SRT & SBRT Physical point of view

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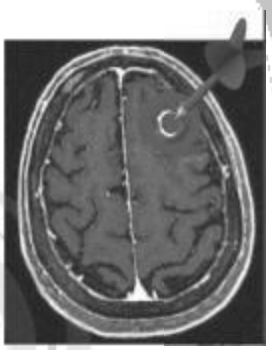
Medical Physicist

SRT

- Most widely used focal treatment modality for patients with brain metastases
- Non-invasive
- Does not require general anesthesia

Stereotactic RT



Treatment in stereotactic conditions
-precision <1mm

Why this precision?

-high (or very high) dose, very few fraction (12 to 9 Gy in 1.5 fraction vs 2Gy/fraction !)
Very small size of treated zone (2-3cc vs 20-30cc)

Dedicated system for treatment planning and delivery to targets
Accurate targeting to reproduce planned dose
Patient immobilization technique to maintain this accuracy

IMRT/VMAT OR SRT

Technique	IMRT/VMAT	SRT
Beams / arcs	Beams or arcs modulated in fluence coming from multiple directions	High number of small beam sized or arcs ± non coplanar ± isocentric
Conformity	Good conformity Complex volumes or with concavity, Sane tissue sparing	High conformity High isodoses + intermediate and low
Homogeneity in target, effect recherché	Homogeneous dose distributions	Non homogeneous dose distributions - Many isocenters with overlapping - to increase dose decrease outside PTV or to increase mean dose in target

- Combination of IMRT and SRT possible
- Heterogeneity of dose or homogeneity of dose in SRT : clinical debate
- Homogeneous dose distributions or not : impact on prescription (and dose reporting)

Some dedicated stereotactic RT systems

	Mechanical accuracy	Accuracy on overall treatment
Gamma Knife	0.30 mm	0.93 mm
Dedicated Linac	0.31 mm	0.50 - 1.5 mm
Cyberknife	0.50 mm	0.85 mm

Tomotherapy SRT

Tomotherapy has shown potential as a precision stereotactic radiosurgery delivery system

*The on-board MVCT can be used for stereotactic localization

*System is capable of sub-millimeter delivery accuracy

if

used in conjunction with a precise intracranial stereotactic patient positioning system

*Tomotherapy produces conformal plans for small targets

Tomotherapy SRT

Delivery is non-isocentric

it could potentially provide an efficiency advantage in the case of multiple intracranial targets large

Simulation Imaging and Treatment Planning

Simulation imaging

Patient-specific tumor-motion determination and respiratory motion management

Treatment planning

Imaging artifacts

Dose heterogeneity

Gradient and fall-off

Beam geometry

Calculation grid size

Normal tissue dose tolerance

Patient positioning, Immobilization

PARDISNOOR

SBRT CT Scan Protocol

Treatment site	Lung	Spine	Body	Abdomen	Pelvic
Setup position	Supine	Supine	Supine	Supine	Supine
Hand position	using arm rest/grip	using arm rest/hand grip	using arm rest/hand grip	using arm rest/hand grip	using arm rest/hand grip
SBRT Plate	Yes	Yes	Yes	Yes	Yes
Using knee rest	Yes	Yes	Yes	Yes	Yes
Using feet rest	Yes	Yes	Yes	Yes	Yes*
MRI Gated 3-4mm	Yes	No	yes	yes	No
Using vacuum bag	No	Yes	Yes	Yes	No
Using Abdominal compression	Yes	Yes	Yes/No**	Yes/No**	No
CT Scan slice thickness	1mm	1mm	1mm	1mm	1mm
OAR table	Report	Report	Report	Report	Report
Preparation before treatment	No	fast for 5-6hr according to physician order	fast for 5-6hr according to physician order	fast for 5-6hr according to physician order & bowel and bladder preparation instruction	bowel and bladder preparation instruction

*Do not use if the patient does not feel comfortable

**Do two CT scans with and without abdominal compression

Planning important parameters

Hot spots within the target volumes

Sharp dose fall-off

Gradient of dose distribution outside the target should be ideally isotropic

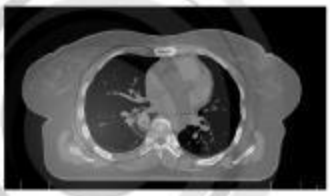
Resolution of beam shaping (leaf width)

The calculation grid resolution used in the TPS affects the accuracy of the dose distribution calculated

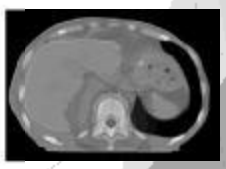
Grid size of 2 mm or finer

For SRS/SRT of a single brain metastasis away from any OAR 100% of the PTV should be covered by the prescription isodose

for lung SBRT only 95% PTV coverage might be safely reached



for spinal SBRT only 80–85% of the PTV can be covered by the prescribed isodose due to the constraints on the spinal cord.



Treatment plan reporting

- Prescription dose,
- Prescription ICRU reference point or dose/volume, isodose covering PTV to a particular percentage
- Number of treatment fractions
- Total treatment delivery period
- Target coverage,
- Plan conformity

example: Ratio of prescription isodose volume to PTV or a conformity index

- Dose falloff outside the target

example: Ratio of the volume of the 50% of prescription isodose curve to PTV

- Heterogeneity indexe

the ratio of highest dose received by 5% of PTV to lowest dose received by 95%of PTV

- Notable areas of high or low dose outside of the PTV and
- Dose to organs at risk

dose to 1% and 5% volumes and mean doses

ICRU91

Dose conformity CI is given by the volume encompassed by the isodose hyper surface with the prescribed dose (prescription isodose volume, PIV)
the volume of the target (PTV)
the volume of the target receiving the prescribed dose or more (PTV_{PIV}).

$$CI = \frac{PTV \times PIV}{PTV_{PIV}^2}$$

Paddick's CI

The dose-gradient GI given by the volume encompassed by the isodose hypersurface with half the prescribed dose (PIV_{half})
the volume encompassed by the isodose hypersurface with the prescribed dose (PIV):

$$GI = \frac{PIV_{half}}{PIV}$$

ICRU83

Conformity Index

V_{tv} is the treated volume defined as the volume included in the 95% isodose, V_{PTV} is the volume of PTV and $V_{PTV,95\%}$ is the Volume of PTV included in 95% isodose

$$CI = \frac{V_{tv} x V_{PTV}}{V_{PTV,95\%}^2}$$

Homogeneity Index
Maximum (Dmax) and Prescription (Dp) dose in PTV

$$HI = \frac{D_{max}}{D_p}$$

Gradient Score Index

$$GSI = 100 - \{100 \times [R_{50\%} - R_{95\%} - 0.3]\}$$

PNOC SRT treatment results

Field width	1cm
Jaw mode	fixed
Modulation Factor	1.5-2.5
Pitch	0.13-0.210
Dose rate	8.7 Gy/min

23-30 Gy 3-5 fr

Number of Targets	PTV Length	Estimated Gantry Period (s)	Active rotation	Time(s)	CI	HI	PD	Fraction
11	5-20mm	19.1	79.6	1523	1.34	1.1	27	3
1	15mm	15.8	19.6	310.1	1.58	1.29	30	5
4	7-11mm	18.8	76.5	1438	1.41	1.24	27	3
1	28mm	24	14.7	352	1.23	1.13	28	5
1	27mm	33.6	16.7	580	1.09	1.27	27	3
4	6-14mm	24.6	33	812.8	1.32	1.25	27	3
7	11-36mm	24.5	60	1492	1.25	1.27	30	5
2	6-8mm	52	8.7	454.7	1.58	1.15	23	3
2	5-7mm	22.4	15.2	341.7	1.45	1.06	23	3
1	23mm	21.4	24.3	519.5	1.29	1.21	27	3
15	5-12mm	26.4	57.6	1520	1.75	1.18	21	3

Mean CI:1.388 Mean HI:1.195

Table II. *Dosimetric index comparison.*

PTV Vol [cc] (Mean)	Conformity Index (Mean)	Homogeneity Index (Mean)	Gradient Score (Mean)	Reference Index
6.2±5.7	1.36±0.17	1.04±0.02	50±20	Barra *et al.* (16)
14.9±12.4	1.26±0.10	1.18±0.09	43±14	Han *et al.* (20)

PTV, Planning Target Volume.

Tomotherapy vs Linac (SRT&SBRT dosimetry)

An appropriate dosimeter with a spatial resolution of approximately 1 mm or better

- relative output factor
- tissue-phantom ratio
- Off axis ratios

Detector should be less than half the FWHM of the smallest beam measured in

Linac SBRT tests

dose-calculation algorithms
MLC leaf sequencing
MU calculation algorithms
leaf speed
machine dose rates used for SBRT
accuracy of calibration at these dose rates
Delivery precision at small MUs
patient positioning and localization

Tomotherapy quality assurance SRT and SBRT

Frequency	Test	Tolerance
daily	Red laser initialization (congruence with green laser)	1mm
	Image/laser coordinate coincidence	1mm
	Image registration/alignment	1mm
	Accelerator output constancy (rotational or static)	±3%
monthly	Transverse beam profile	1% average difference in field core
	Longitudinal beam profile (each slice width)	1% of slice width FWHM
	Output constancy and rotational output variation	±2%
	beam quality constancy	±1%PDD 10 or TPR20/10
	red and green laser alignment	1mm
	couch positioning accuracy	1mm
	MVCT dimensional accuracy	1mm
Annual	couch speed uniformity	±2% dose non uniformity
	couch translation per gantry rotation	1mm per 5cm
	Accelerator output	±1.0%
	beam quality	±1% PDD or TPR20/10
	verification of small field beam data	±2% from baseline for >1 cm apertures, ±5% from baseline for <1cm apertures
	MVCT imaging- treatment -laser coordinate coincidence	1mm
	E2E localization assessment	1mm
	E2E dosimetric evaluation	±5% measured vs. calculated

Quality Assurance: End to End (Lucy)

The Lucy Phantom is a **multipurpose phantom for clinical medical physicists.**

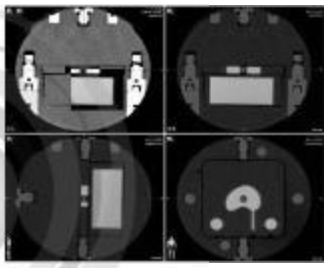
Not only is Lucy a very important tool for Stereotactic Radiosurgery but it is also ideal for CT and MRI QA work

Quality Assurance: End to End (Lucy)

	Right cylinder	Left cylinder	Central shape
Reference (manufacturer)	0.89 cc	0.89 cc	5.25 cc
CT	0.93 cc	0.93 cc	5.22 cc
MRI T1	0.92 cc	0.93 cc	5.30 cc

Agreement of volume between CT and MRI :quantitative method

Agreement volume between CT and MRI



Insert N°	Material	Mass density (reference) (g/cm³)	Relative electron density	HU (TPS)	Mass density (TPS)	Electron density (TPS)
1	Adipose	0.94	0.928	91	0.94	0.928
2	Trabecular bone	1.20	1.156	256	1.167	1.124
3	Cortical bone	1.91	1.782	1440	1.867	1.734
4	Air	-	-	987	0.9068	0.0132

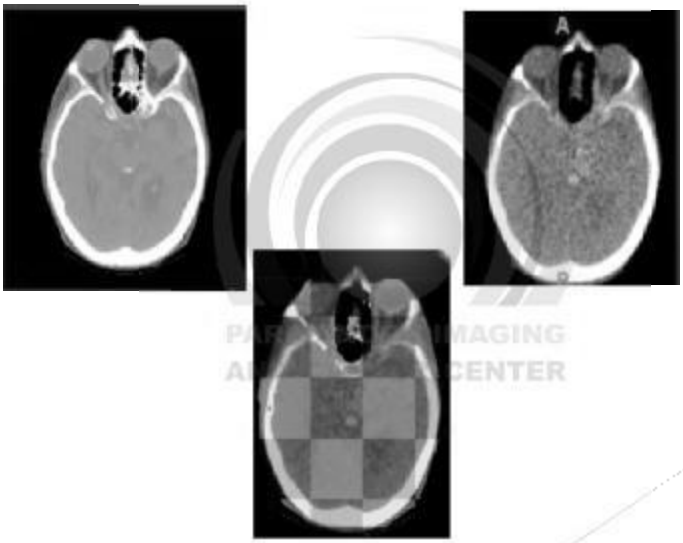
Verification of electronic density

Supplier and model types

	Sun Nuclear	PTW	PTW	PTW	IBA	Sun Nuclear	ScandiDos
	MapCheck 2	Octavius II	Octavius 1000 SRS	Octavius 4D	MatriXX	ArcCHECK	Delta4
Array		Seven29	1000SRS	Seven29 1000SRS			
Resolution (mm)	7.1	10	2.5-5	10/2.5-5	7.6	1.0	5-10
Detector	Diode	IC	Liquid IC		IC	Diode	Diode
Application	IMRT, Arc, FFF	IMRT, Arc, FFF	SRS/SBRT, IMRT, Arc, FFF	IMRT, Arc, FFF	IMRT, FFF*, Arc with MultiCube	IMRT, Arc, FFF, SRS/SBRT	IMRT, Arc, FFF
2D/3D	2D	2D	3D	2D and 3D	2D and 3D	2D and 3D	2D and 3D

Image Guided Patient Setup

Image Guided Stereotactic TomoTherapy



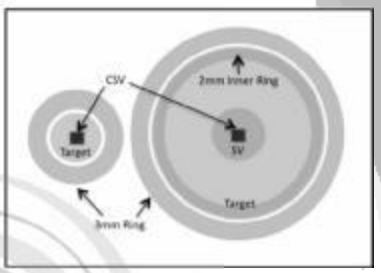
How Large can Tomo Treat?

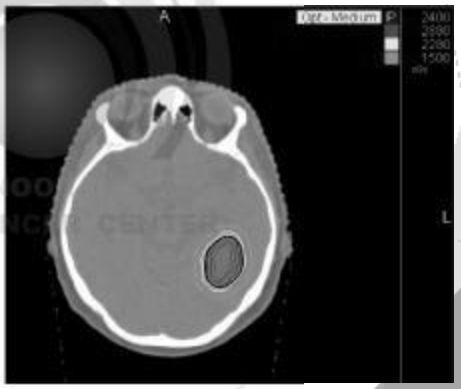
Small target

Large target

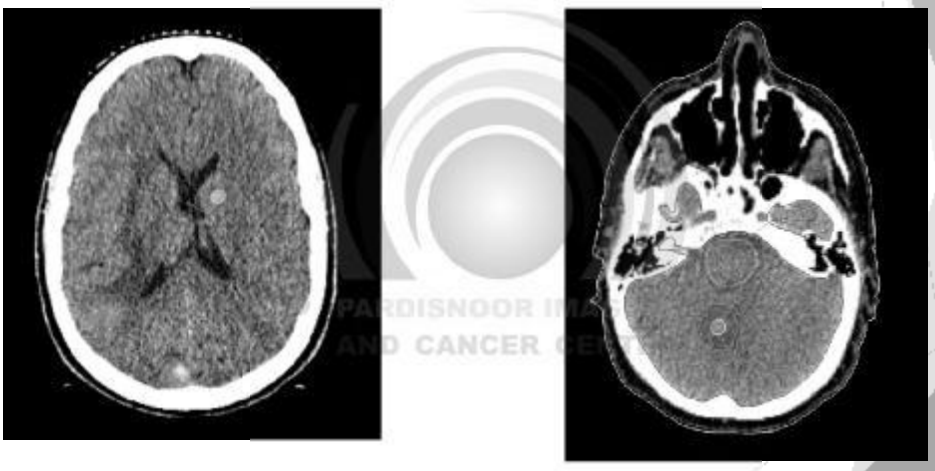
Examples of added contours for treatment planning

PD: 24Gy/3 fr





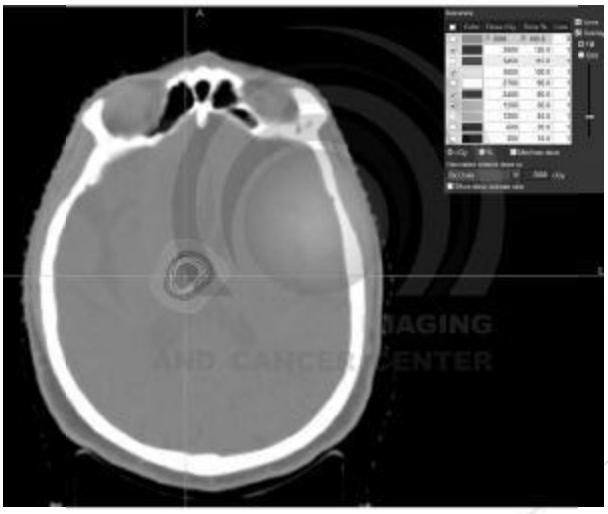
Example of brain met single and multi target



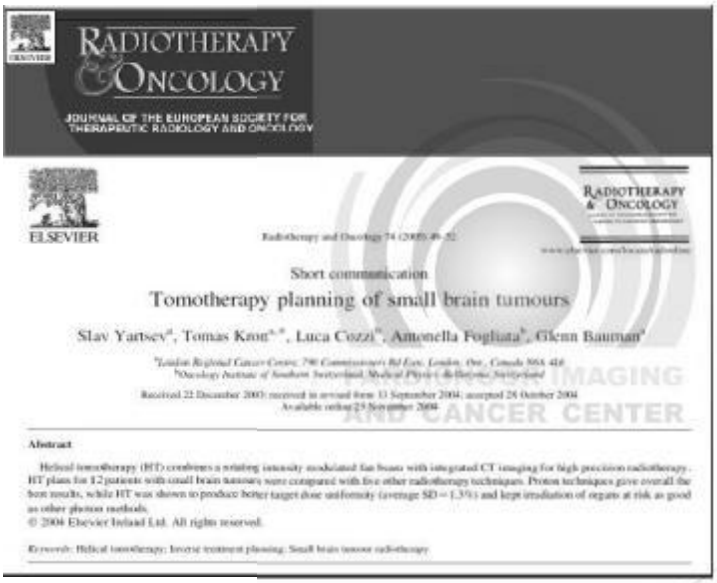
Brain met

Single target

PD: 30 Gy/5 Fr



Mean Dose to Normal Brain



RADIOTHERAPY & ONCOLOGY

JOURNAL OF THE EUROPEAN SOCIETY FOR THERAPEUTIC RADIOLOGY AND ONCOLOGY

ELSEVIER

Short communication

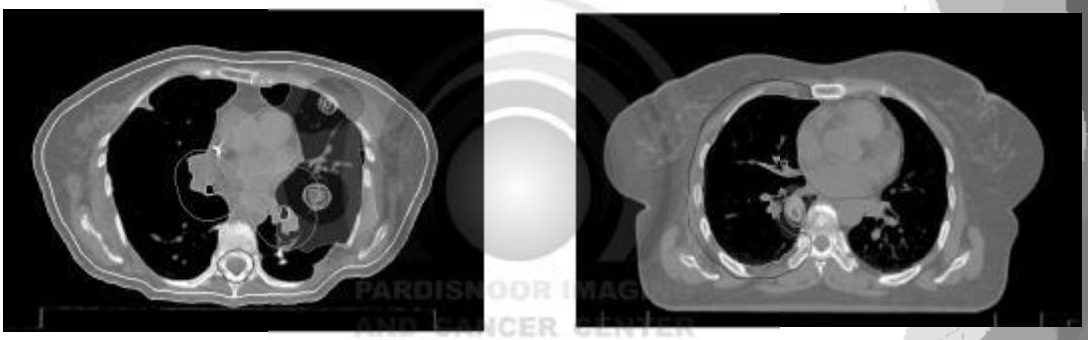
Tomotherapy planning of small brain tumours

Slav Yartsev[a], Tomas Kron[a,*], Luca Cozzi[b], Antonella Fogliata[b], Glenn Bauman[a]

Abstract

Helical tomotherapy (HT) combines a rotating intensity modulated fan beam with integrated CT imaging for high precision radiotherapy. HT plans for 12 patients with small brain tumours were compared with five other radiotherapy techniques. Proton techniques give overall the best results, while HT was shown to produce better target dose uniformity (average SD = 1.3%) and kept irradiation of organs at risk as good as other photon methods.

Lung SBRT



Tomo and IMAT Comparison for Lung SBRT

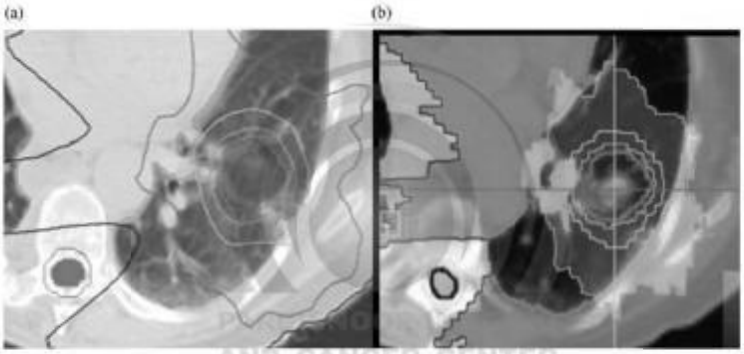
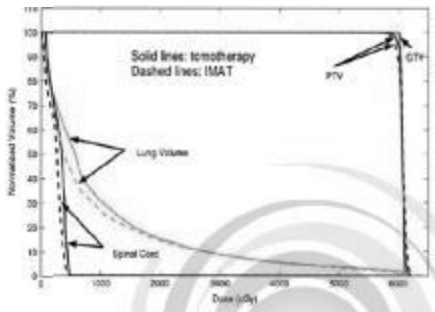


Fig. 1. Comparison of two-dimensional dose distribution for (a) intensity-modulated arc therapy and (b) tomotherapy plans for lung case (Case 1). Same slice and isodose levels plotted in both.

IMAT with 4 arcs



IMAT mean lung Dose of 929

IMAT max cord Dose of 470 cGy

IMAT mean cord Dose of 225 cGy

Revised Helical Tomotherapy

Lower Lung Dose

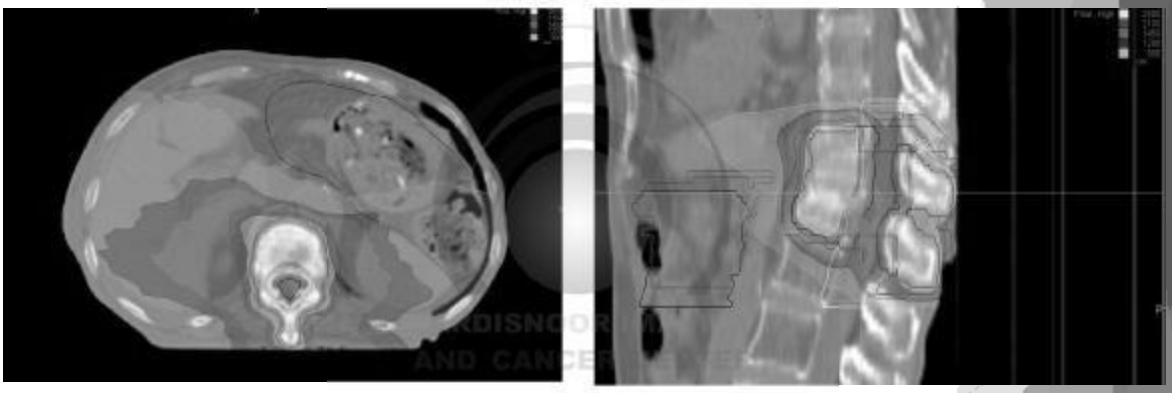
Lower Cord Dose

Tomo mean Lung Dose of 765 cGy

Tomo max cord Dose of 195 cGy

Tomo mean cord Dose of 82cGy

Pancreatic Ca, bone met:T12
PD: 30Gy/5 fr



Dose constraint (example)

		One fraction		Three fractions		Five fractions		
Serial tissue	Max critical volume above threshold	Threshold dose (Gy)	Max point dose (Gy)[a]	Threshold dose (Gy)	Max point dose (Gy)[a]	Threshold dose (Gy)	Max point dose (Gy)[a]	End point (>Grade1)
Optic pathway	<0.2 cc	8	10	15.3 (5.1 Gy/fx)	17.4 (5.8 Gy/fx)	23 (4.6 Gy/fx)	25 (5 Gy/fx)	Neuritis
Cochlea			9		17.1 (5.7 Gy/fx)		25 (5 Gy/fx)	Hearing loss
Brainstem (not medulla)	<0.1 cc	10	12	18 (6 Gy/fx)	25.5 (8.5 Gy/fx)	23 (4.6 Gy/fx)	31 (6.2 Gy/fx)	Cranial neuropathy
Spinal cord and medulla	<0.35 cc <1.2 cc	10 7	14	18 (6 Gy/fx) 12.3 (4.1 Gy/fx)	21.9 (7.3 Gy/fx)	23 (4.6 Gy/fx) 14.5 (2.9 Gy/fx)	30 (6 Gy/fx)	Myelitis
Spinal cord subvolume C=4 mm above and below level treated per Ryu	<10% of subvolume	10	14	18 (6 Gy/fx)	21.9 (7.3 Gy/fx)	23 (4.6 Gy/fx)	30 (6 Gy/fx)	Myelitis
Cauda equina	<5 cc	14	16	21.9 (7.3 Gy/fx)	24 (8 Gy/fx)	30 (6 Gy/fx)	32 (6.4 Gy/fx)	Neuritis
Sacral plexus	<5 cc	14.4	18	22.5 (7.5 Gy/fx)	26.1 (8.7 Gy/fx)	30 (6 Gy/fx)	32 (6.4 Gy/fx)	Neuropathy
Esophagus[b]	<5 cc	11.9	13.4	17.7 (5.9 Gy/fx)	25.2 (8.4 Gy/fx)	19.5 (3.9 Gy/fx)	35 (7 Gy/fx)	Stenosis/fistula
Brachial plexus	<3 cc	17.5	23.4 (7.8 Gy/fx)	24 (8 Gy/fx)	27 (5.4 Gy/fx)	30.5 (6.1 Gy/fx)	Neuropathy
Heart/pericardium	<15 cc	16	22	24 (8 Gy/fx)	30 (10 Gy/fx)	32 (6.4 Gy/fx)	38 (7.6 Gy/fx)	Pericarditis
Great vessels	<10 cc	31	37	39 (13 Gy/fx)	45 (15 Gy/fx)	47 (9.4 Gy/fx)	55 (10.8 Gy/fx)	Aneurysm
Trachea and large bronchus[b]	<4 cc	10.5	20.2	15 (5 Gy/fx)	30 (10 Gy/fx)	16.5 (3.3 Gy/fx)	40 (8 Gy/fx)	Stenosis/fistula
Bronchus-smaller airways	<0.5 cc	12.4	13.3	18.9 (6.3 Gy/fx)	23.1 (7.7 Gy/fx)	23 (4.2 Gy/fx)	33 (6.6 Gy/fx)	Stenosis with atelectasis
Rib	<1 cc <30 cc	22	30	28.8 (9.6 Gy/fx) 30.0 (10.0 Gy/fx)	36.9 (12.3 Gy/fx)	35 (7 Gy/fx)	43 (8.6 Gy/fx)	Pain or fracture
Skin	<10 cc	25	26	30 (10 Gy/fx)	33 (11 Gy/fx)	36.5 (7.3 Gy/fx)	39.5 (7.9 Gy/fx)	Ulceration
Stomach	<10 cc	11.2	12.4	16.5 (5.5 Gy/fx)	22.2 (7.4 Gy/fx)	18 (3.6 Gy/fx)	32 (6.4 Gy/fx)	Ulceration/fistula
Duodenum[b]	<5 cc <10 cc	11.2 9	12.4	16.5 (5.5 Gy/fx) 17.4 (5.8 Gy/fx)	22.2 (7.4 Gy/fx)	18 (3.6 Gy/fx) 22.5 (2.5 Gy/fx)	32 (6.4 Gy/fx)	Ulceration
Jejunum/ileum[b]	<5 cc	11.9	15.4	17.7 (5.9 Gy/fx)	25.2 (8.4 Gy/fx)	19.5 (3.9 Gy/fx)	35 (7 Gy/fx)	Enteritis/ obstruction
Colon[b]	<20 cc	14.5	18.4	24 (8 Gy/fx)	28.2 (9.4 Gy/fx)	25 (5 Gy/fx)	38 (7.6 Gy/fx)	Colitis/fistula
Rectum[b]	<20 cc	14.5	18.4	24 (8 Gy/fx)	28.2 (9.4 Gy/fx)	25 (5 Gy/fx)	38 (7.6 Gy/fx)	Proctitis/fistula
Bladder wall	<15 cc	11.4	18.4	16.8 (5.6 Gy/fx)	28.2 (9.4 Gy/fx)	18.5 (3.65 Gy/fx)	38 (7.6 Gy/fx)	Cystitis/fistula
Penile bulb	<3 cc	14	34	21.9 (7.3 Gy/fx)	42 (14 Gy/fx)	30 (6 Gy/fx)	50 (10 Gy/fx)	Impotence
Femoral heads (right and left)	<10 cc	14		21.9 (7.3 Gy/fx)		30 (6 Gy/fx)		Necrosis
Retail lation/vascular trunk	<2/3 volume	10.5	18.8 (6.3 Gy/fx)			23 (4.6 Gy/fx)		Malignant hypertension

Dose constraint (example)

Serial tissue	Max critical volume above threshold	One fraction		Three fractions		Five fractions		End point (=Grade 1)
		Threshold dose (Gy)	Max point dose (Gy)*	Threshold dose (Gy)	Max point dose (Gy)*	Threshold dose (Gy)	Max point dose (Gy)*	
Parallel tissue	Minimum critical volume below threshold	One fraction Threshold dose (Gy)	Max point dose(Gy)*	Three fractions Threshold dose(Gy)	Max point dose(Gy)*	Five fractions Threshold dose(Gy)	Max point dose(Gy)*	End point (=Grade 3)
Lung (right and left)	1500 cc	7	NA-Parallel tissue	11.5 (2.9 Gy/fx)	NA-Parallel tissue	12.5 (2.5 Gy/fx)	NA-Parallel tissue	Basic lung function
Lung (right and left)	1000 cc	7.4	NA-Parallel tissue	12.4 (3.1 Gy/fx)	NA-Parallel tissue	13.5 (2.7 Gy/fx)	NA-Parallel tissue	Pneumonitis
Liver	700 cc	9.1	NA-Parallel tissue	19.2 (4.8 Gy/fx)	NA-Parallel tissue	21 (4.2 Gy/fx)	NA-Parallel tissue	Basic liver function
Renal cortex (right and left)	200 cc	8.4	NA-Parallel tissue	16 (4 Gy/fx)	NA-Parallel tissue	17.5 (3.5 Gy/fx)	NA-Parallel tissue	Basic renal function

Summary

Highly conformal treatment with fast dose gradient due to highly modulated, arc-based delivery
Designed to be a CT-guided solution to IMRT
SRT or Special Procedures.
Quality assurance is different but easy
Faster SRS especially for multiple metastases
Setup ideal
Compatible with industry-standard radiosurgery
Head rest for invasive or non-invasive immobilization
Cranial SRS or SRT and Body SRT typically as good or better than conventional technology.

Thank you