stereotactic Radiosurgery (9 Gy × 3) of the Postoperative Resection Cavity for Treatment of Large Brain Metastases

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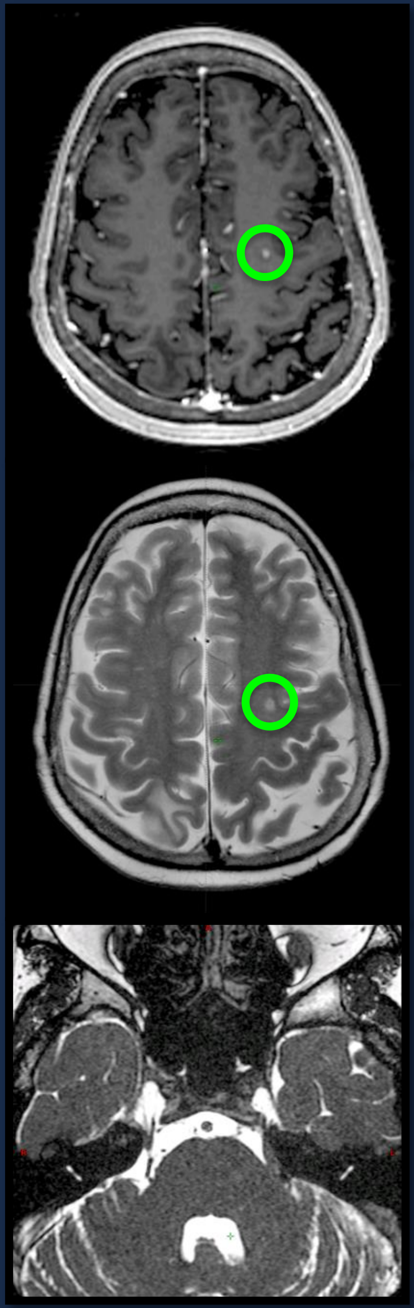
- 101 patients
- > 3 cm cavities
- the most effective tx. option for large radioresistant brain met
- V_{24Gy} : radionecrosis

Imaging

- Metastatic
  - MRI with Gadolinium
    - T1 post contrast (thin slice)
    - Small non-enhancing lesions may be seen on T2
  - CT Head with contrast – If MRI unavailable
    - May miss small posterior fossa lesions
- AVM
  - CTA, DSA, MRA
- Trigeminal Neuralgia
  - T1 post, FIESTA

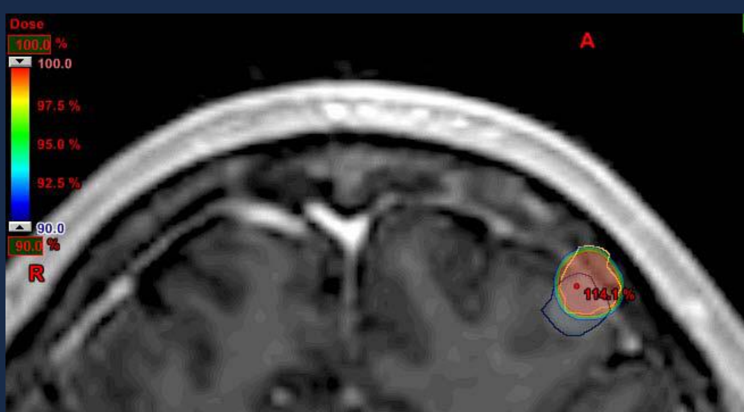


TG-54

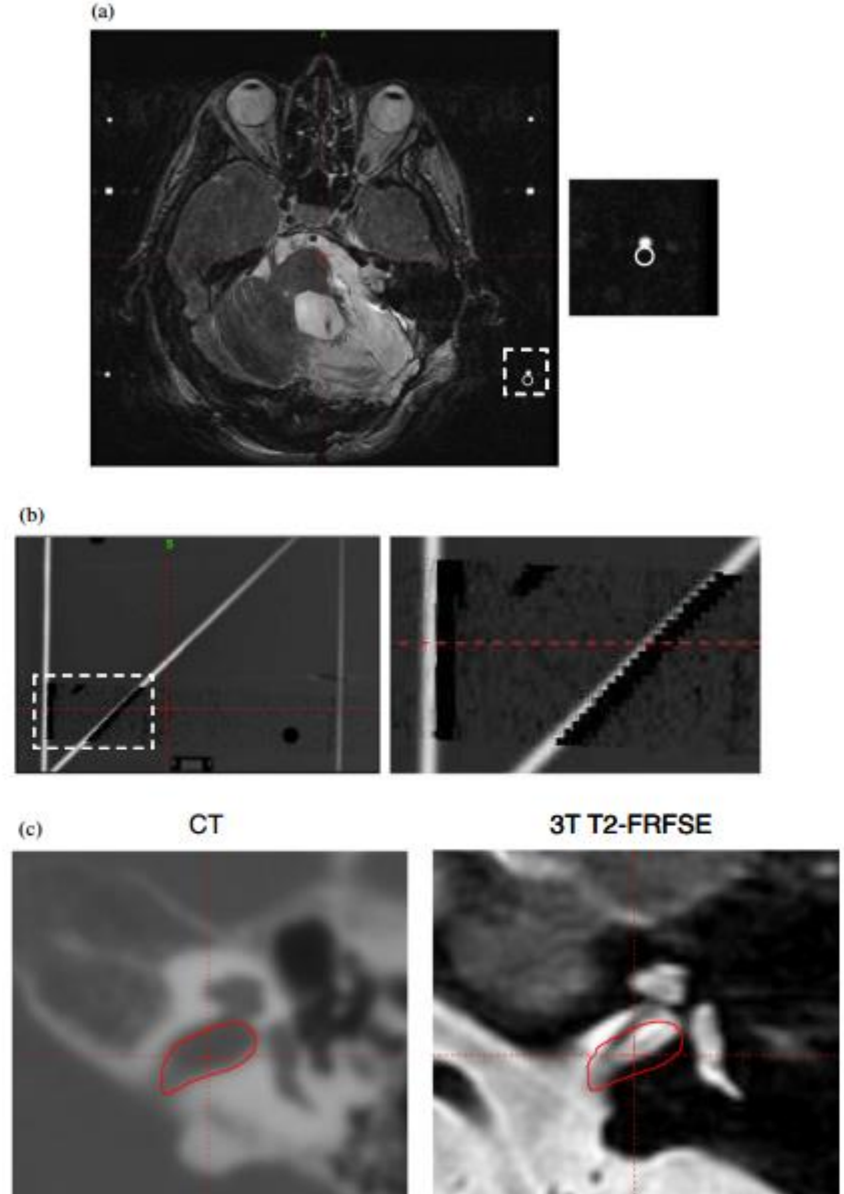
"MRI contains distortions which impede direct correlation with CT data at the level required for SRS"

TG-117

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



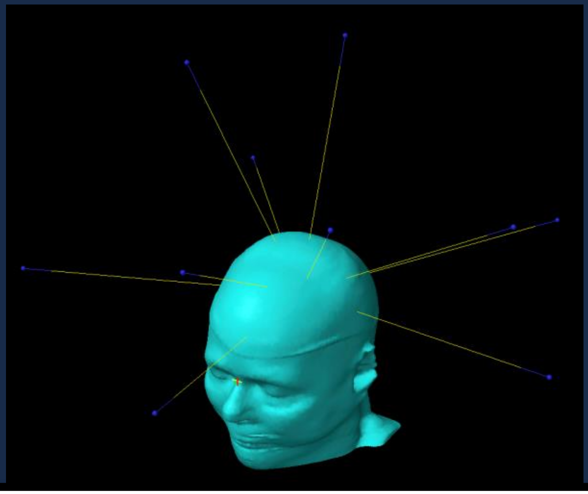
Gradient nonlinearity distortion, Siebert et al, ASTRO 2014

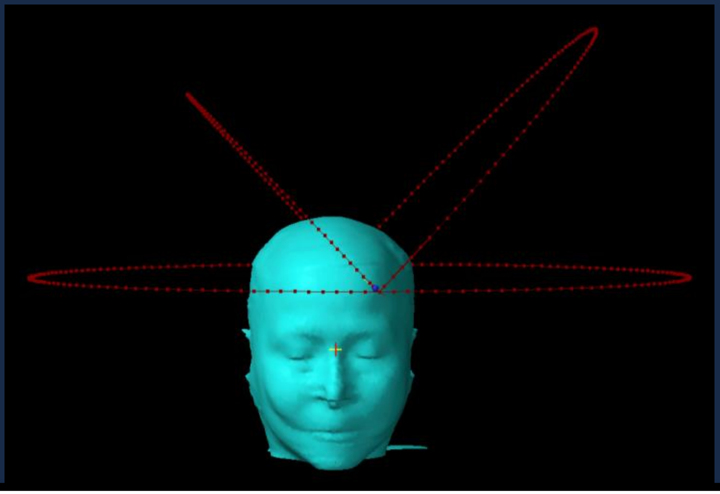


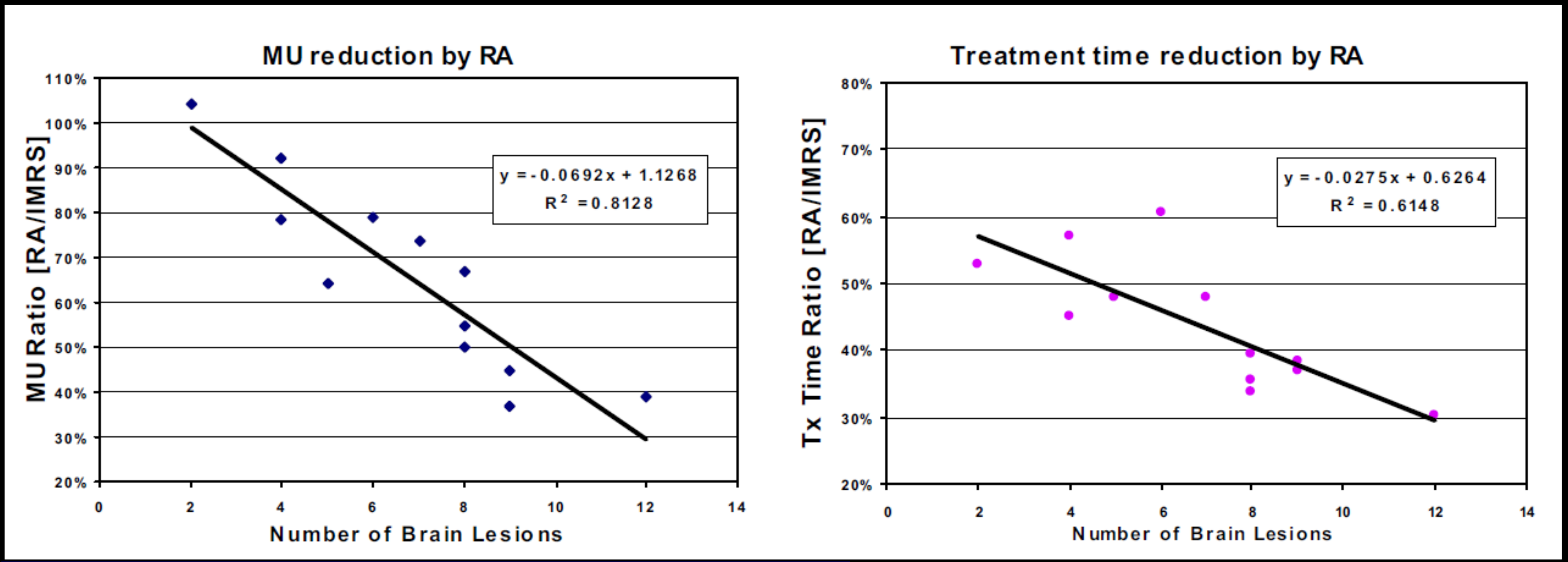
B Zhang et al., Phys. Med. Biol. 55 (2010) 6601-6615

...cal impact of geometric distortion of stereotactic references. (a) Stereotactic ...on 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.

IMRS vs. VMAT

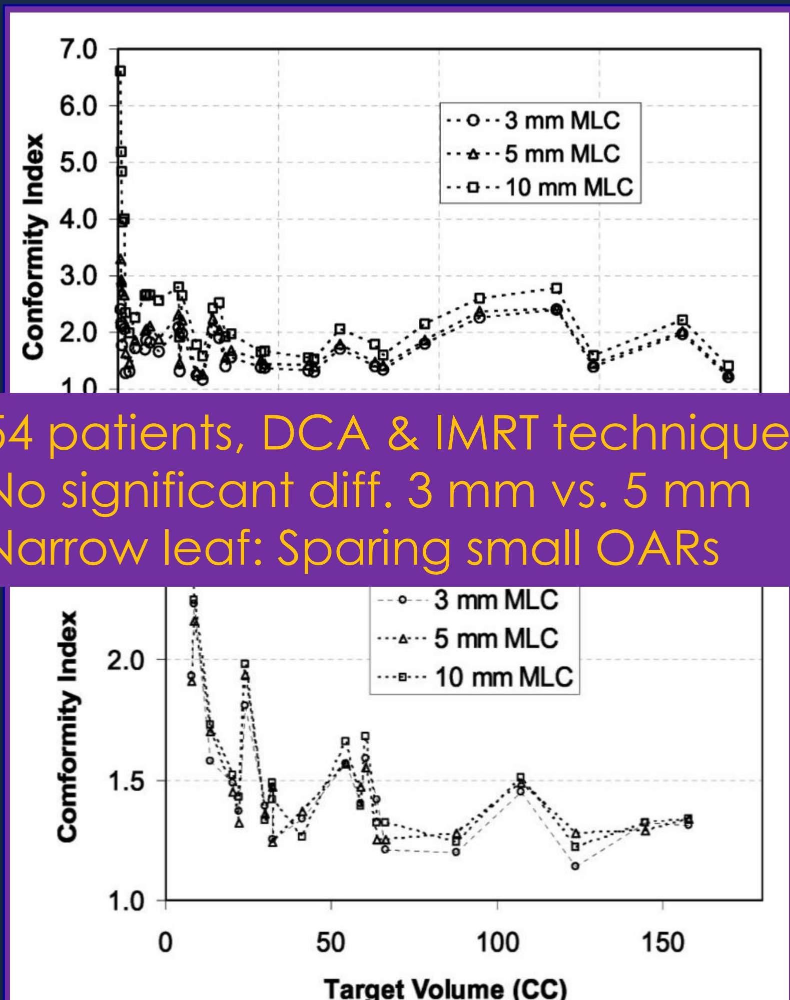






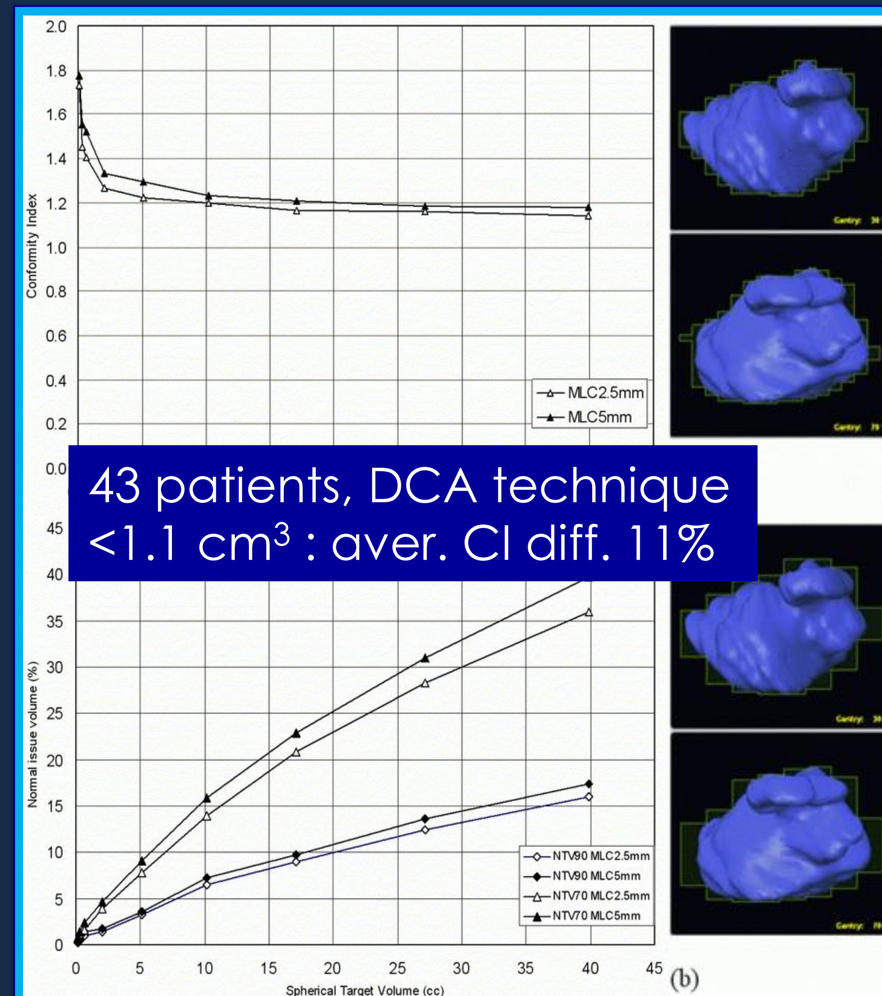
JZ Wang et al, Medical Dosimetry 37 (2012) 31-36

MLC leaf width



54 patients, DCA & IMRT techniques
No significant diff. 3 mm vs. 5 mm
Narrow leaf: Sparing small OARs

Jian-Yue Jin et al., Med. Physics, 32, 405 (2005)

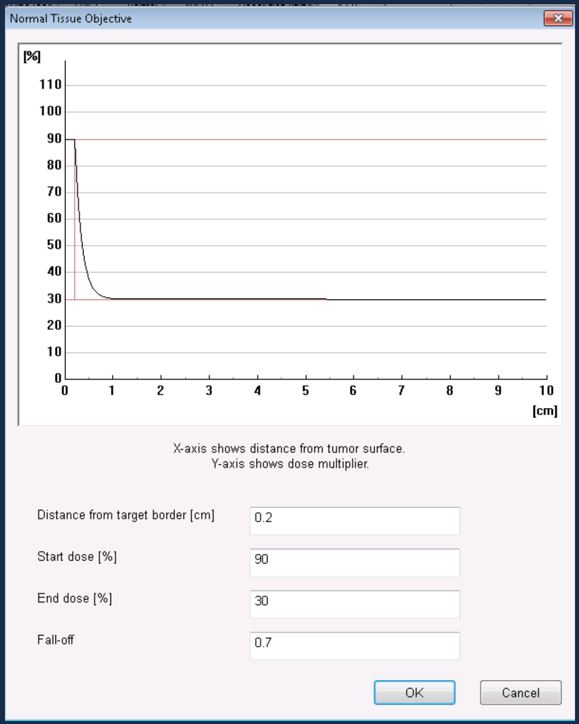


43 patients, DCA technique
<1.1 cm^3 : aver. CI diff. 11%

Annes Dhabaan et al., JACMP, Vol. 11, No.3 (2010)

Plan optimization

- Constraints
- Normal Tissue Objective
- Tuning Structures
- MU constraint



- Target structure 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

- Lens Max. dose <10 Gy (1 fx)
- Normal Brain V10 < 12 cc or V12 < 10 cc
- Cranial Nerves (fifth, seventh and eighth CN) 12.5-15 Gy

(Flicker et al., IJROBP 2004)

Normal brain dose

Stereotactic radiosurgery for brain metastases: analysis of outcome and risk of brain radionecrosis

Giuseppe Minniti[1,2*], Enrico Clarke[1], Gaetano Lanzetta[2], Mattia Falchetto Osti[1], Guido Trasimeni[3], Alessandro Bozzao[3], Andrea Romano[3] and Riccardo Maurizi Enrici[1]

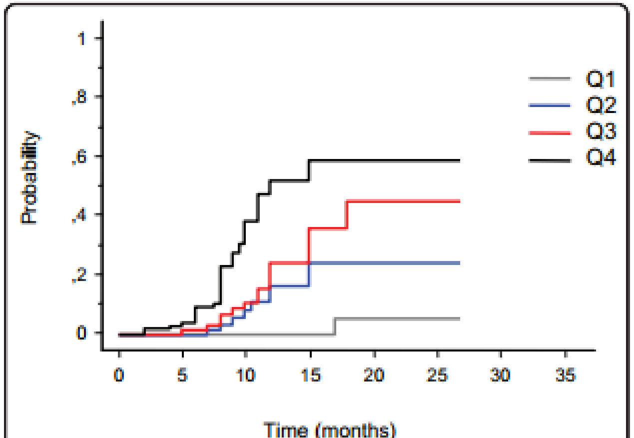


Figure 2 Risk of brain radionecrosis after stereotactic radiosurgery for brain metastases in relation to brain volumes receiving 12 Gy (V12 Gy) stratified for quartiles (Q1-Q4). The risk increased significantly through Q1-Q4, corresponding to V12 Gy < 3.3 cm^3, 3.3-5.9 cm^3, 6.0-10.9 cm^3, and >10.9 cm^3, respectively. The actuarial risk at 1 year was 0% for Q1, 16% for Q2, 24% for Q3, and 51% for Q4

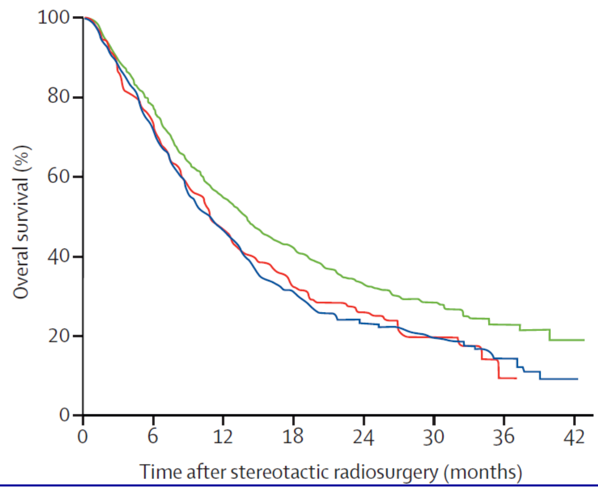
Table 1 Summary of tumor characteristics and treatment parameters

Parameter	No(%)
number of patients	206
median age	62
sex (F/M)	99/107
no of lesions per patient	
1 lesion	126 (61%)
2 lesions	56 (27%)
3 lesions	24 (12%)
histology	
lung	106 (51%)
breast	38 (18%)
melanoma	34 (17%)
others	28 (14%)
tumor location	
frontal	68 (22%)
parietal	78 (25%)
temporal	62 (20%)
cerebellar	43 (14%)
occipital	45 (15%)
brainstem	14 (4%)
radiosurgical dose (Gy)	
20	118 (38%)
18	120 39%)
15-16	72 (23%)
range	0.2-23.7

- **V10 and V12 volumes greater than 4.5-7.7 and 6.0-10.9 cc carry >10% risk of symptomatic radiation necrosis , respectively**

G Minniti et al, Radiation Oncology 2011, 6:48

Multi-metastases



Group	Median overall survival, months (95% CI)	HR (95% CI)	p value
1 tumour	13·9 (12·0–15·6)	0·76 (0·66–0·88)	0·0004
2–4 tumours	10·8 (9·4–12·4)	Reference	
5–10 tumours	10·8 (9·1–12·7)	0·97 (0·81–1·18)	0·78

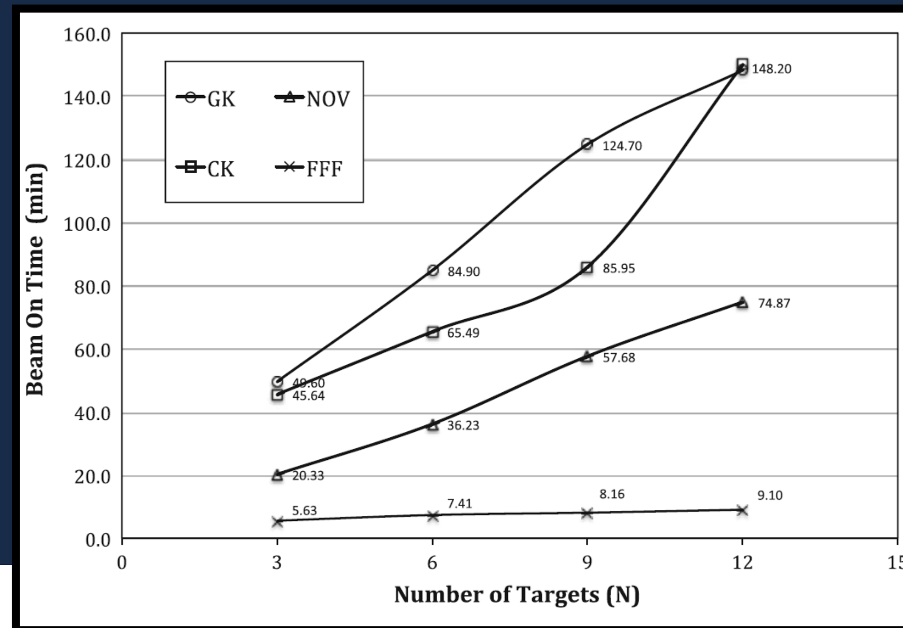
	Total (n=1194)	1 tumour (A) (n=455)	2–4 tumours (B) (n=531)	5–10 tumours (C) (n=208)	p value (B vs C)
Maintained neurocognitive function‡					
4 months after SRS	623/662 (94%)	243/256 (95%)	263/284 (93%)	117/122 (96%)	0·27
12 months after SRS	333/366 (91%)	141/154 (92%)	139/152 (91%)	53/60 (88%)	0·60
24 months after SRS	120/128 (94%)	55/60 (92%)	47/48 (98%)	18/20 (90%)	0·20
36 months after SRS	28/30 (93%)	14/15 (93%)	10/11 (91%)	4/4 (100%)	1·00

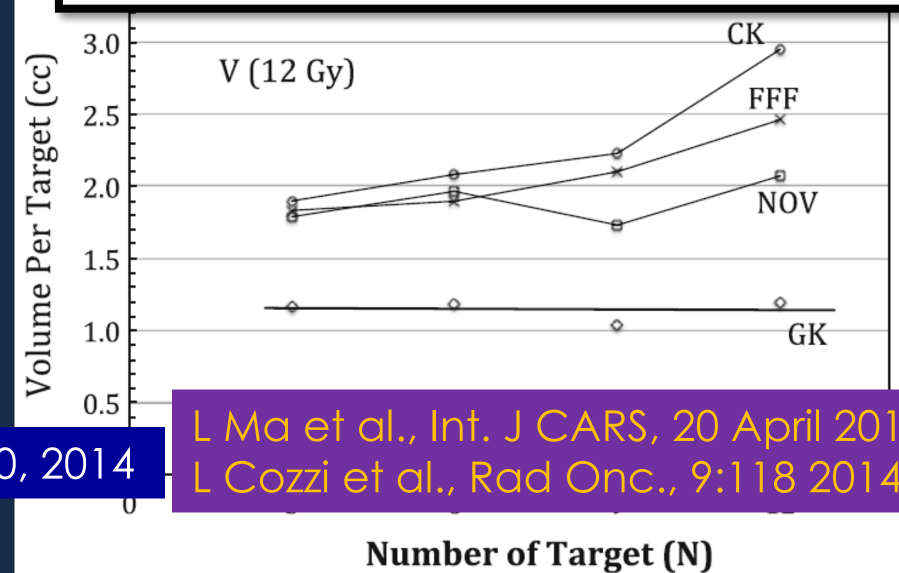
Data are number of patients with one or more adverse event (%), unless otherwise specified. MMSE=Mini-Mental State Examination. SRS=stereotactic radiosurgery. *Graded according to Common Terminology Criteria for Adverse Events,

patients who completed MMSE at that timepoint.[5]

Table 6: Adverse events and maintenance of neurocognitive function

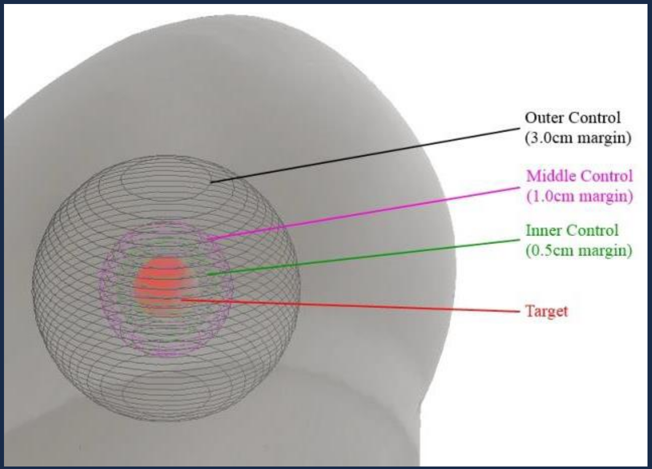
M Yamamoto et al., Lancet Oncol, March 10, 2014





L Ma et al., Int. J CARS, 20 April 2014
L Cozzi et al., Rad Onc., 9:118 2014

Tuning Structures



- Individual target(s) (not the composite PTV_total): lower = 100% of the target to receive 102% of prescription, no upper constraint
- **Inner control max dose** = 98% of prescription dose
- **Middle control max dose** = 50% of prescription
- **Outer control max dose** = 40% of prescription

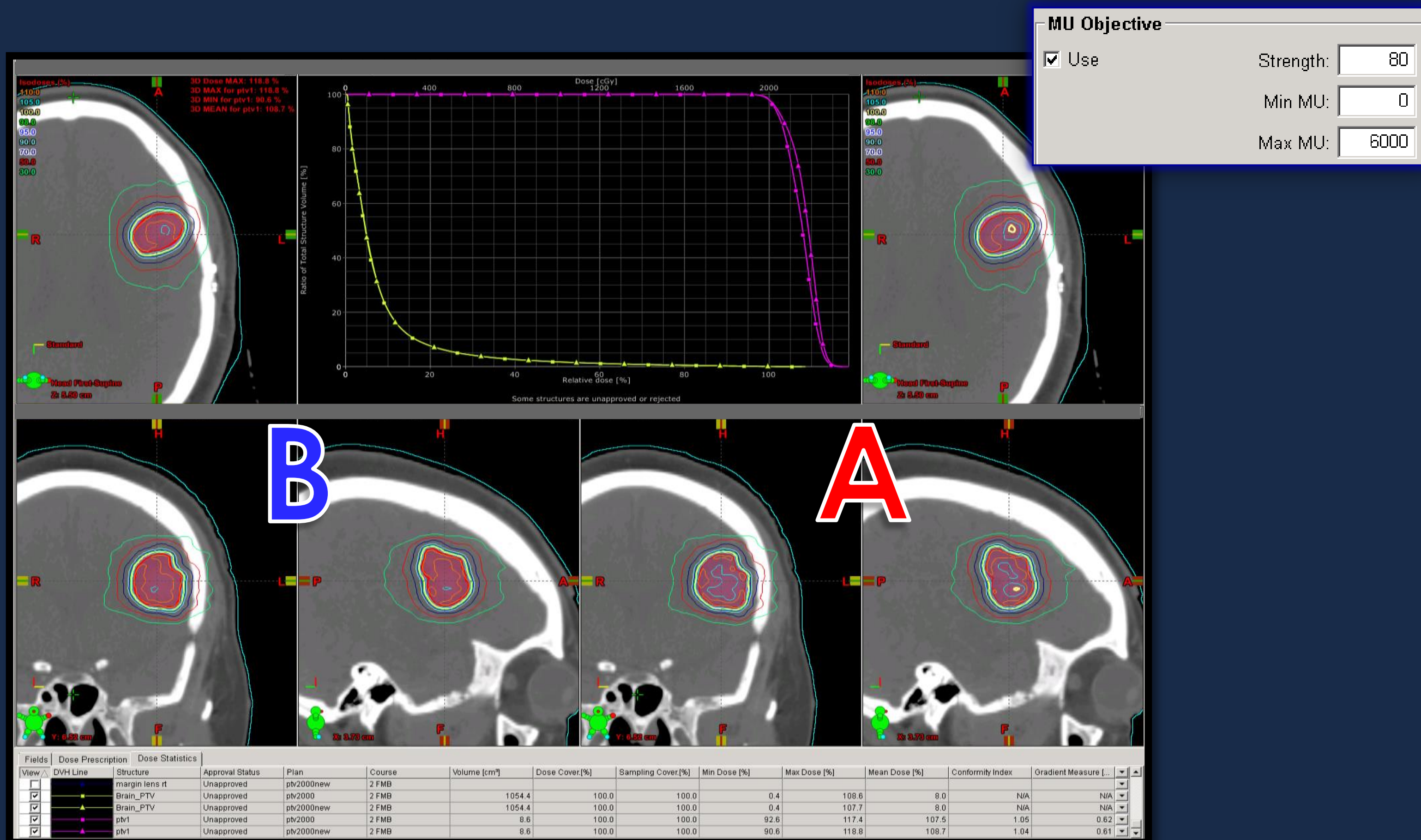
Table 3 Dosimetric indices (15 patients with 1-5 targets)

Patient	Target(s)	Target volume (cm^3)	Conformity index	Homogeneity index	Gradient index [a]
Mean		13.17	1.12	1.44	3.34
Standard deviation		13.81	0.13	0.11	0.42
Range		0.43-44.68	0.99-1.49	1.19-1.65	2.53-4.13

[a] Gradient index (GI) is calculated on per-plan basis, with GI = volume of 50% isodose line divided by the volume of the 100% isodose line.

G. Clark et al., Practical Radiation Oncology (2012) 2, 306–313

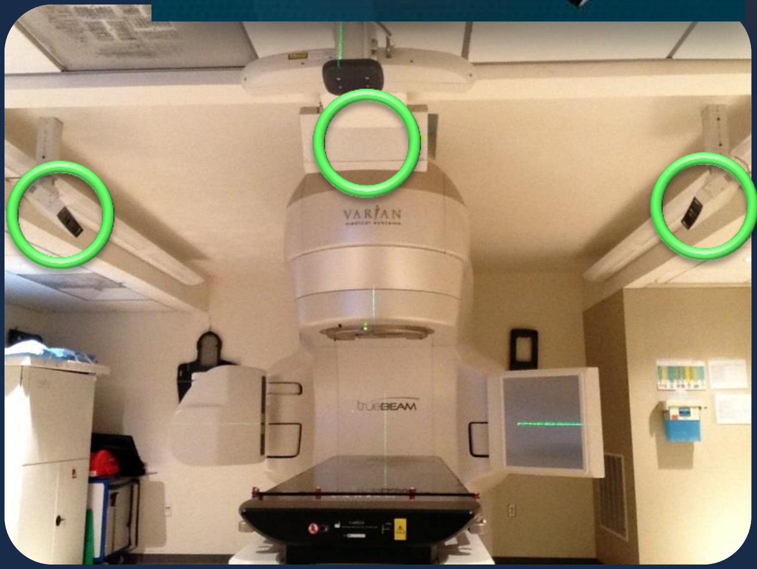
Plan optimization – MU



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

Surface Imaging System

- **Stereo photogrammetry**
  - 3 cameras & visible light projector
  - Reference image
    - Contours from DICOMRT
    - Previous captured image
- **Registration algorithm**
  - Minimize distance between reference image & real-time surface
  - Rotations & translations



Clinical Work Flow

CT Simulation	
Patient Simulation	Create mask & head cushion

↓

Planning	
Plan and isocenter	Create body contour

↓

Surface image registration	
Importing plan & body str.	Select ROI

↓

Initial setup	
Manual head adjuster	Start from bridge of nose

↓

Capturing new-reference Image	
CBCT image registration	Capture new reference

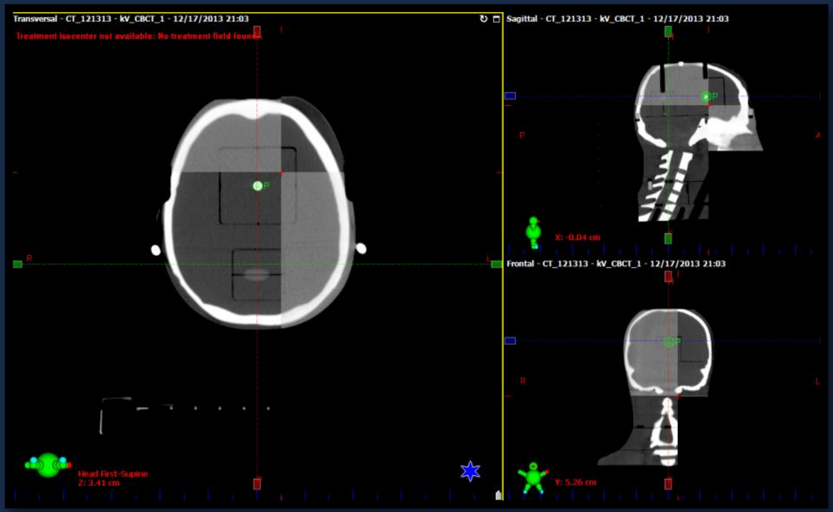
↓

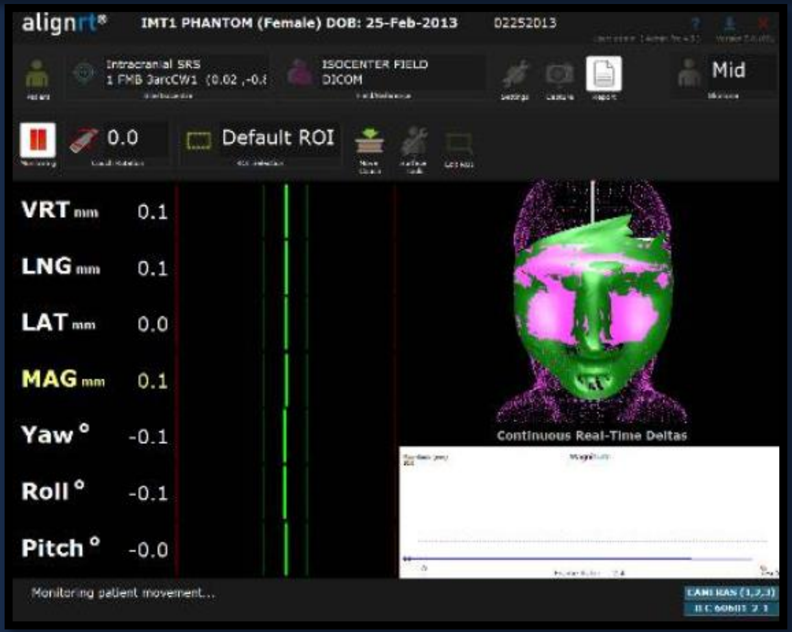
Treatment	
Monitoring	Adjust if needed

Patient Setup

Capture New Reference

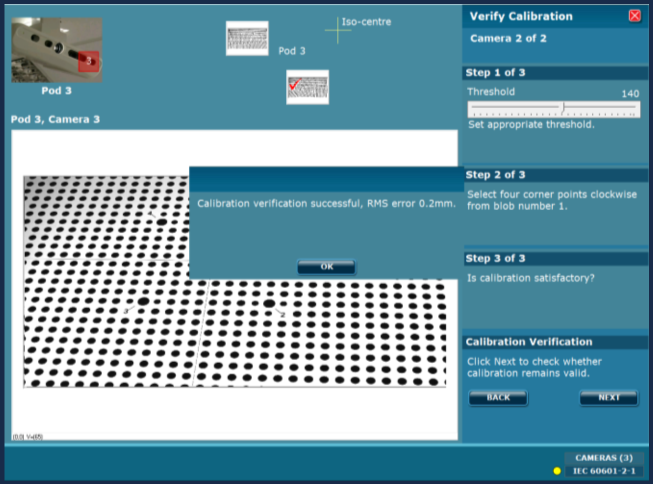
- kV/kV match to check for rotations (e.g., pitch)
- CBCT-indicated shifts are used to put patient in their final Tx position
- New reference image is captured with AlignRT (zero offsets)
- Monitor patient's position during treatment
- Discontinue treatment and reposition if offsets exceed ~1 mm
- Couch angle changed in AlignRT for beams utilizing couch rotations





Quality Assurance

- **Daily QA**
  Cal. verification



- **Monthly QA**
  Camera calibation

- **Isocenter Cal.**
  Allows AlignRT isocenter to be calibrated to MV isocenter

Clinical Results

- 44 patients
  - 115 intracranial metastatic lesions
- Median follow-up of 4.7 months
  - 1 year actuarial local control rate was 84%
    - 95% confidence interval: 69-99%

RESEARCH—HUMAN—CLINICAL STUDIES

Pan et al., Neurosurgery, pp. 844-852, October 2012

Frameless, Real-Time, Surface Imaging-Guided Radiosurgery: Clinical Outcomes for Brain Metastases

Clinical Results

Comparison of local control & survival for retrospective studies of brain metastases treated with radiosurgery

Treatment System	Pts (n)	Actuarial 1y LC* (%)	Actuarial 1y Survival (%)
Frame-based linac	80	89	33
Frame-based Gamma Knife	205	71	37††
Frameless linac	53	80	44
Frameless linac	65	76	40
Frameless, surface-imaging guided linac	**44**	**84**	**37**

*LC: local control; † -: not reported; ††estimated from Kaplan-Meier curve

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