Spine SRS: LINAC

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Disclosures

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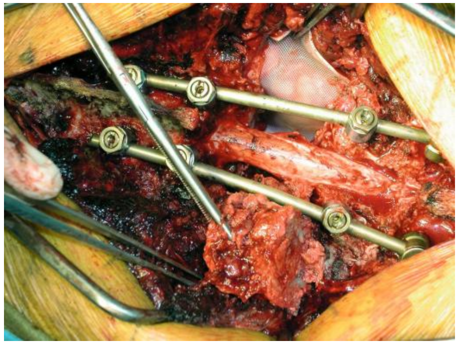
- Member of Multi-institutional international spine SRS research consortium supported by Elekta
- MGH has received research support from Raysearch

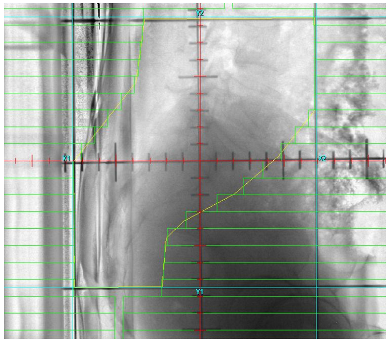
Overview

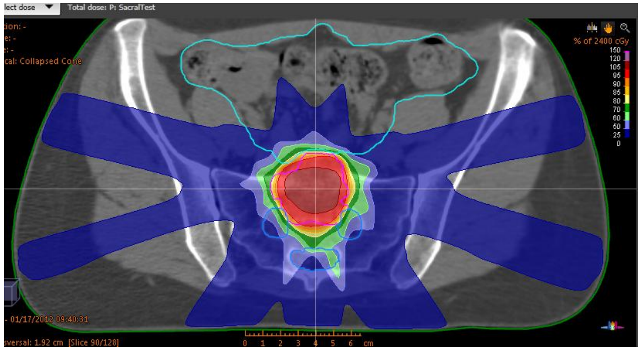
- Spine SRS: alternate treatment for mets
- Some primary lesions
  - Depends upon histology and geometry

Overview

- Several treatment options exist for spinal metastases:
  - Surgery: decompression, en bloc resection, stabilization, minimally invasive
  - Augmentation: vertebroplasty or kyphoplasty
  - Radiation therapy: conventional or stereotactic radiosurgery







Spine metastases

- About 40% of cancer patients develop vertebral metastases: serious consequences pain, paralysis, quality of life
- Palliative low-dose radiotherapy is well established evidence-based treatment
- Limited long-term efficacy of conventional palliative RT

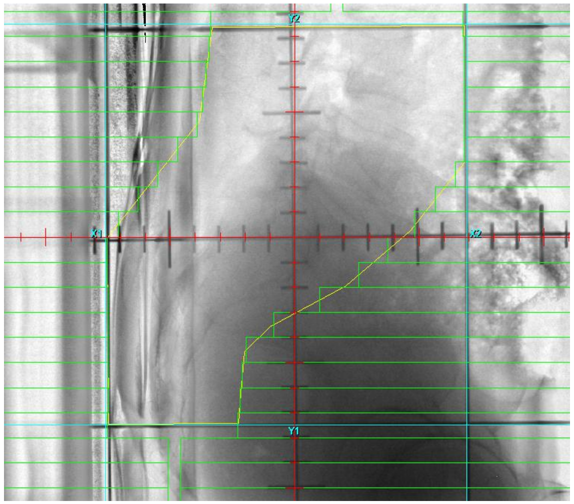
- **Dose-intensified spine radiosurgery / SBRT**
- Practiced by 44% of US Radiation Oncologists (*Pan Cancer 2011*)
- Quicker and more durable pain relief and local tumor control

Overview

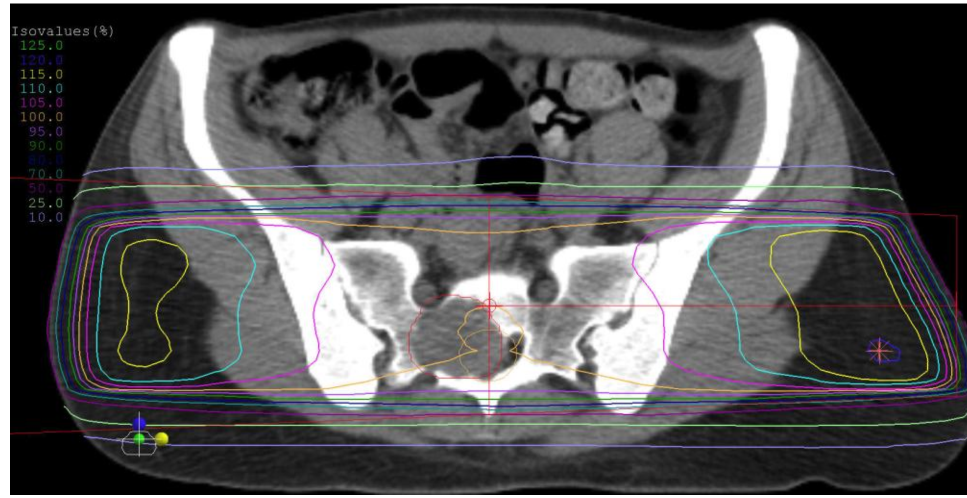
- Shift the paradigm for treating spinal metastases
- Focus on minimizing morbidity of spine care in order to:
  - Improve pain control and quality of life
  - Maximize opportunities for systemic therapy
  - Retain durable local control
- Use of intensity modulated treatment modalities to increase dose to GTV/CTV/PTV while avoiding dose to critical structures: cord, cauda, esophagus

Evolution of Radiation Techniques

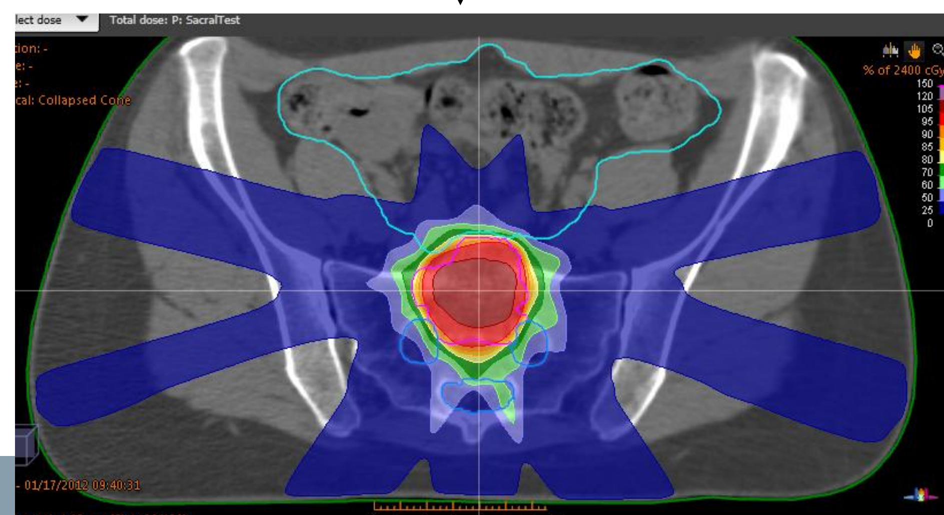
2-dimensional



3-dimensional



IMRT



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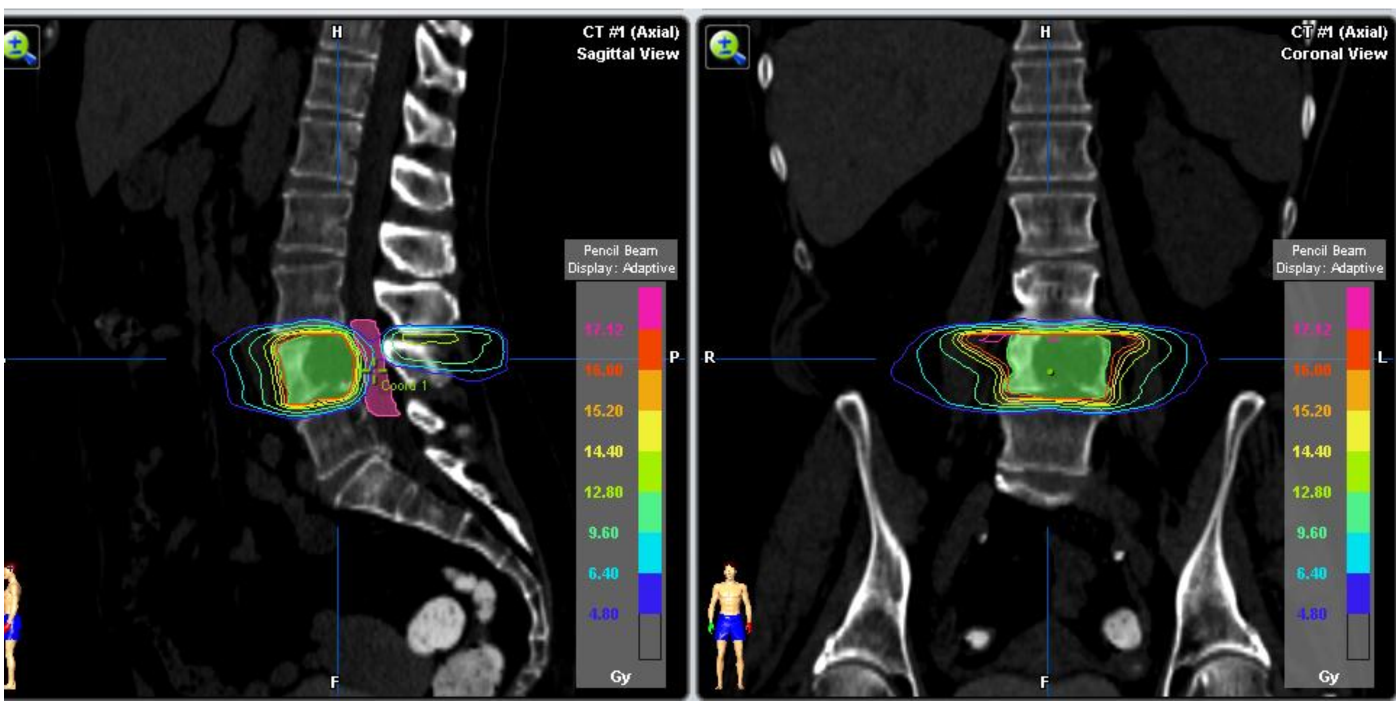
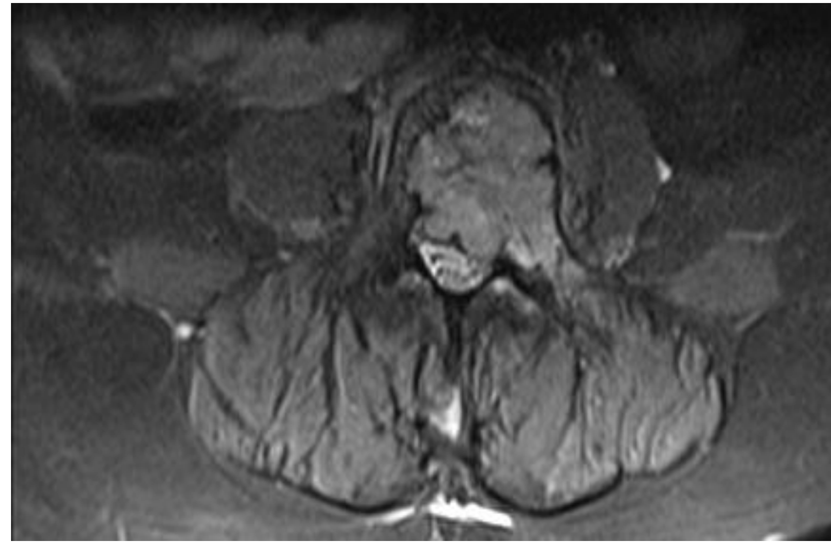
Stereotactic Body Radiation Therapy
"Spine Radiosurgery"

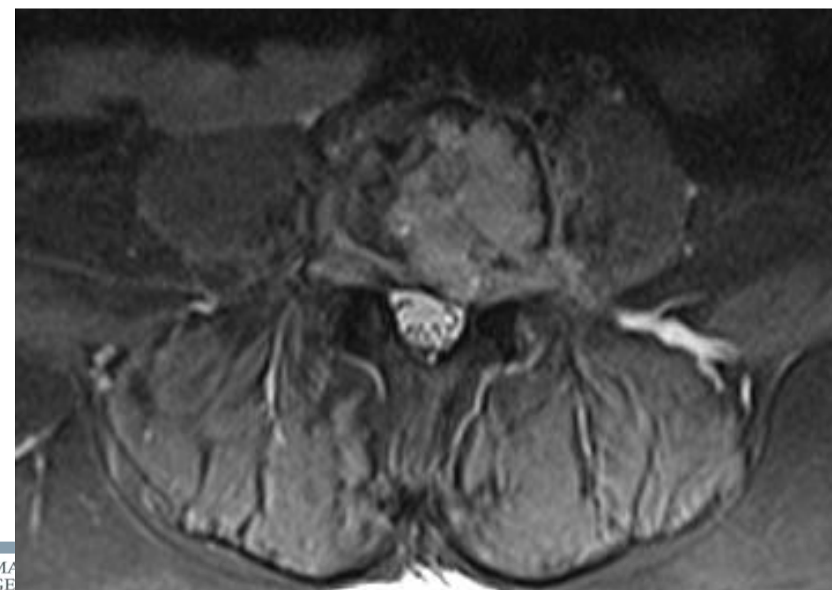
- SRS: Delivery of a high radiation dose (18-24 Gy) in a single fraction with high precision
- SBRT: fractionation of ablative doses (2-5 fractions)



Case #1: Solitary and radioresistant metastasis

68 yo with metastatic RCC and solitary L4 metastasis causing back and left leg pain





T1 STIR

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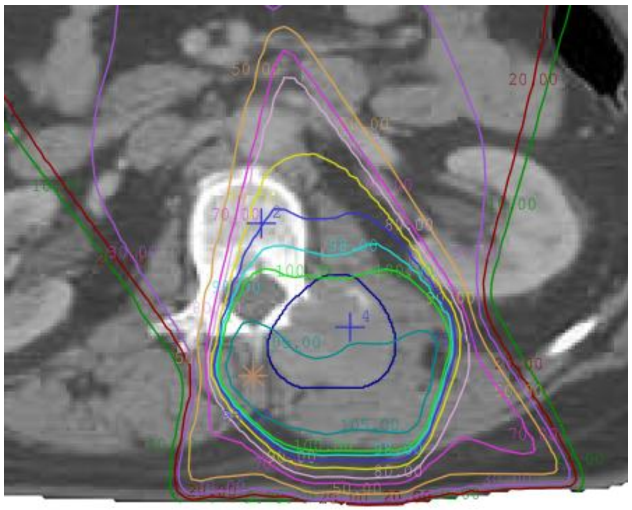
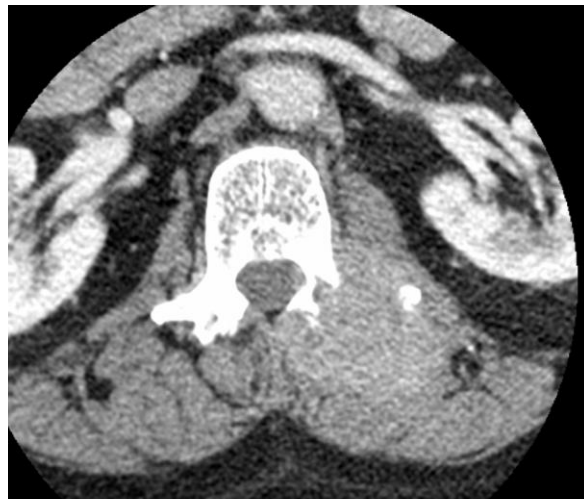
Case #2: Retreatment after progression

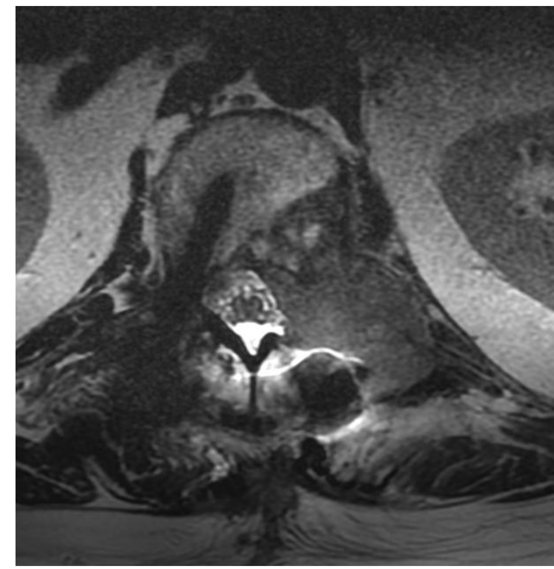
60 yo man with metastatic HCC and painful L1 metastasis, treated with 3 Gy x 10 in 6/2011.
In 1/2012, progressed with new LLE numbness.
Underwent partial corpectomy + instrumentation + fusion



6/2011
3 Gy x 10



1/2012
Clinical and radiographic progression



6/2012
5 months after resection

↓

???

Spine SRS

- Does it work?
- Several studies
- Multi-Institutional Results

Stereotactic Body Radiation Therapy: Outcomes

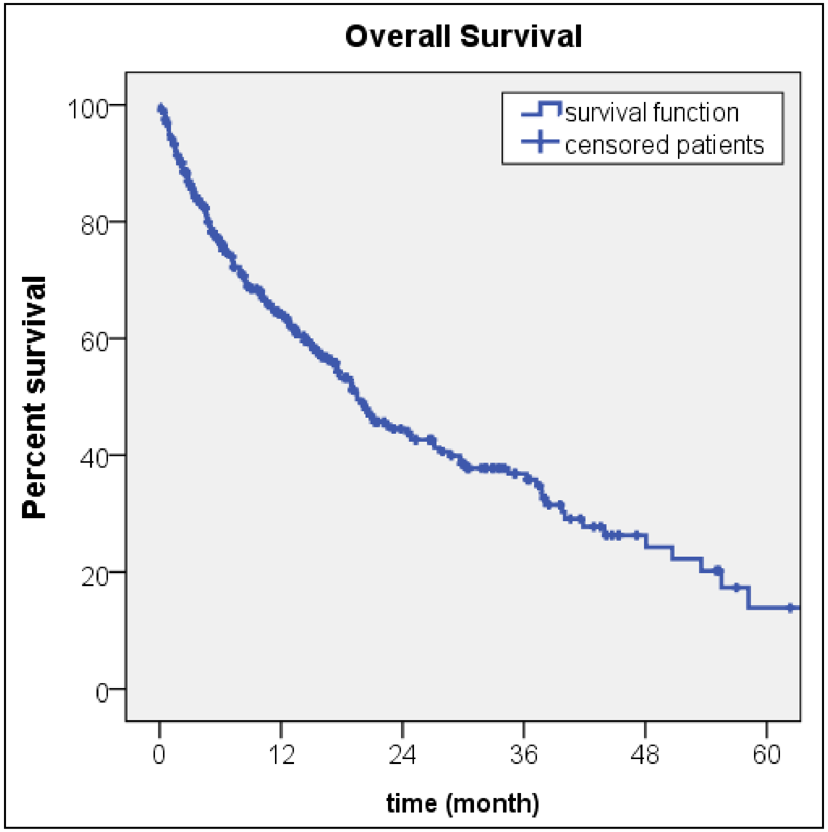
Study	Year	N (tumors)	Fractionation (median)	Are salvage RT	pain relief	local control
HFH Detroit	2005	61	10-16 Gy x 1	0%	85%	93%
U Pitt	2007	500	20 Gy x 1	69%	86%	88%
MDACC	2007	74	6 Gy x 5 or 9 Gy x 3	56%	NR	77%
MSKCC	2008	103	24 Gy x1	0%	NR	90%
PMH	2009	60	8 Gy x 3	62%	67%	85%
Taiwan	2009	127	7.75 Gy x 2	22%	88%	97%

Histology	N (tumors)	dose	pain relief	local control
Breast	83	20 Gy x 1	96%	100%
Lung	80	20 Gy x 1	93%	100%
Renal cell	93	20 Gy x 1	94%	87%
Melanoma	38	20 Gy x 1	96%	75%

median follow-up = 21 months

from Gerszten et al. Spine 2007;32: 193-9

Overall survival



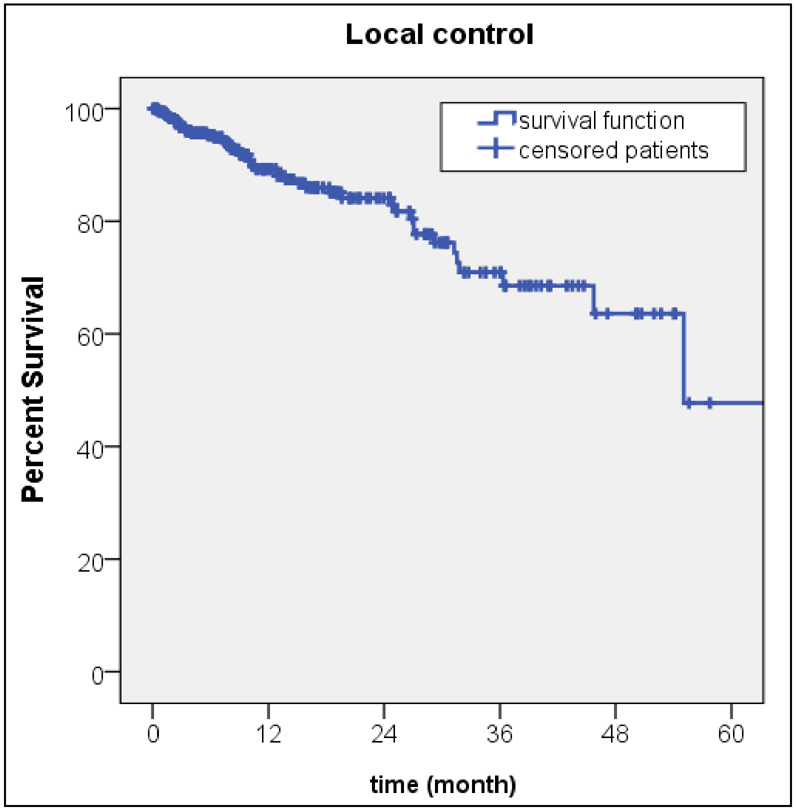
Median FU: 12 mo

Multivariate Analysis:

Influence parameter	p-value	HR (CI)
Sex (male)	0.010	0.60
Performance Status (< 90)	0.001	0.52
Visceral Metastases (no)	0.013	1.79
Controlled systemic disease (no)	0.026	0.53

Performance status and metastatic disease for selection of patients with long OS expectancy

Imaging verified local tumor control



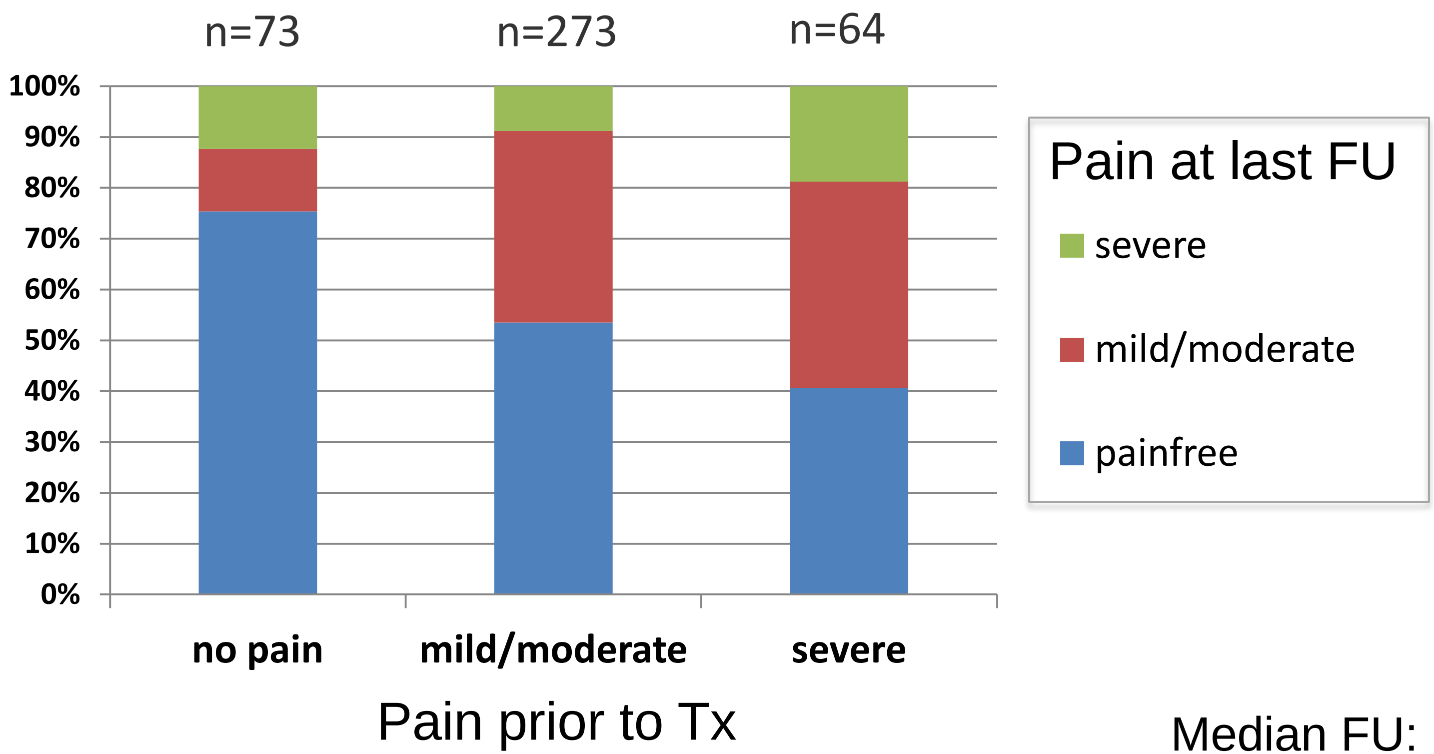
Median FU: 9.5 mo

Multivariate Analysis:

Influence parameter	p-value	HR (CI)
Interval PD to SBRT: ≤ 29.9 months	0.017	0.40
Histology: Other, NSCLS, Kidney, Melanoma	0.005	0.21

Number of Tx fractions, prescribed dose, EQD2/10 and Bilsky Score **not** correlated local tumor control

Pain control assessed at last clinical follow-up



Median FU: 11.0 months

- Long term pain control
- High rates of complete pain response

Toxicity

Acute toxicity

	Dermatitis	Dysphagia	Pain
Tox assessment	322	324	348
G0	307	290	290
G1	15	31	35
G2	0	3	20
G3	0	0	3

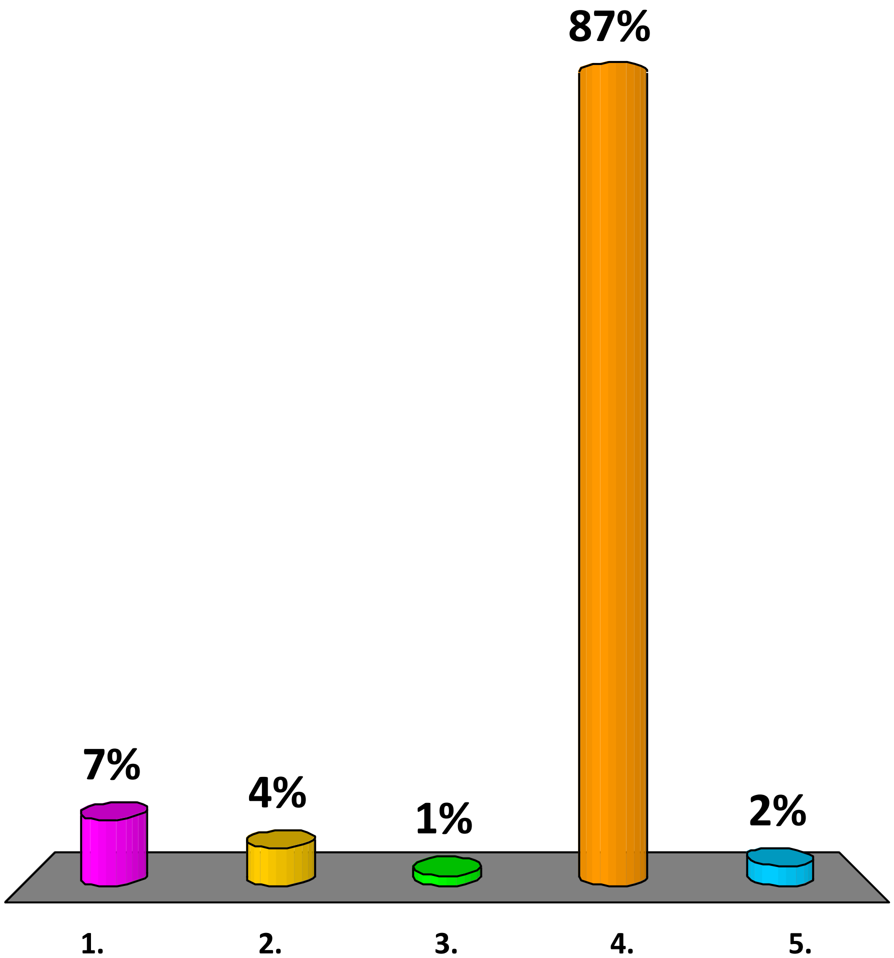
Fracture

	New fracture	Progressive fracture
Tox assessment	403	400
Positive	17 (4.2%)	21 (5.3%)

- Low rates and low grade acute toxicity
- 10% fracture rate, but 50% progressive fracture
- No case of radiation induced myelopathy

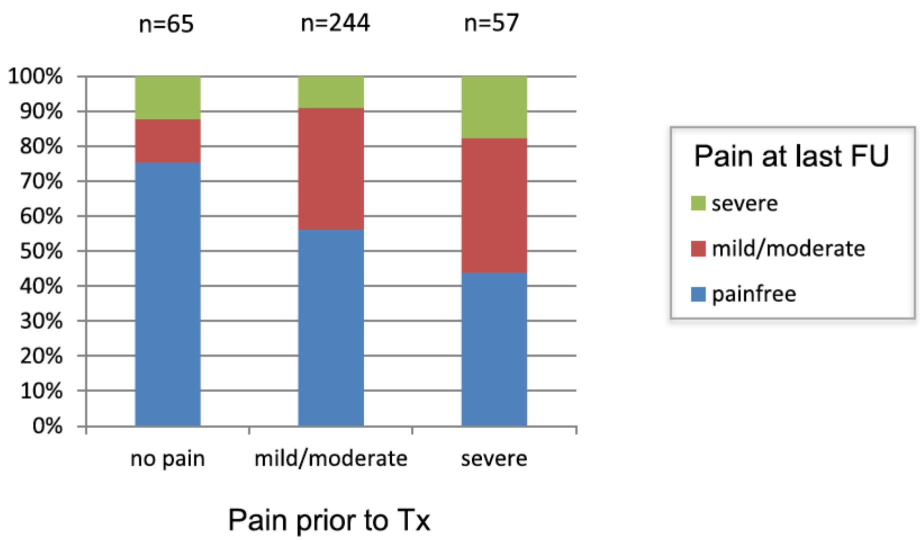
What are the primary aims of spine SRS/SBRT for vertebral metastases?

1. Pain Reduction
2. Local Control
3. Curative
4. 1 and 2
5. 2 and 3



Answer

- 1 and 2
- “maximize pain control and local control for the long term”
- Guckenberger et al. Radiation Oncology 2014, 9:226



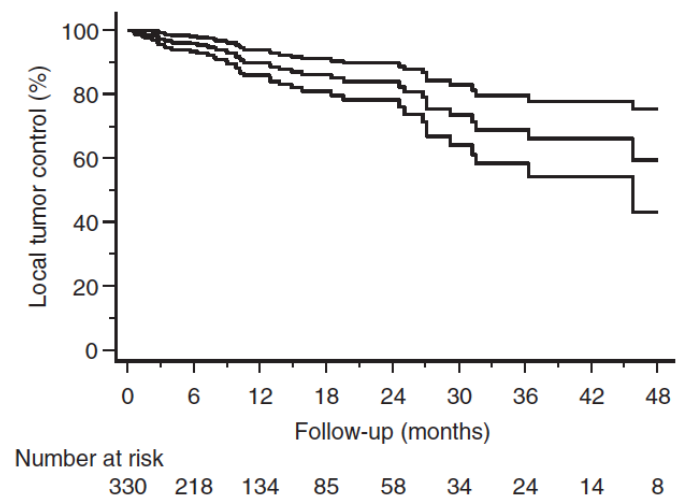
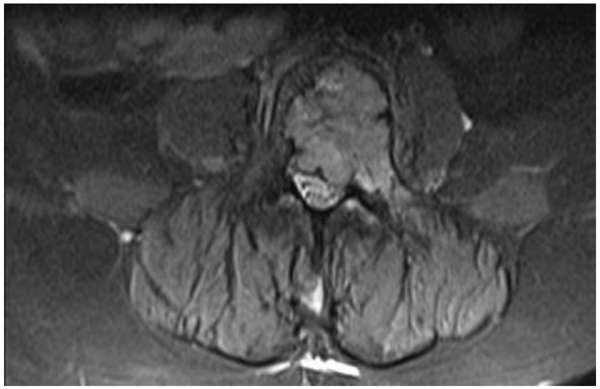


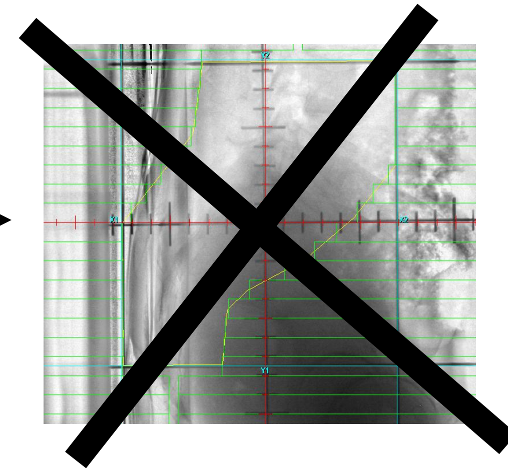
Figure 4 **Local tumor control analyzed per treated lesion: Kaplan Meier Curve with 95% confidence interval.**

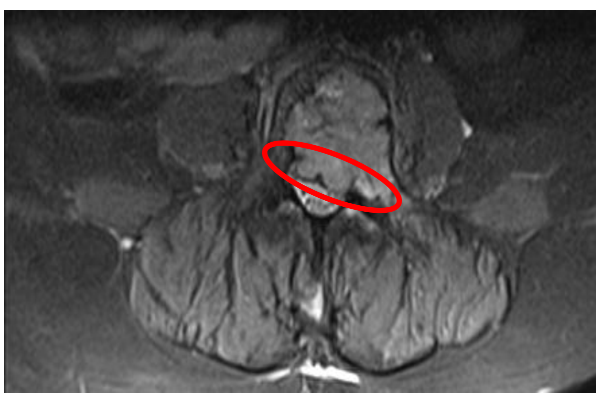
Spine Radiosurgery

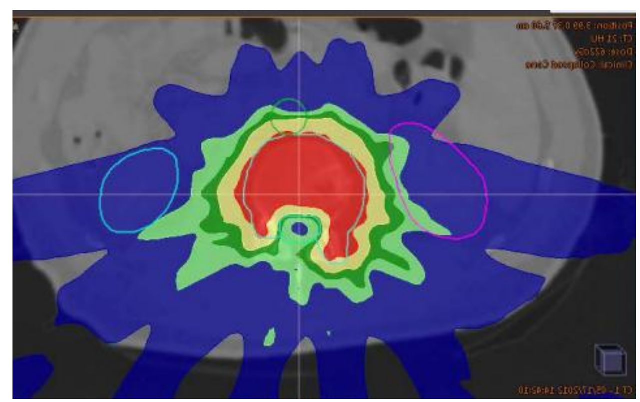
- Benefits
  - Single session
  - Higher dose to tumor (“radioresistant”)
  - Retreatment after failed conventional RT (“salvage”)
  - Multimodality therapy to minimize extent of resection (“separation surgery”)
- Potential drawbacks
  - Vertebral body fractures which are dose-dependent
  - Reoccurrence local to the cord

Case #1 revisted: Solitary and radioresistant metastasis









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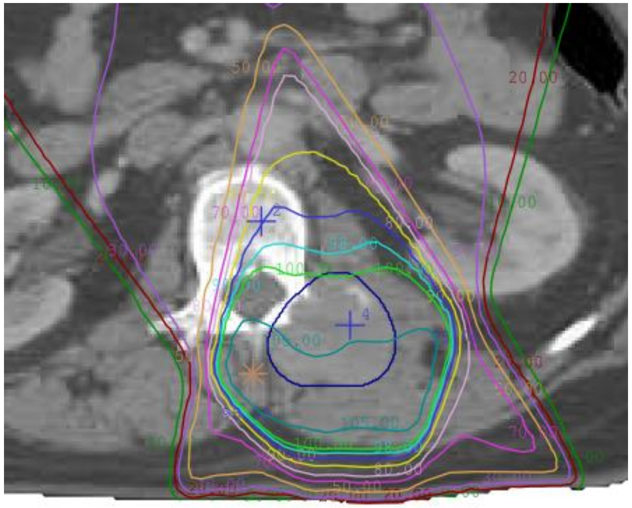
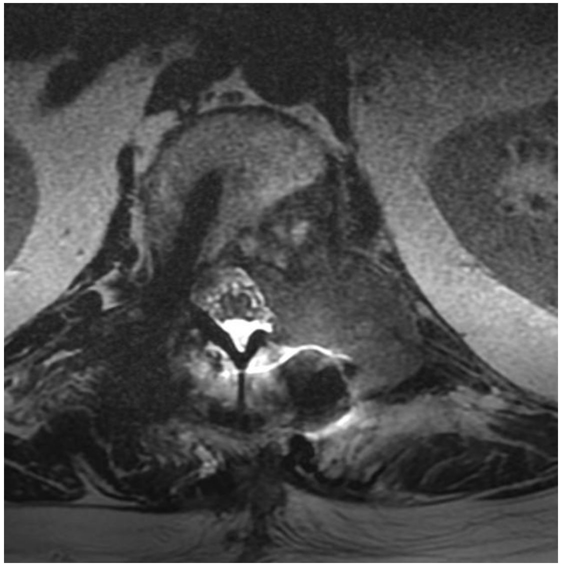
Case #2 revisited: Retreatment after progression



6/2011

1/2012



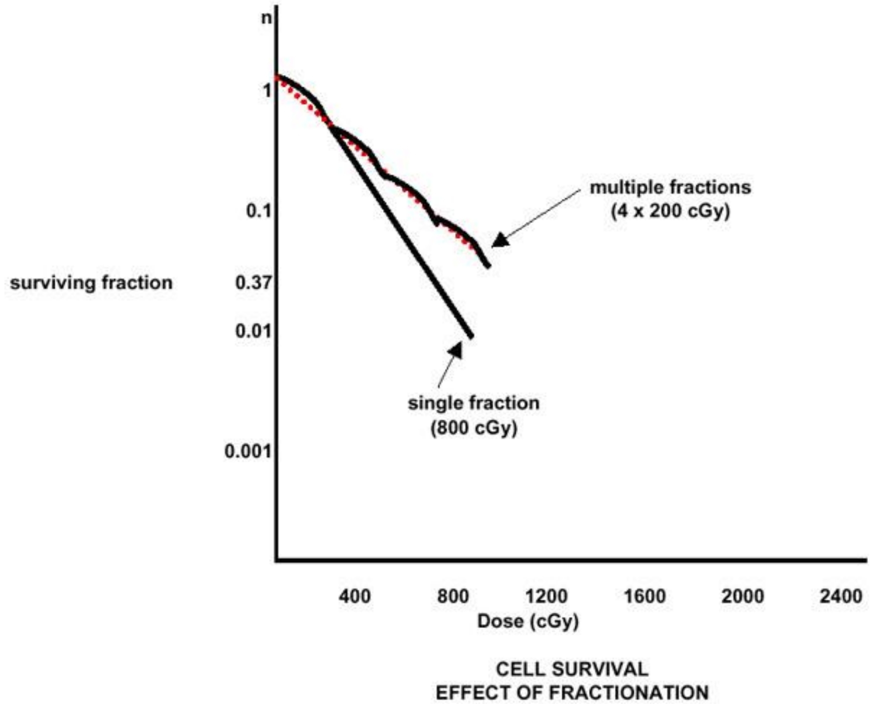
6/2012
5 months after resection

Spine radiosurgery alone
limited surgery + spine radiosurgery

Stereotactic Body Radiation Therapy: How does it work?

- Exploit dose and fractionation

Influence of dose per treatment



Biologically:

(18 Gy x 1) > (2 Gy x 9)

Stereotactic Body Radiation Therapy: How does it work?

- Exploit dose and fractionation
- Rigid immobilization
- Precise patient positioning
- Sophisticated radiation planning
- Reduce toxicity to the cord by dose avoidance instead of fractionation

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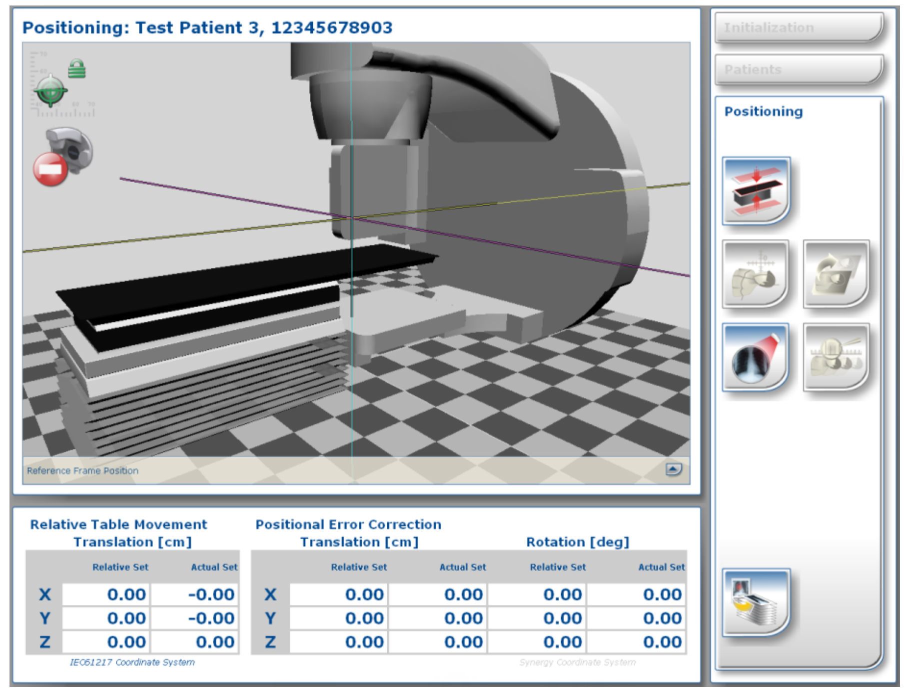
Immobilization and Visualization

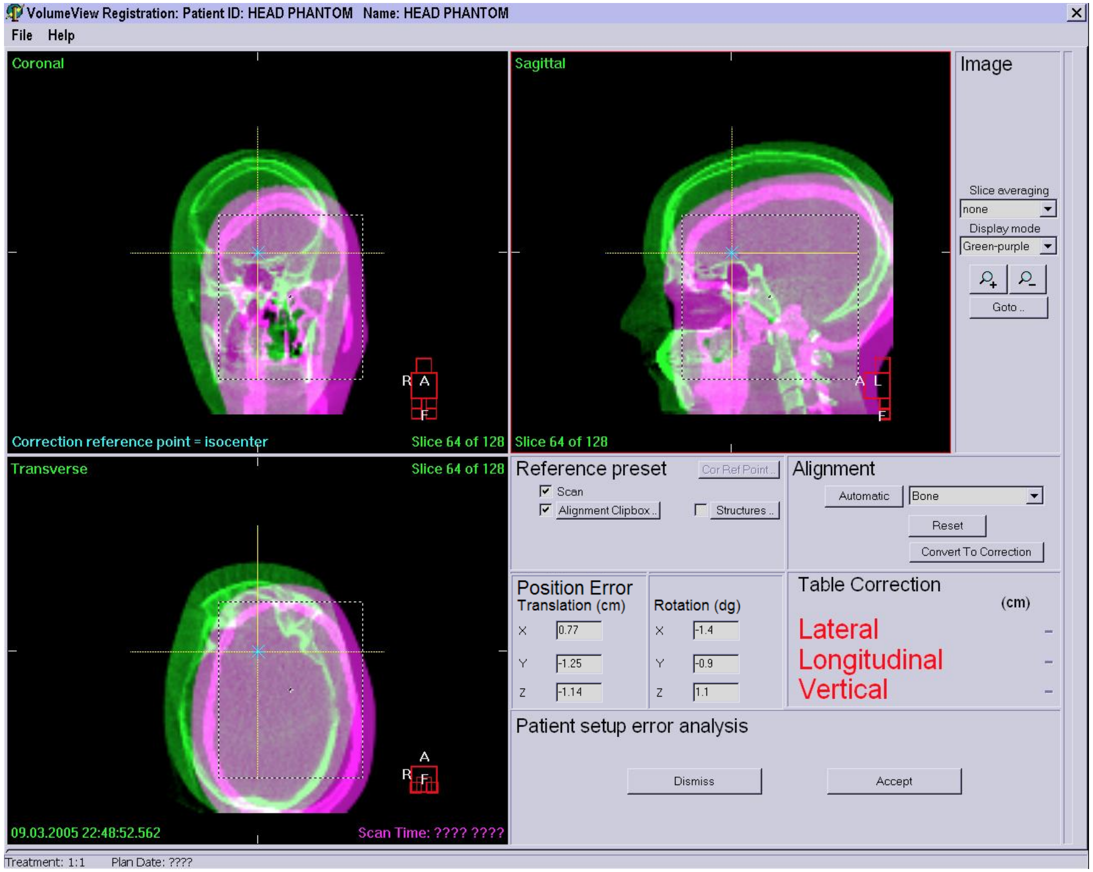
- Rigid immobilization using custom body mold and vacuum bag (BodyFix) or QFix (Mask) for upper T-spine and C-Spine
- Real-time CT in treatment position with integrated hexapod couch

6 DOF Robotic Couch

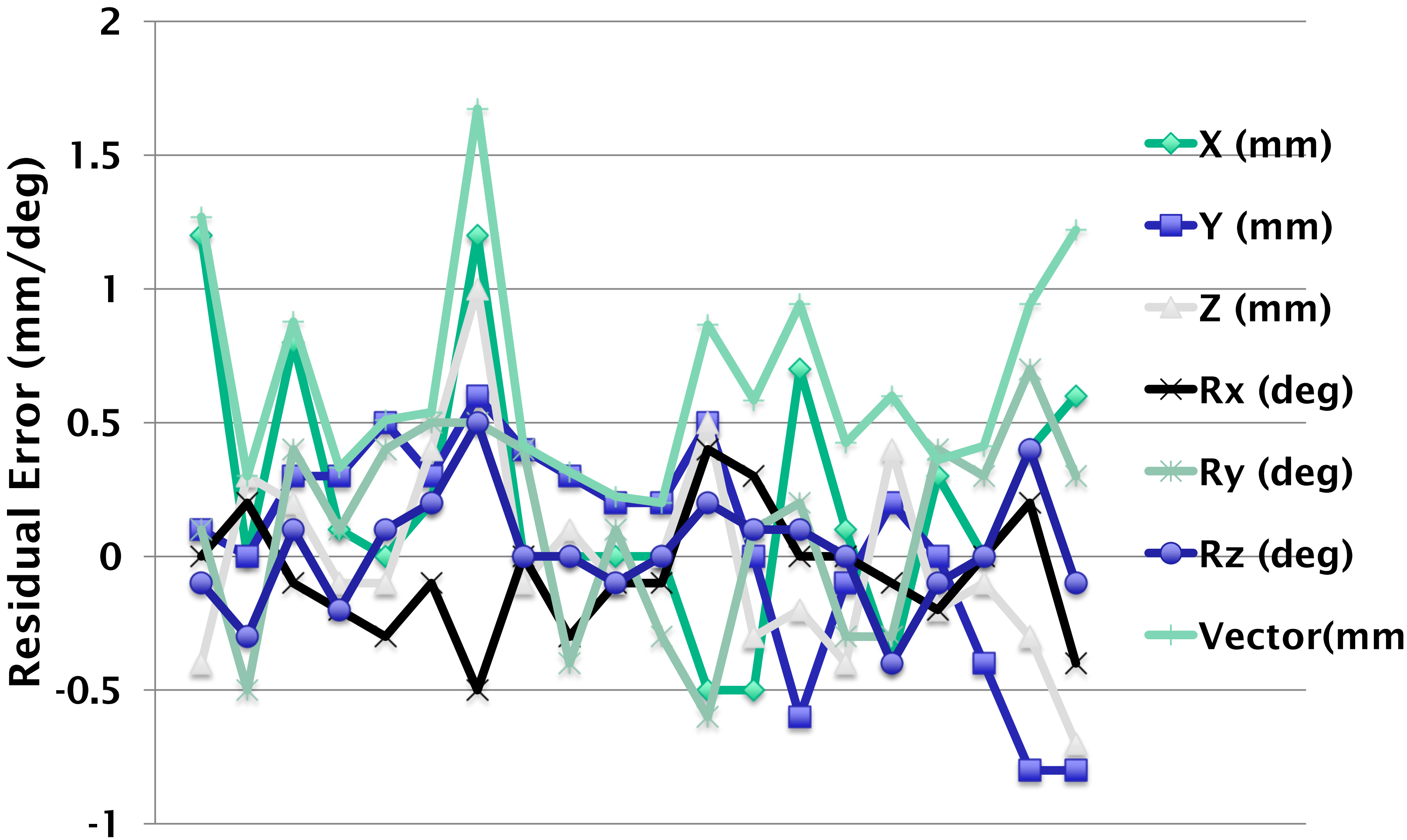


CBCT System

- Automatic 6 DOF Registration
- Bone, Gray-Scale
- Clip Box
- 200 deg, Fast Scan
- 1 mm^3 Voxels

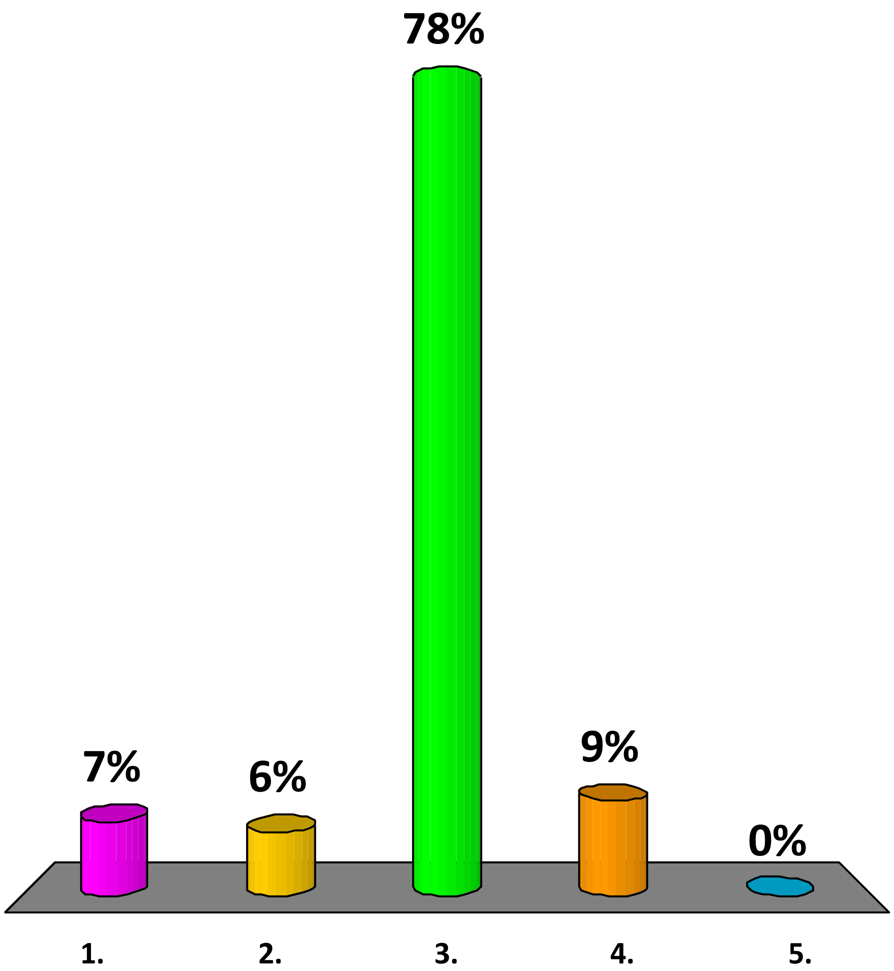


Patient Setup Uncertainty



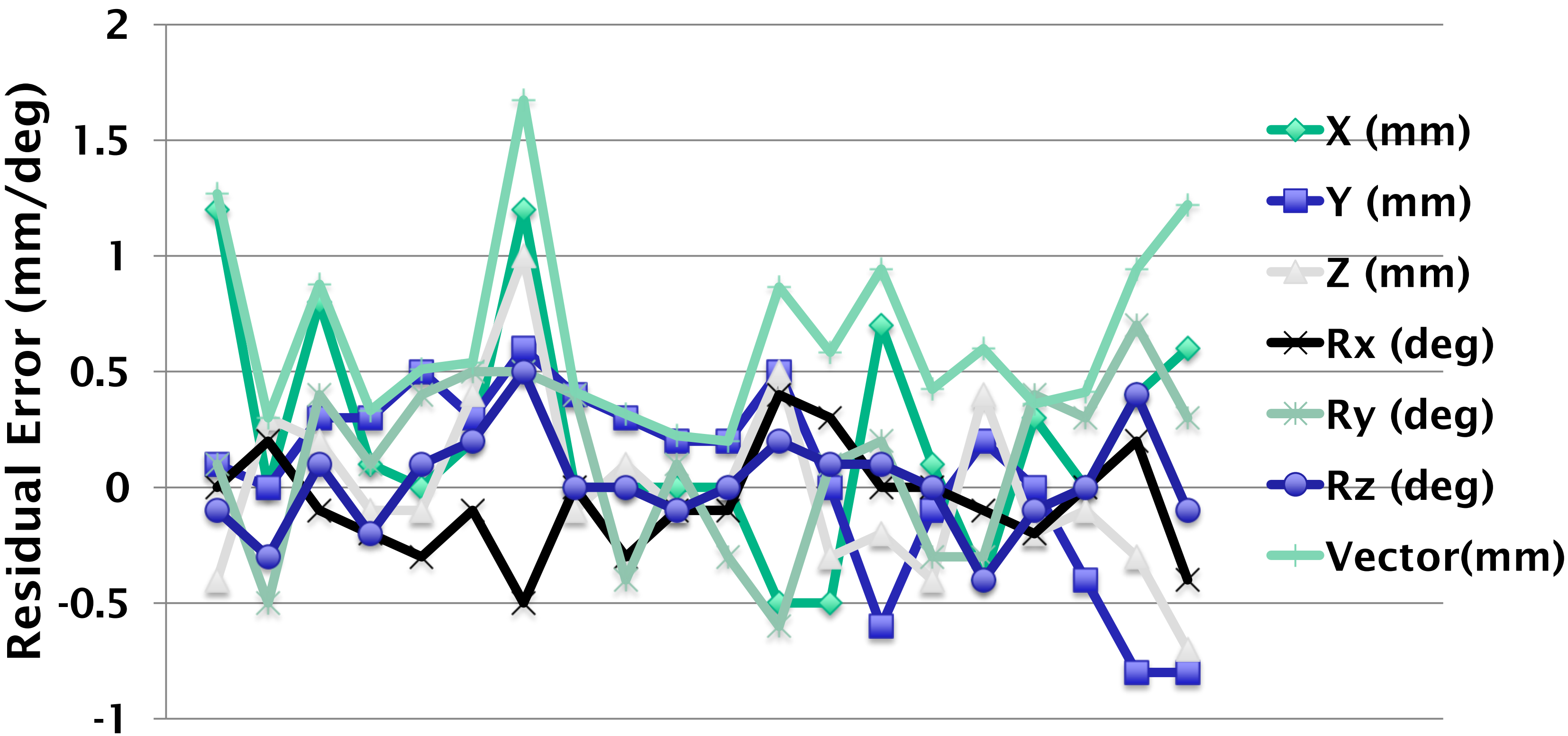
What is the expected accuracy of patient positioning for CBCT guided linac Spine SRS?

1. Within 0.5 mm
2. 0.5 mm
3. 1.0 mm
4. 2.0 mm
5. 3.0 mm



Answer

- 1.0 mm

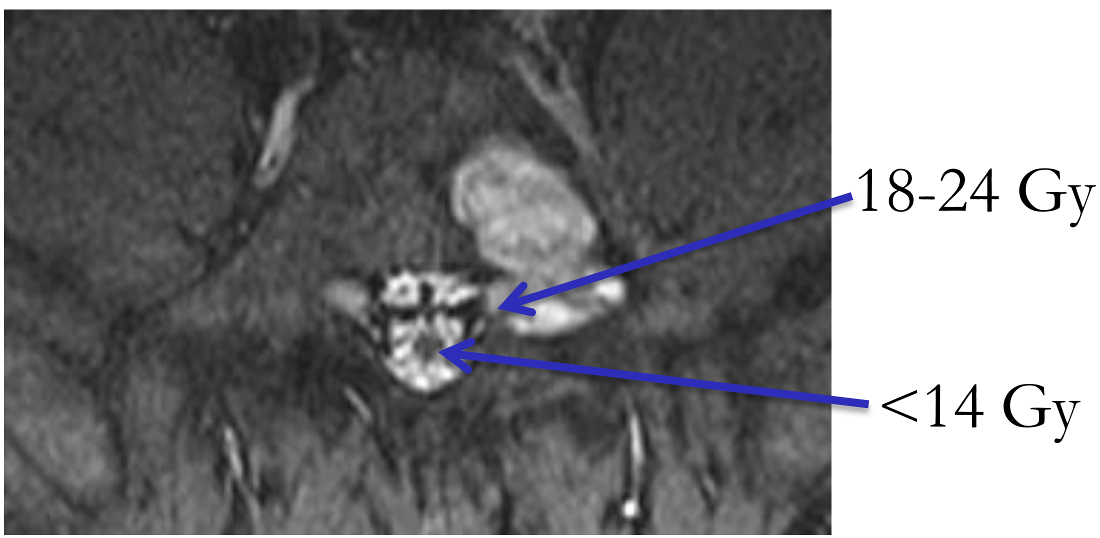


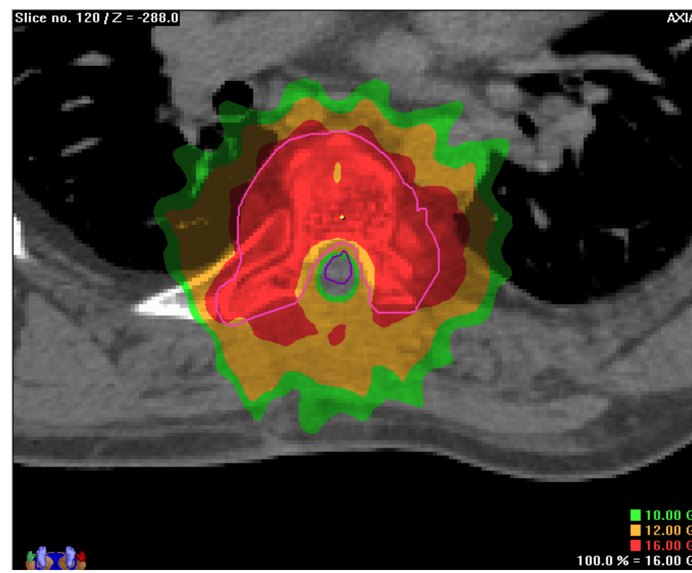
Other studies have demonstrated the same level of accuracy:
Gerszten, *et. al.* JNS 2010 "Setup accuracy of spine radiosurgery using cone beam computed tomography image guidance in patients with spinal implants"

MASSACHUSETTS GENERAL HOSPITAL RADIATION ONCOLOGY
HARVARD MEDICAL SCHOOL

Sophisticated Radiation Planning

- Dose constraints:
  - Spinal cord < 12-14 Gy x 1
  - Cauda equina < 16 Gy x 1
  - Sacral plexus < 18 Gy x 1





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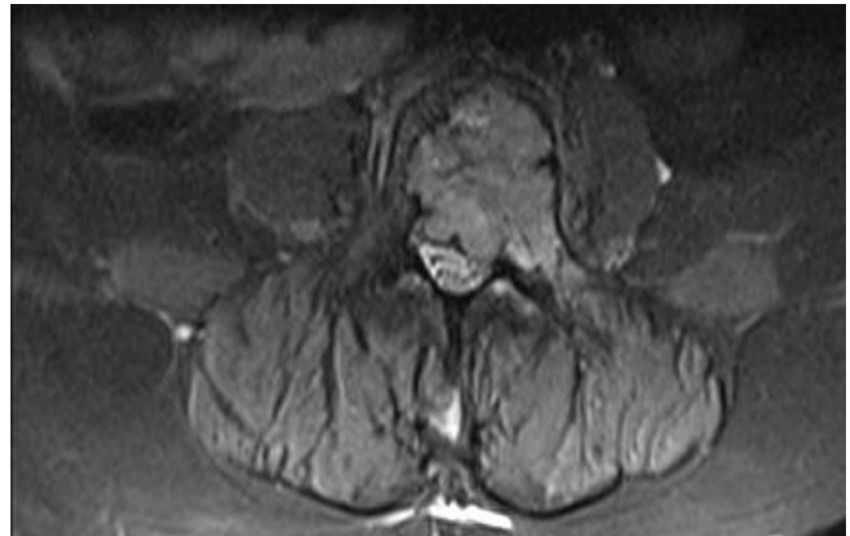
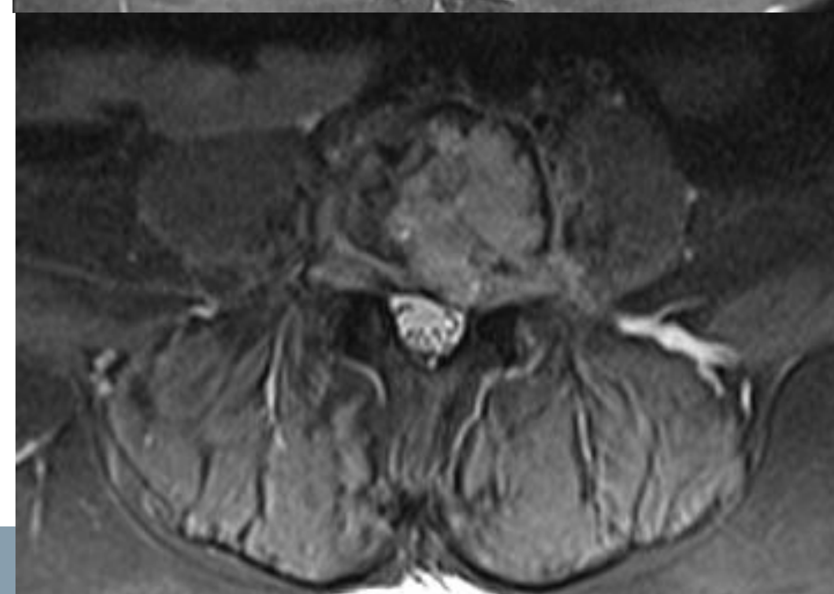
Clinical Summary

- Provide fast and multidisciplinary care for patients with spinal metastases
- Goal of minimizing morbidity and while preserving local control and QOL

LINAC SRS Workflow

Diagnosis

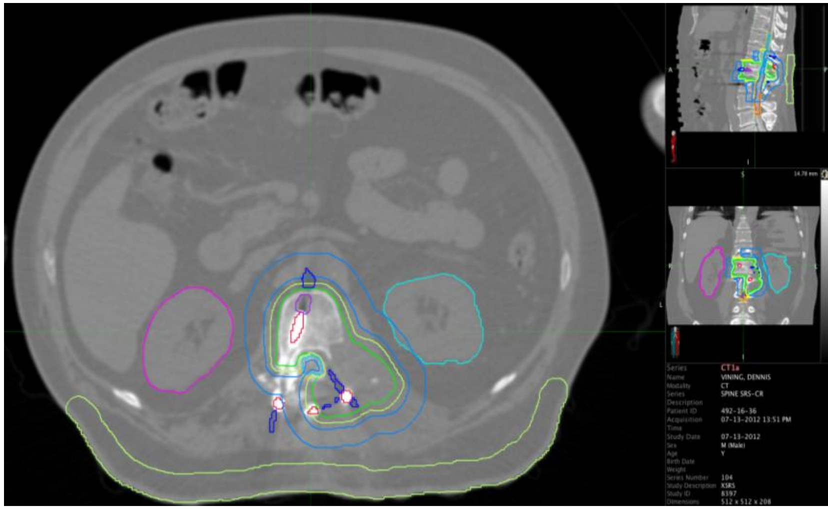


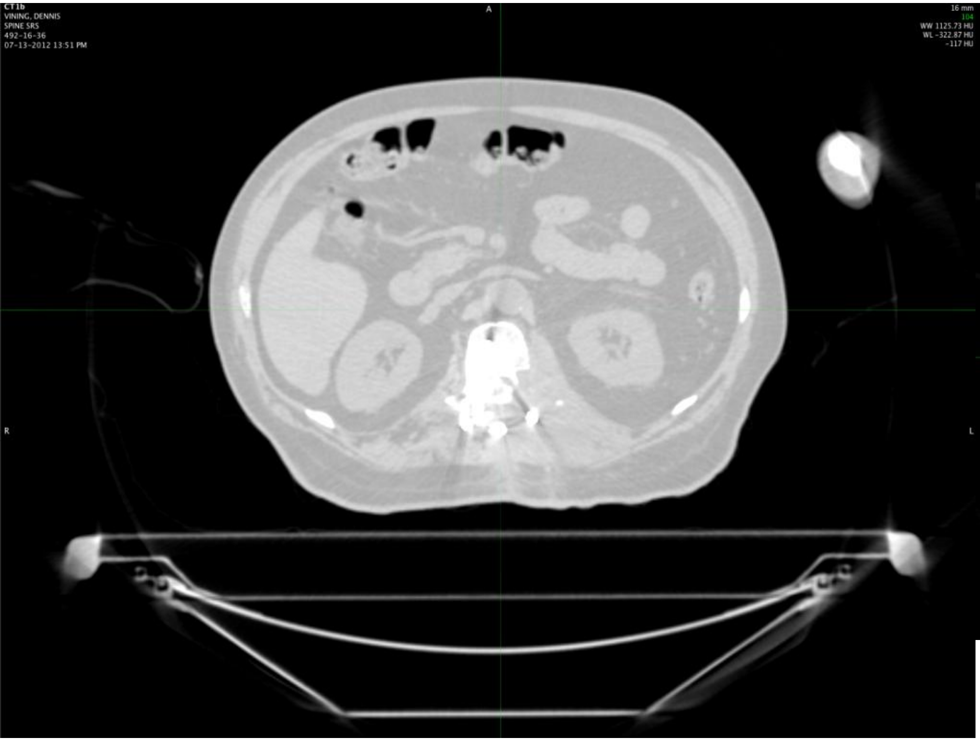


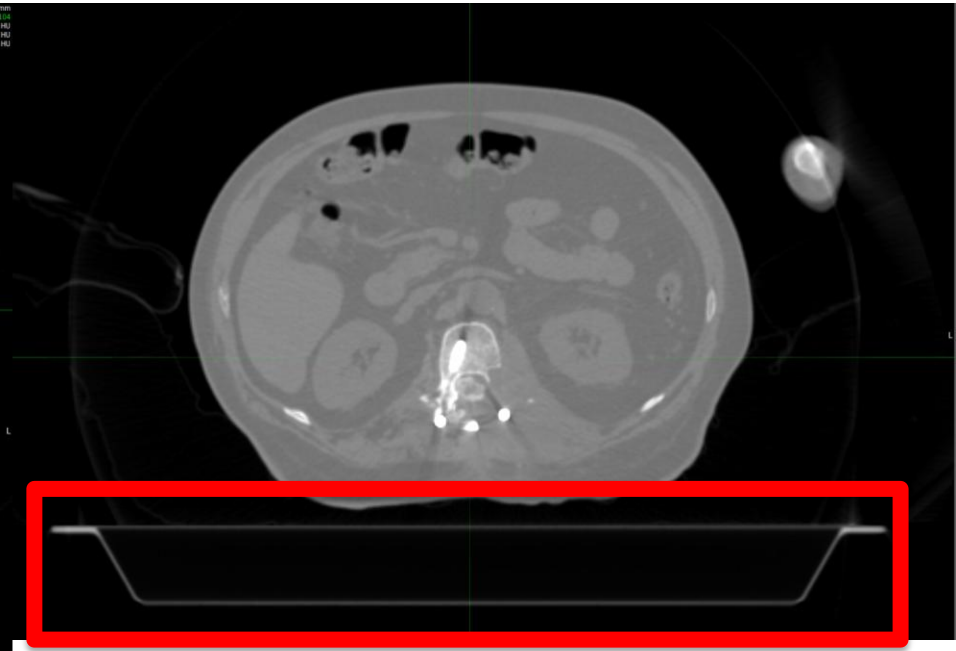
Immobilization

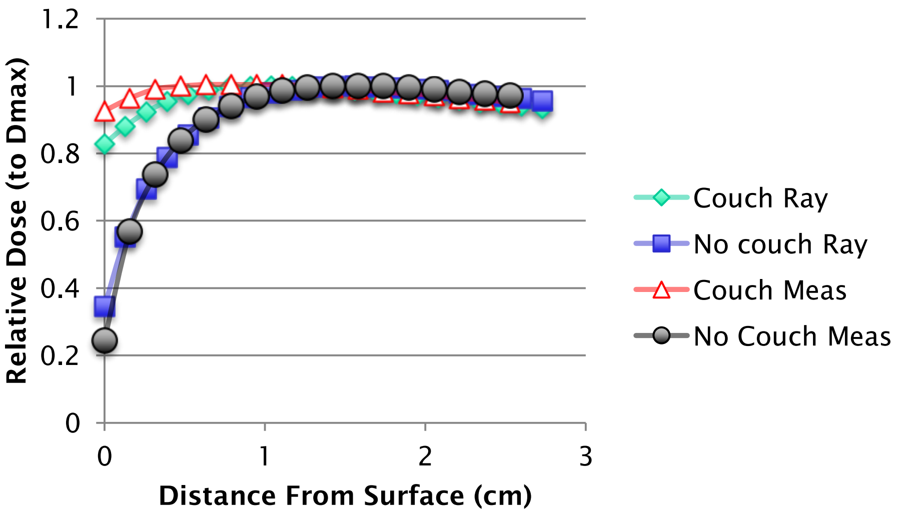
Initial Contouring

- PTV, OARs- physician
- Planning Structures
- Hardware, artifacts
- Add Couch to CT
  (T5 and lower)
- T5 and above, typically use QFix or mask

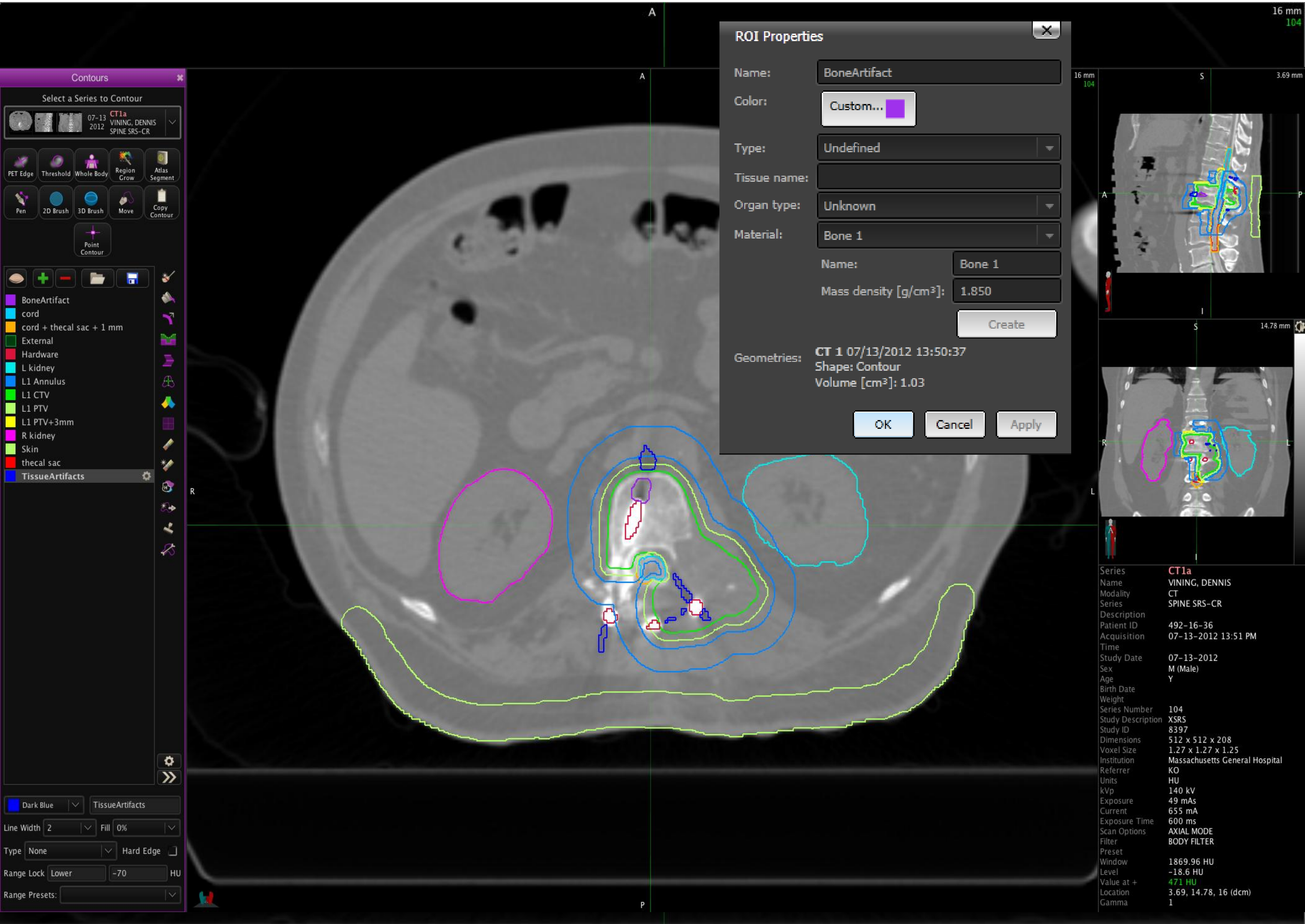








Relative Dose (to Dmax)
Distance From Surface (cm)
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
Couch Ray
No couch Ray
Couch Meas
No Couch Meas

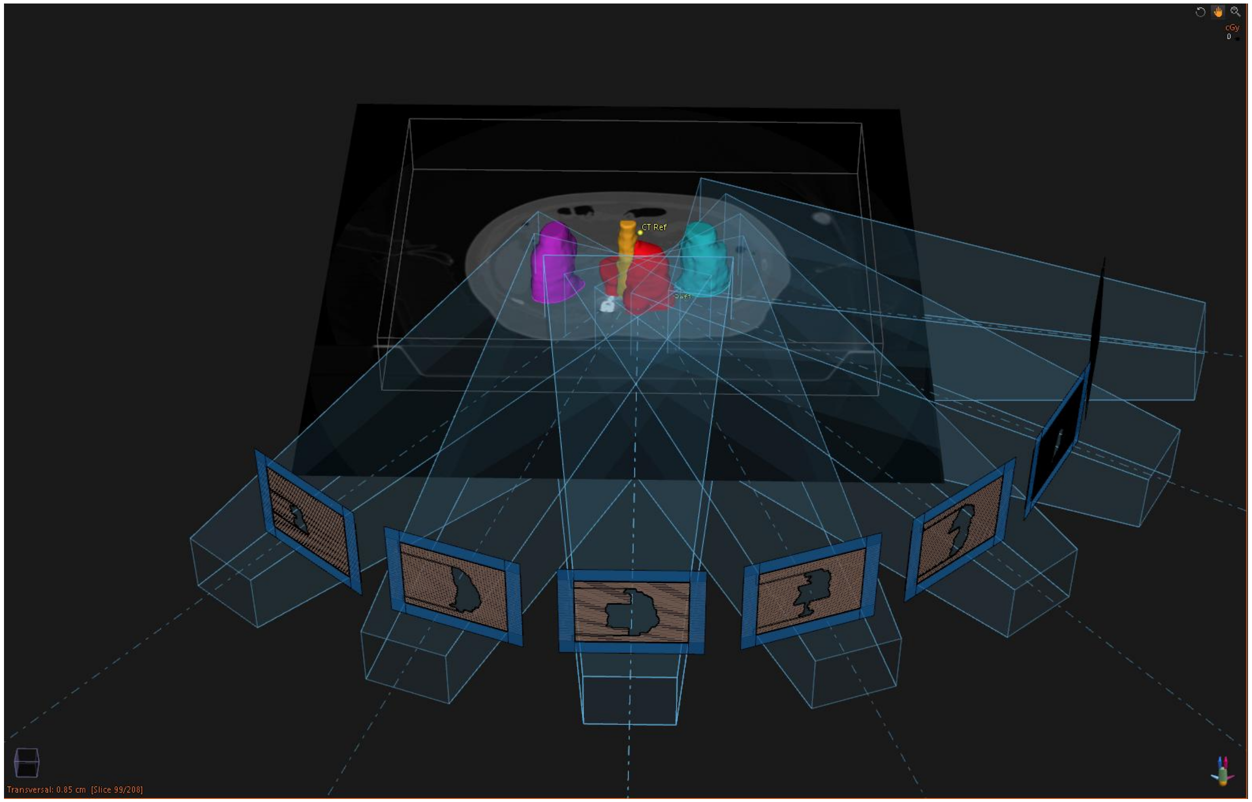


ROI Properties
Name: BoneArtifact
Color: Custom...
Type: Undefined
Tissue name:
Organ type: Unknown
Material: Bone 1
Name: Bone 1
Mass density [g/cm³]: 1.850
Create
Geometries: CT 1 07/13/2012 13:50:37
Shape: Contour
Volume [cm³]: 1.03
OK
Cancel
Apply
Contours
Select a Series to Contour
07-13 2012 CT1a VINING, DENNIS SPINE SRS-CR
PET Edge
Threshold
Whole Body
Region Grow
Atlas Segment
Pen
2D Brush
3D Brush
Move
Copy Contour
Point Contour
BoneArtifact
cord
cord + thecal sac + 1 mm
External
Hardware
L kidney
L1 Annulus
L1 CTV
L1 PTV
L1 PTV+3mm
R kidney
Skin
thecal sac
TissueArtifacts
Dark Blue
TissueArtifacts
Line Width 2
Fill 0%
Type None
Hard Edge
Range Lock Lower -70 HU
Range Presets:
16 mm
104
3.69 mm
14.78 mm
Series CT1a
Name VINING, DENNIS
Modality CT
Series Description SPINE SRS-CR
Patient ID 492-16-36
Acquisition Time 07-13-2012 13:51 PM
Study Date 07-13-2012
Sex M (Male)
Age Y
Birth Date
Weight
Series Number 104
Study Description XSRS
Study ID 8397
Dimensions 512 x 512 x 208
Voxel Size 1.27 x 1.27 x 1.25
Institution Massachusetts General Hospital
Referrer KO
Units HU
kVp 140 kV
Exposure 49 mAs
Current 655 mA
Exposure Time 600 ms
Scan Options AXIAL MODE
Filter BODY FILTER
Preset
Window 1869.96 HU
Level -18.6 HU
Value at + 471 HU
Location 3.69, 14.78, 16 (dcm)
Gamma 1

Planning

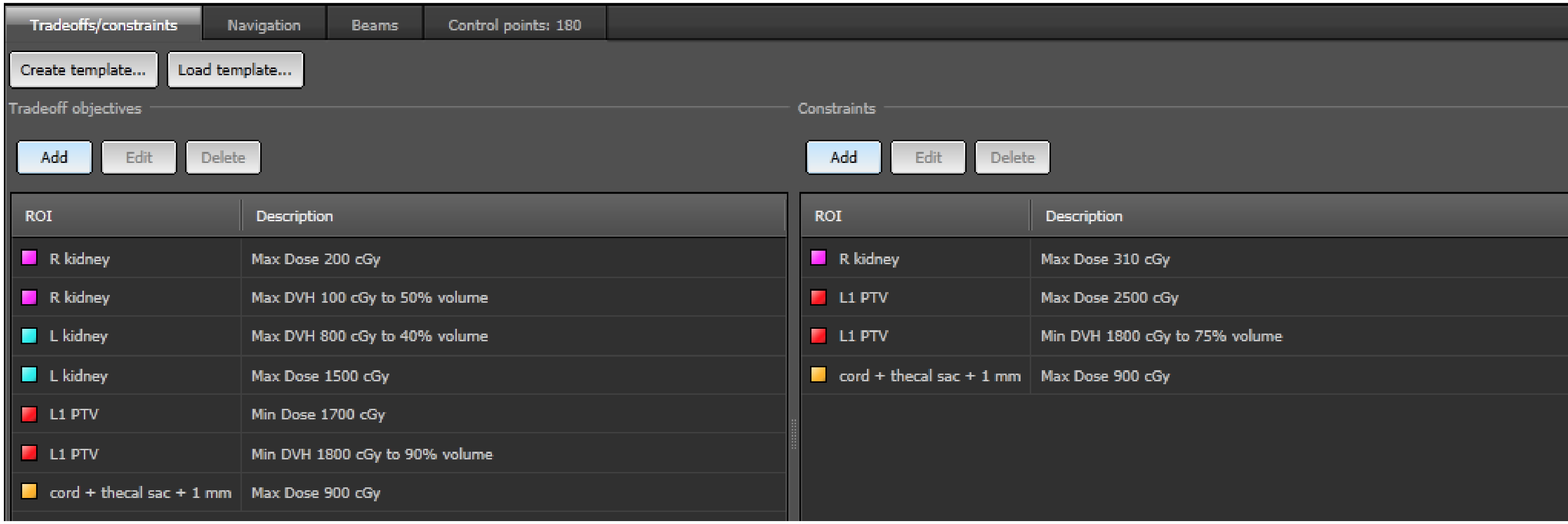
- IMRT or VMAT
- Coplanar 7-9 beams/2 arcs
- Posterior (Anterior used for Cervical Vertebral locations)
- ~20 deg separation
- 600-1000 MU/beam
- Collimator Rotation Can Reduce MUs

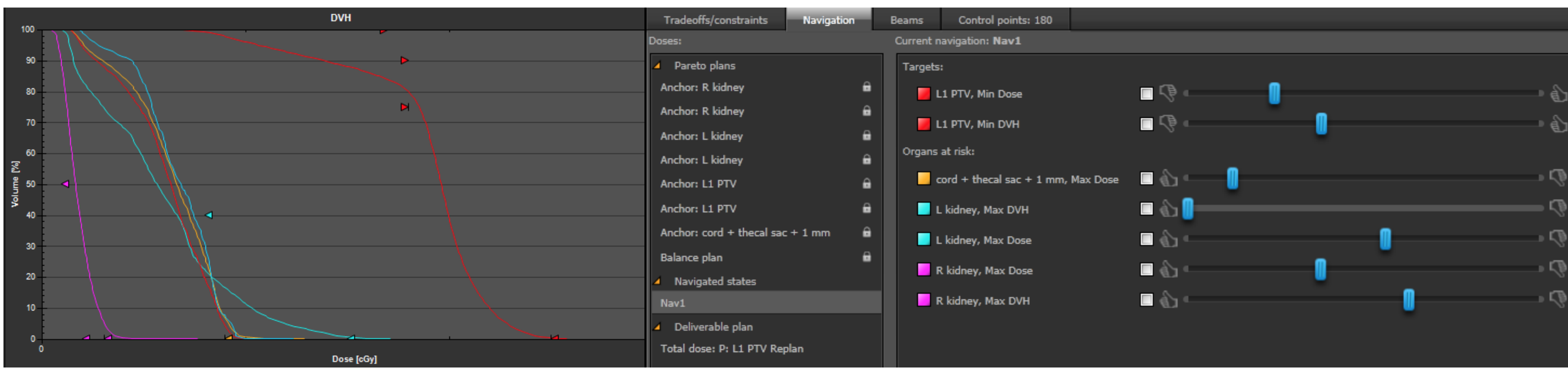
Planning



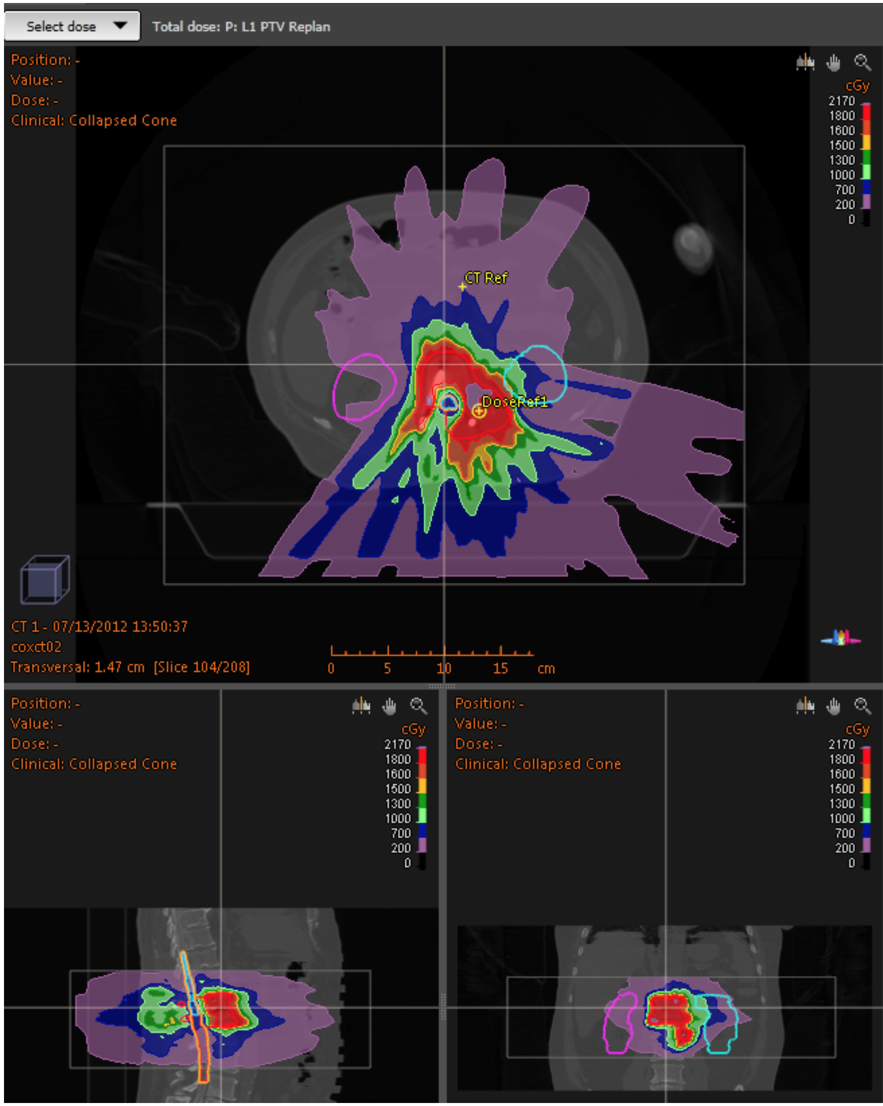
Number	Name	Isocenter [cm]			Treatment unit	Gantry angle [deg]	Coll. Angle [deg]	Couch Angle [deg IEC]	Jaw position [cm]				Jaw assignment	Segments	MU/Fraction
		R-L	I-S	P-A					X1	X2	Y1	Y2			
0	180	1.65	-0.03	-2.27	MGH Synergy_S [6.0 MV]	180.0	0.0	0.0	-10.50	10.50	-8.00	8.00	Fixed	9	1224.69
1	160	1.65	-0.03	-2.27	MGH Synergy_S [6.0 MV]	160.0	0.0	0.0	-10.50	10.50	-8.00	8.00	Fixed	7	983.45
2	140	1.65	-0.03	-2.27	MGH Synergy_S [6.0 MV]	140.0	0.0	0.0	-10.50	10.50	-8.00	8.00	Fixed	4	682.16
3	120	1.65	-0.03	-2.27	MGH Synergy_S [6.0 MV]	120.0	0.0	0.0	-10.50	10.50	-8.00	8.00	Fixed	6	496.77
4	220	1.65	-0.03	-2.27	MGH Synergy_S [6.0 MV]	220.0	0.0	0.0	-10.50	10.50	-8.00	8.00	Fixed	9	1200.37
5	200	1.65	-0.03	-2.27	MGH Synergy_S [6.0 MV]	200.0	0.0	0.0	-10.50	10.50	-8.00	8.00	Fixed	8	1074.87
6	100	1.65	-0.03	-2.27	MGH Synergy_S [6.0 MV]	100.0	0.0	0.0	-10.50	10.50	-8.00	8.00	Fixed	6	826.26

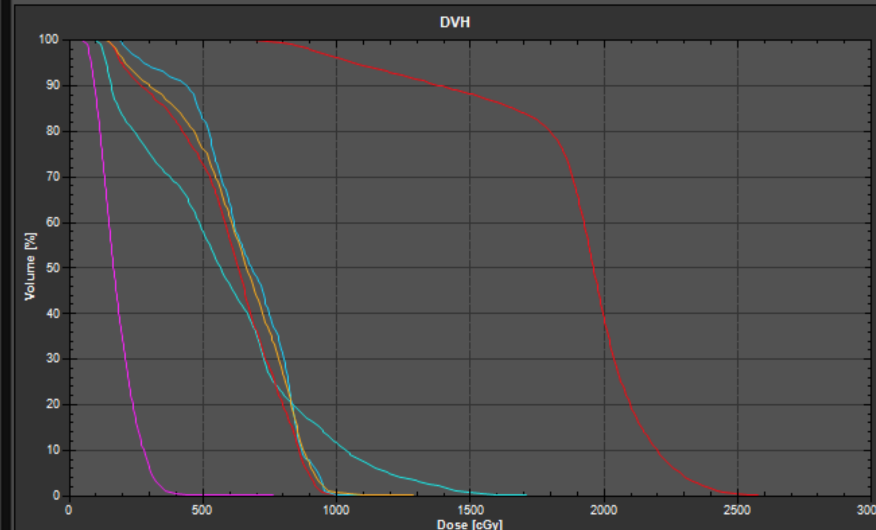
Planning


Tradeoffs/constraints
Navigation
Beams
Control points: 180
Create template...
Load template...
Tradeoff objectives
Add
Edit
Delete
ROI | Description
R kidney | Max Dose 200 cGy
R kidney | Max DVH 100 cGy to 50% volume
L kidney | Max DVH 800 cGy to 40% volume
L kidney | Max Dose 1500 cGy
L1 PTV | Min Dose 1700 cGy
L1 PTV | Min DVH 1800 cGy to 90% volume
cord + thecal sac + 1 mm | Max Dose 900 cGy
Constraints
Add
Edit
Delete
ROI | Description
R kidney | Max Dose 310 cGy
L1 PTV | Max Dose 2500 cGy
L1 PTV | Min DVH 1800 cGy to 75% volume
cord + thecal sac + 1 mm | Max Dose 900 cGy


DVH
Volume [%]
Dose [cGy]
0
10
20
30
40
50
60
70
80
90
100
Tradeoffs/constraints
Navigation
Beams
Control points: 180
Doses:
Pareto plans
Anchor: R kidney
Anchor: R kidney
Anchor: L kidney
Anchor: L kidney
Anchor: L1 PTV
Anchor: L1 PTV
Anchor: cord + thecal sac + 1 mm
Balance plan
Navigated states
Nav1
Deliverable plan
Total dose: P: L1 PTV Replan
Current navigation: Nav1
Targets:
L1 PTV, Min Dose
L1 PTV, Min DVH
Organs at risk:
cord + thecal sac + 1 mm, Max Dose
L kidney, Max DVH
L kidney, Max Dose
R kidney, Max Dose
R kidney, Max DVH

Final Dose

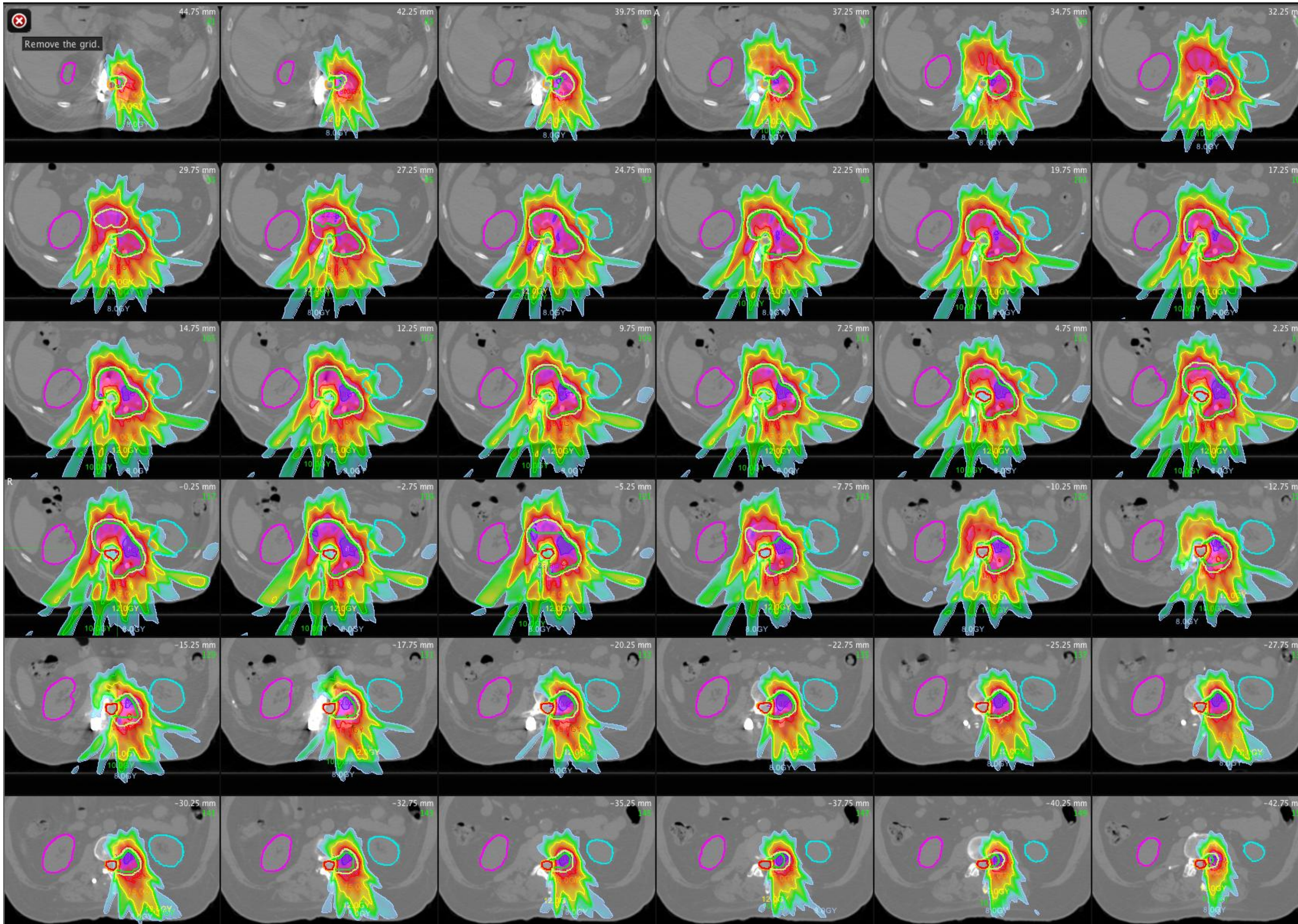




Dose axis display options: Absolute values | Relative max dose value | Relative reference value [cGy]:

Dose statistics | Clinical goal definitions | Clinical goals

Dose	ROI	ROI vol. [cm³]	Dose [cGy] D99	D98	D95	Average	D50	D2	D1
Total dose: P: L1 PTV Replan	cord	4.42	203	218	284	667	684	952	956
Total dose: P: L1 PTV Replan	cord + thecal sac + 1 mm	24.36	161	175	210	638	665	952	973
Total dose: P: L1 PTV Replan	L kidney	158.2	121	127	140	585	567	1382	1457
Total dose: P: L1 PTV Replan	L1 PTV	210.19	835	897	1067	1892	1963	2373	2426
Total dose: P: L1 PTV Replan	R kidney	182.78	69	73	84	179	168	340	362
Total dose: P: L1 PTV Replan	thecal sac	12.7	158	169	198	607	636	923	939


Remove the grid.
44.75 mm
42.25 mm
39.75 mm
37.25 mm
34.75 mm
32.25 mm
29.75 mm
27.25 mm
24.75 mm
22.25 mm
19.75 mm
17.25 mm
14.75 mm
12.25 mm
9.75 mm
7.25 mm
4.75 mm
2.25 mm
-0.25 mm
-2.75 mm
-5.25 mm
-7.75 mm
-10.25 mm
-12.75 mm
-15.25 mm
-17.75 mm
-20.25 mm
-22.75 mm
-25.25 mm
-27.75 mm
-30.25 mm
-32.75 mm
-35.25 mm
-37.75 mm
-40.25 mm
-42.75 mm

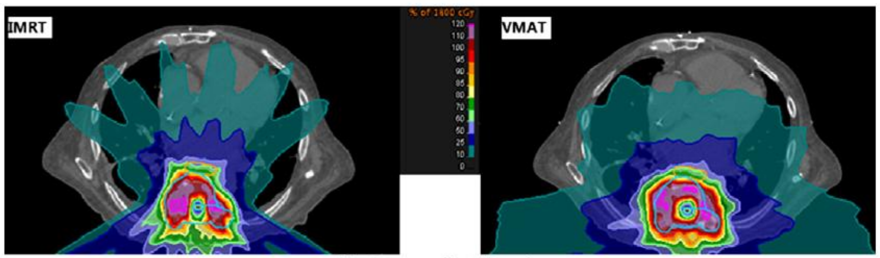
Delivery

- Pre Treatment kV/MV coincidence tests
- CBCT 1to calculate transformation
- CBCT 2 to confirm shifts
- CBCT 3 if CBCT 2 has residuals >0.5mm
- Treat First Half
- CBCT3(4) account for intrafraction motion
- Treat Second Half
- CBCT4(5) measure residuals
- Tx Time: ~25 min (Depends on Dose rate)

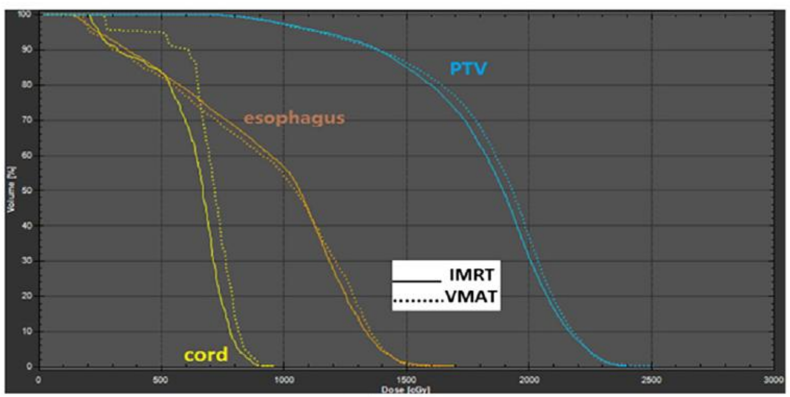
IMRT versus VMAT

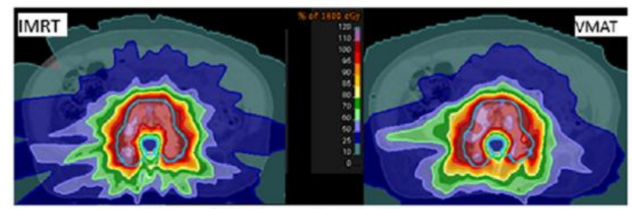
- Highly dependent on Maximum Dose Rate
- Both IMRT and VMAT will use maximum dose rate for many segments due to high dose/fraction
- Great potential for FFF treatments

IMRT versus VMAT



A) Dose distribution





A) Dose distribution

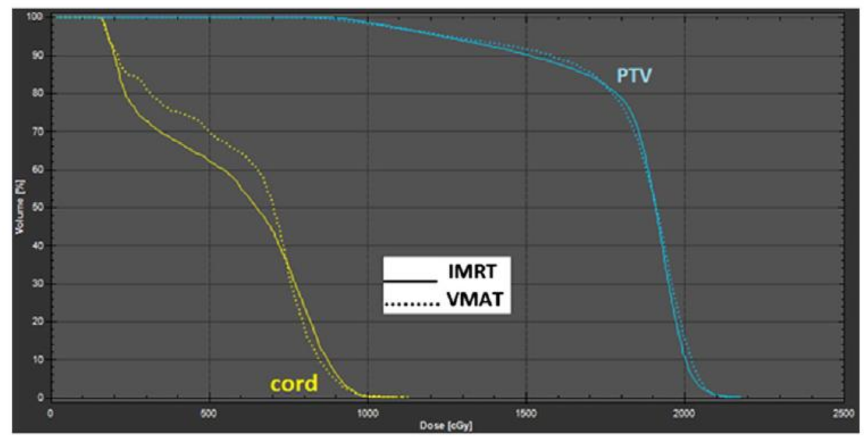


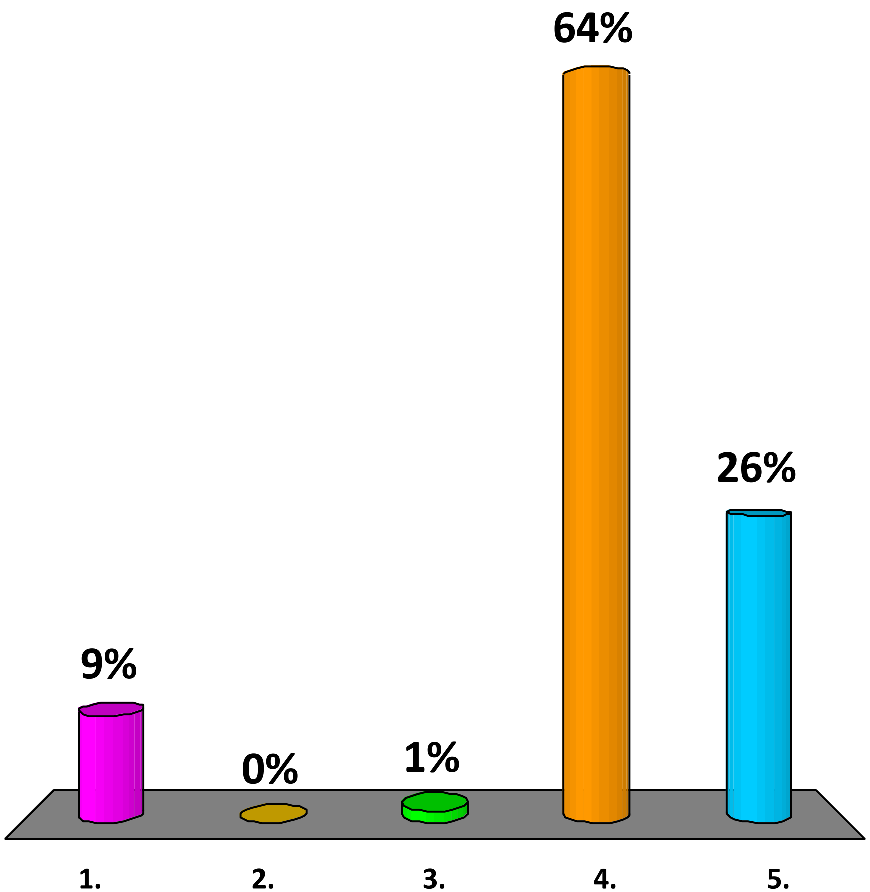
Table 2 Monitor units (MU) and delivery time (average ± SD) comparison for MCO-IMRT and VMAT with or without collimator rotation

Variable	Colli: 0		Colli: Rot	
	MCO-IMRT	VMAT	MCO-IMRT	VMAT
MU	6216 ± 756[a]	5861 ± 896[b]	4681 ± 726[a]	4360 ± 722[b]
Delivery time (min)	–	–	18.3 ± 2.5[c]	14.2 ± 2.0[c]

Chen *et al* PRO 2015 "Efficiency Gains for Spine SRS using MCO IMRT guided VMAT Planning"

What is the most important technique for reducing the treatment delivery time for Spine SRS?

1. Use VMAT instead of IMRT
2. Use fewer IMRT fields
3. Use more IMRT fields
4. Use higher dose rates
5. Rotate the collimator



Answer:

- User higher dose rate
- VMAT may be faster but not always significant
- Collimator rotation can reduce MU
- Dose rate is the primary limiting factor for delivery time

Table 2 Monitor units (MU) and delivery time (average ± SD) comparison for MCO-IMRT and VMAT with or without collimator rotation

Variable	Colli: 0		Colli: Rot	
	MCO-IMRT	VMAT	MCO-IMRT	VMAT
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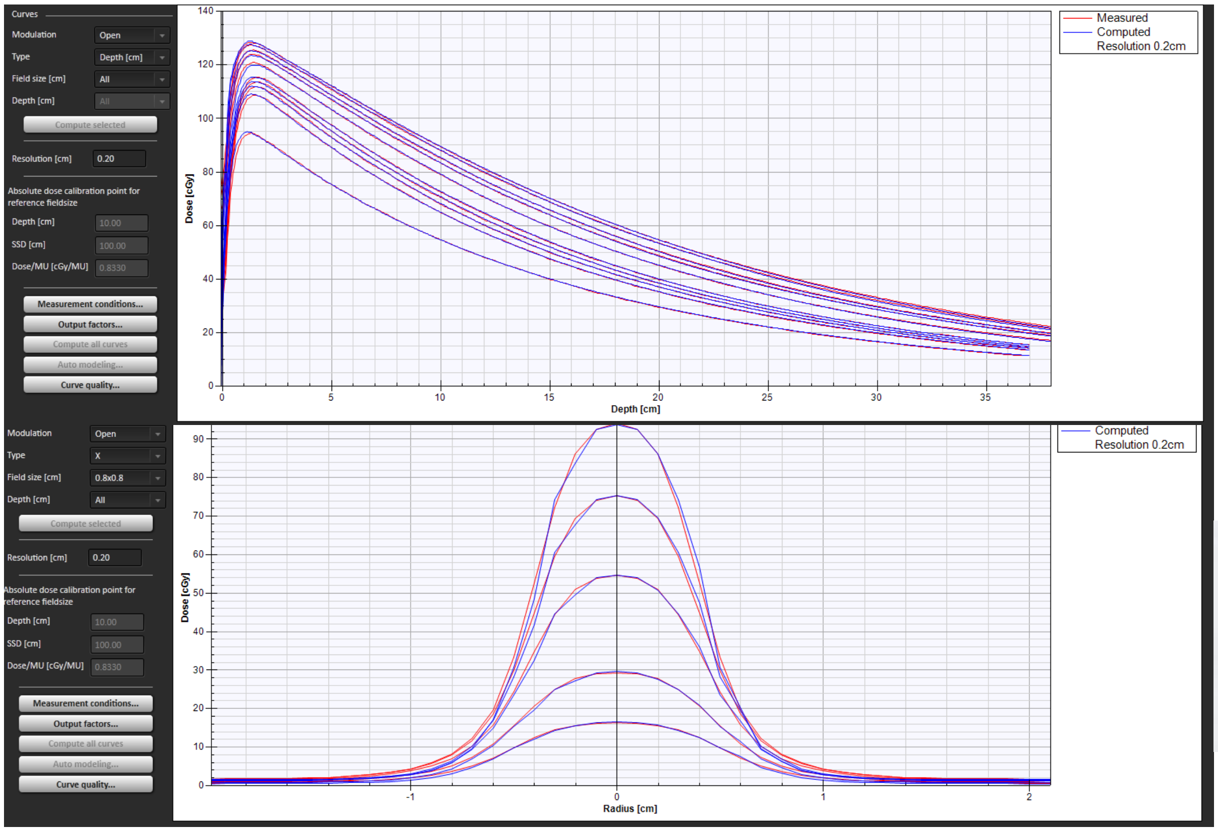
Chen *et al* PRO 2015 "Efficiency Gains for Spine SRS using MCO IMRT guided VMAT Planning"

Quality Assurance

- TG-142
- Commissioning
- Isocentricity tests: Imaging, MV, Robotic positioner
- Dosimetric QA

Commissioning

- Small fields (1x1 cm^2 and larger)



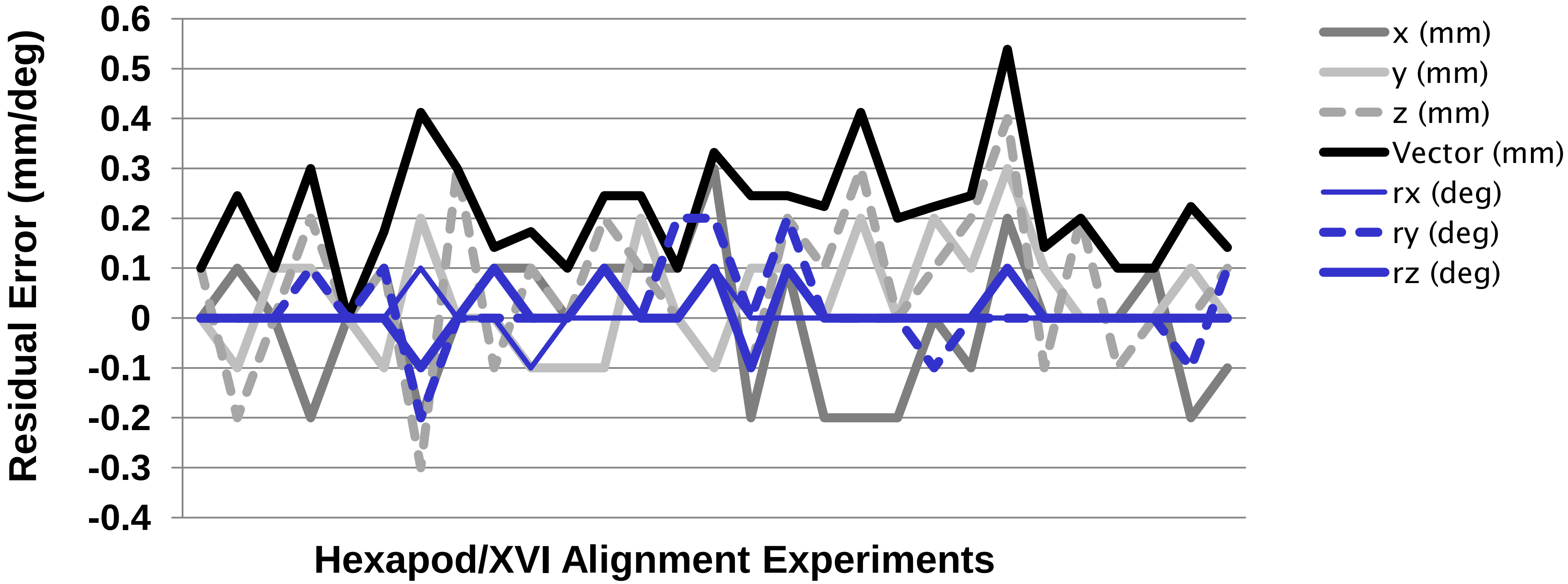
Output factors

Field size [cm]	Factor
0.8x0.8	0.65500
1.6x1.6	0.77800
2.4x2.4	0.81500
3.2x3.2	0.84500
4x4	0.87000
7.2x7.2	0.94830
10.4x10.4	1.00000
12x12	1.02160
16x16	1.05600
21x16	1.07290

Output factors measured at depth [cm] 10.00

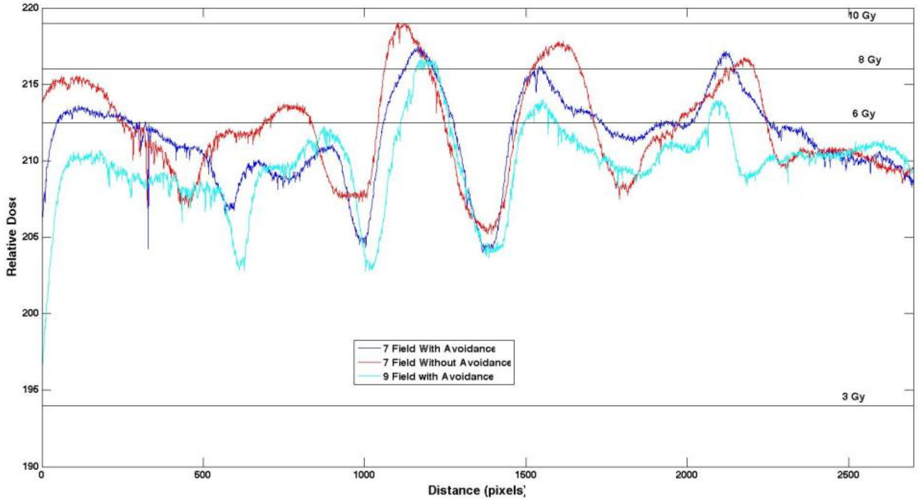
Commissioning

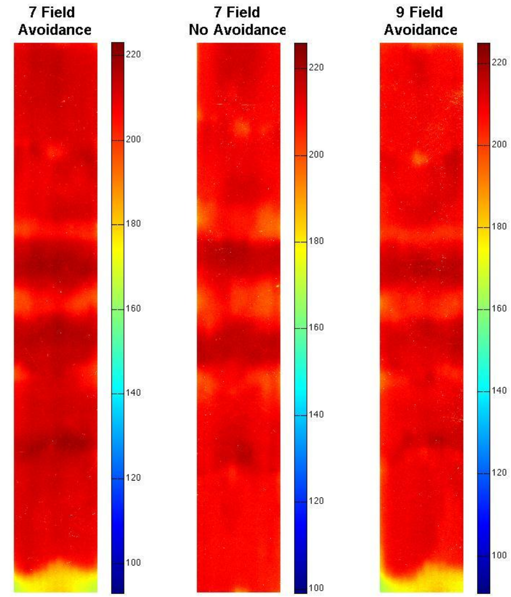
- Small fields (1x1 cm^2 and larger)
- Patient positioning and imaging systems (< 1 mm uncertainty)



Commissioning

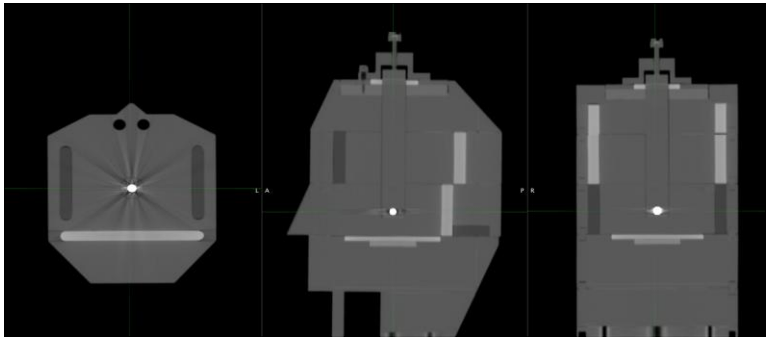
- Small fields (1x1 cm^2 and larger)
- Patient positioning and imaging systems (< 1 mm uncertainty)
- Dosimetric tests

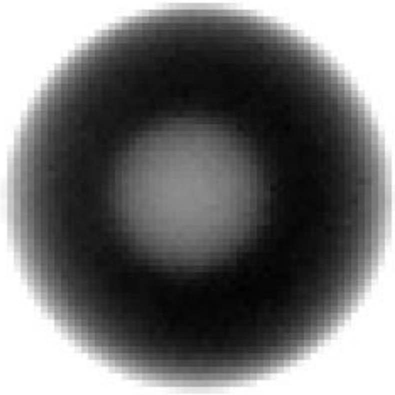


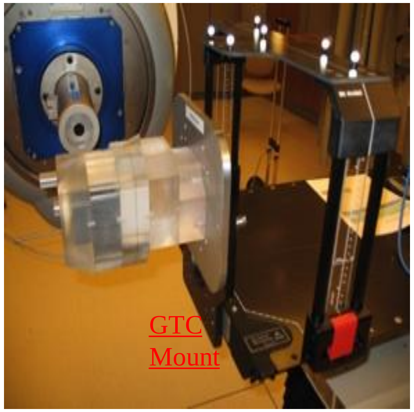


Daily Isocentricity

- Daily
- Plastic Densities
- Tungsten Ball

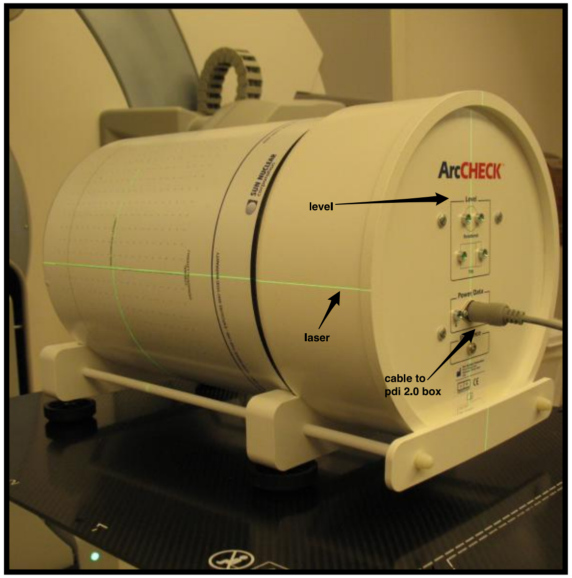


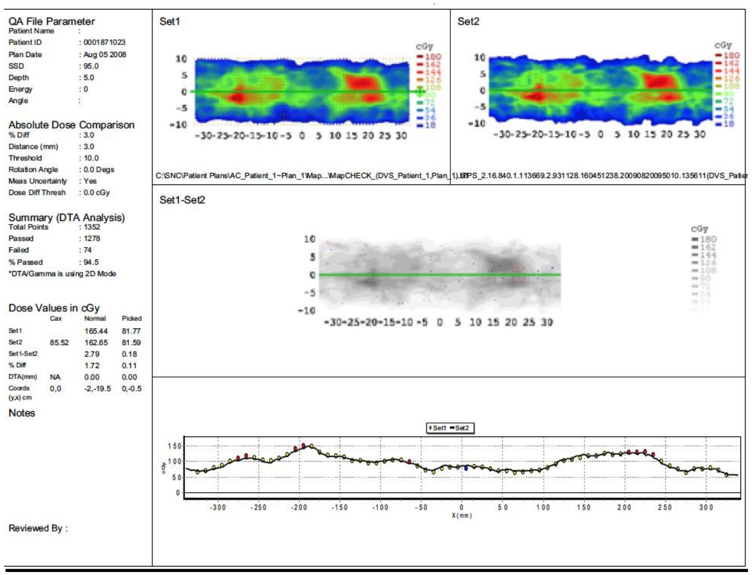




Patient QA

- Multiple solutions
- Rotational independence and resolution





LINAC SRS Conclusions

- SRS is a valuable treatment option for vertebral metastases
- Linacs equipped with CBCT and 6 DOF robotic positioners can accurately and safely treat spine SRS
- FFF can significantly reduce the treatment times and reduce the risk of patient motion