SETTING UP RADIOSURGERY PROGRAM IN THE CLINIC

Dr Raghavendra Holla
Ruby Hall Clinic, Pune

Radiation Errors Reported in Missouri

By WALT BOGDANICH and REBECCA R. RUIZ FEB. 24, 2010

A hospital in Missouri said Wednesday that it had overradiated 76 patients, the vast majority with brain cancer, during a five-year period because powerful new radiation equipment had been set up incorrectly even with a representative of the manufacturer watching as it was done.

The hospital, CoxHealth in Springfield, said half of all patients undergoing a particular type of treatment — stereotactic radiation therapy — were overdosed by about 50 percent after an unidentified medical physicist at the hospital miscalibrated the new equipment and routine checks over the next five years failed to catch the error.

The revelation comes at a time of growing concern about safety procedures for a new generation of powerful, computer-controlled medical radiation equipment.

Stereotactic therapy delivers radiation in such high doses that usually only one treatment is required. It is commonly used to treat small tumors in the

No communication

The New York Times Reprints

December 28, 2010

A Pinpoint Beam Strays Invisibly, Harming Instead of Healing

By WALT BOGDANICH and KRISTINA REBELO

“There were strong similarities between what happened in Missouri and what happened in Toulouse,” said Dr. Ola Holmberg, who heads the radiation protection unit for patients at the International Atomic Energy Agency.

But without a requirement that accidents and near-misses be reported, other hospitals cannot learn from these mistakes, Dr. Holmberg said.

“There is no effective way now of sharing the information or learning in a systematic way,” Dr. Holmberg said. “If something happens, such as Evanston, I would have wanted to know about it at the time.”

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The New York Times
Sunday, January 24, 2010

The Radiation Boom

Radiation Offers New Cures, and Ways to Do Harm

Fatal Radiation

Software problems and poor quality control at St. Vincent's Hospital cause a fatal overdose. Related Article »

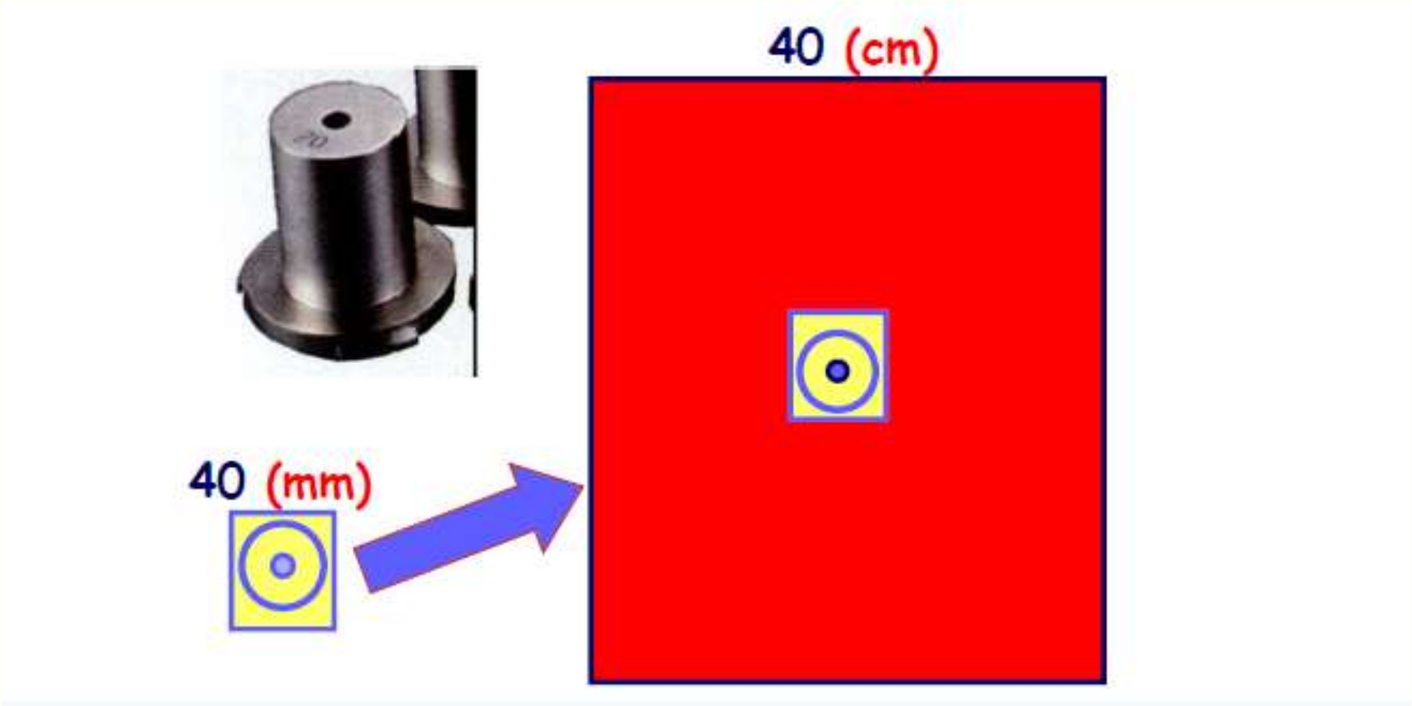
1 2 3 4 5 6 7 8 NEXT

March 16, 2005
Mr. Jerome-Parks's medical physicist ran a series of tests on the equipment. All of them showed that the collimator was wide open, and the hospital realized that a serious overdose of radiation had been administered.

February 2007
After two years of declining health, including loss of sight, hearing and balance, Mr. Jerome-Parks, 43, died of his radiation injuries.

Scott Jerome-Parks

What happened?



The New York Times

PHOTODOCUMENTATION


Figure 1


Figure 2


Figure 3


Figure 4

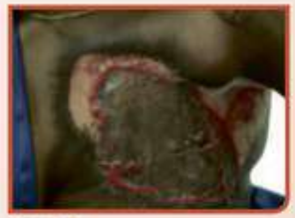


Figure 5

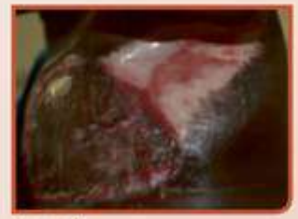


Figure 6


Figure 7


Figure 8


Figure 9


Figure 8

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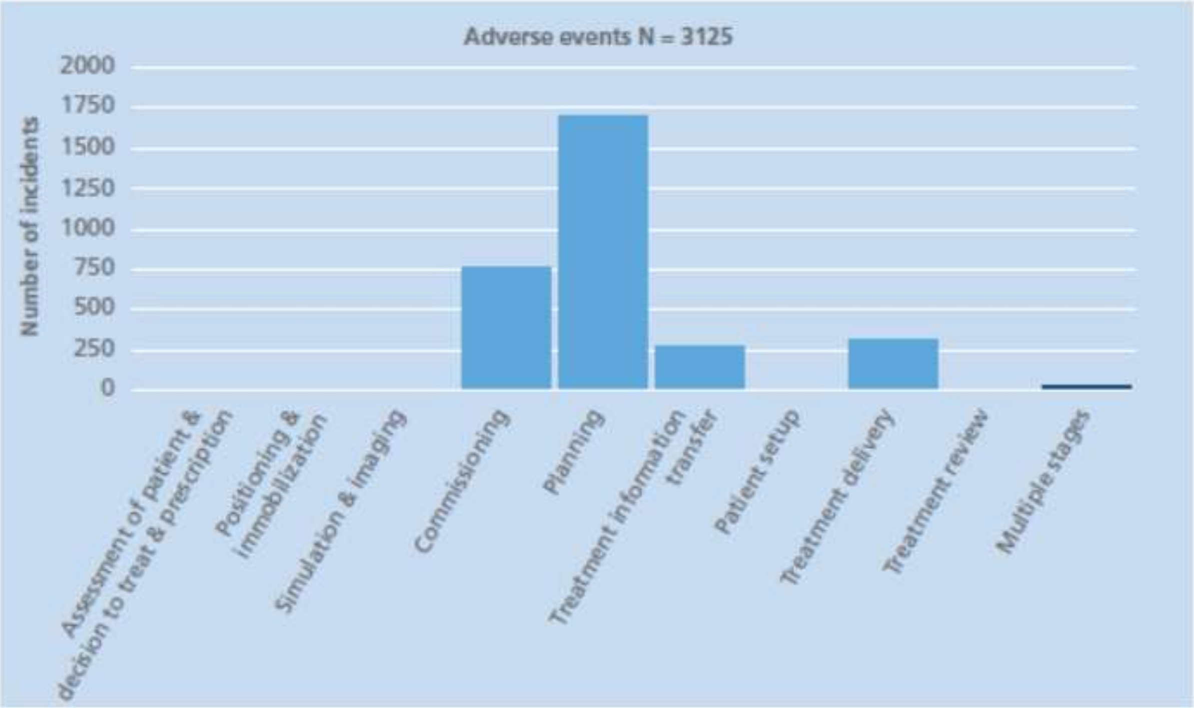
Challenges in Radiation Oncology

What are the sources of errors?

Figure 4: Radiotherapy incidents (1976-2007) by the stages of treatment process



WHO Radiotherapy Risk Profile 2008

- Two Major Categories in SRS/SBRT Accidents
- Commissioning
  - Small field measurements
  - Absolute calibration
- Treatment parameter transfer
  - SRS Cones
  - Wrong side/site treatments

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General Processes for SRS/SBRT

Patient process

- Consultation
- Immobilization/imaging
- Planning/prescription
- Patient specific QA
- Localization
- Delivery
- Motion management
- Real-time verification
- Treatment assessment

Physics process

- Beam data
- QA: Safety
- QA – Isocenter accuracy QA

Like W-L testing

- Dose calculation Accuracy
- device QA - Linac
- Beam calibration

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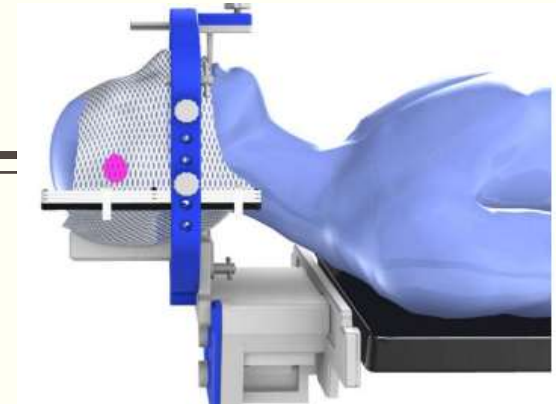
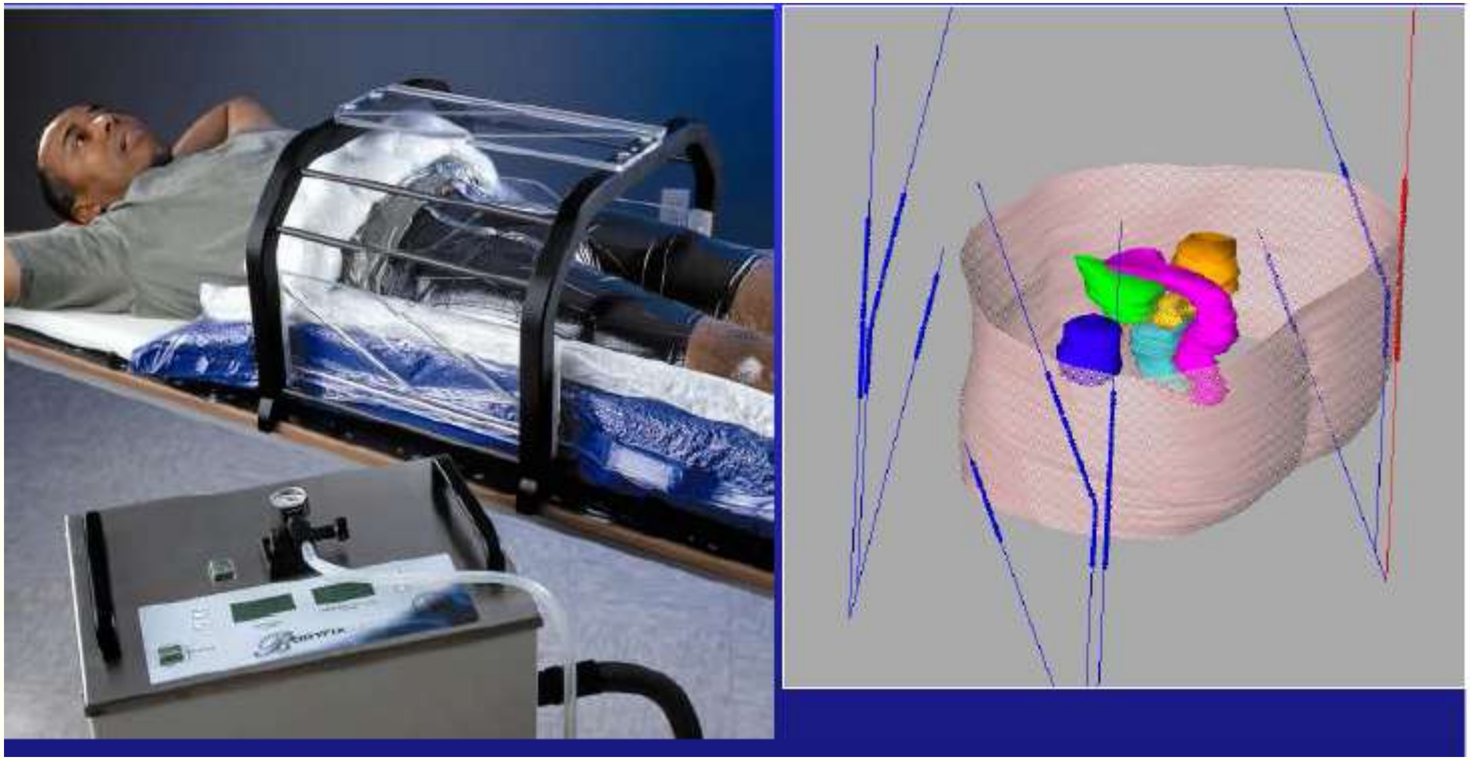
Non invasive frames



- Non-invasive, relocatable device
- Thermoplastic material
- May not good for claustrophobic patients
- Potential for mask shrinkage

Body Localiser



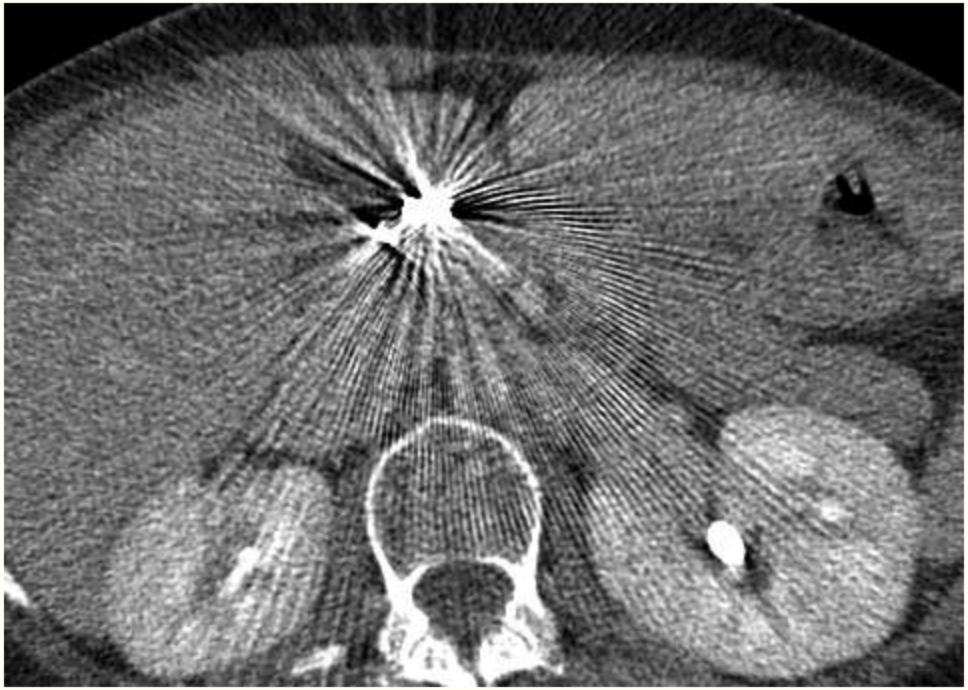
Frameless intracranial positioning

Challenges in simulation

- The most appropriate imaging modality for a given clinical situation is driven by the characteristics of the tissues being imaged.
- Slice Thickness <1 mm(TG -151)
- Scan Boundary : 5-10cm, 15cm for Cyberknife
- Data Acquisition for moving targets – uncertainties involved in it

Imaging artifacts

- artifacts due to high atomic number Z objects such as metal implants, prosthetics, and dental fillings.
  - Solution - MAR algorithm, Contouring the artifacts and assigning the density.
- Motion related artifacts
  - Solution - Immobilization(Patient Cooperation??)



Simulation Accuracy

- Achievable accuracy – Karger et al report CT accuracy of ~0.4 mm and MR accuracy of ~1.4 mm depending on MR device and imaging sequence
- – Representative MR distortion tolerance is < 2mm across a 30 cm field of view (FOV)
- However, delineation accuracy depends on imaging parameters, so per TG-66 – Simulation procedures should standardize scan protocols, use of contrast etc by treatment site – QA process should check that correct parameters were used

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Image Fusion

- Jonker, Benjamin P. "Image Fusion Pitfalls for Cranial Radiosurgery." Surgical Neurology International 4(Suppl 3) (2013): S123–8.

For rigid CT / MR registration, achievable accuracy based on phantom studies is ~2 mm.

- Accuracy will degrade if registering to a surrogate, as distance between target & surrogate increases.

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Fusion QA

Understand limitations of fusion methods applied to different treatment sites

– Do your own testing

  – Provide training

– Ensure treatment process provides adequate review

(See TG-132 Assessment Level for fusion quality)

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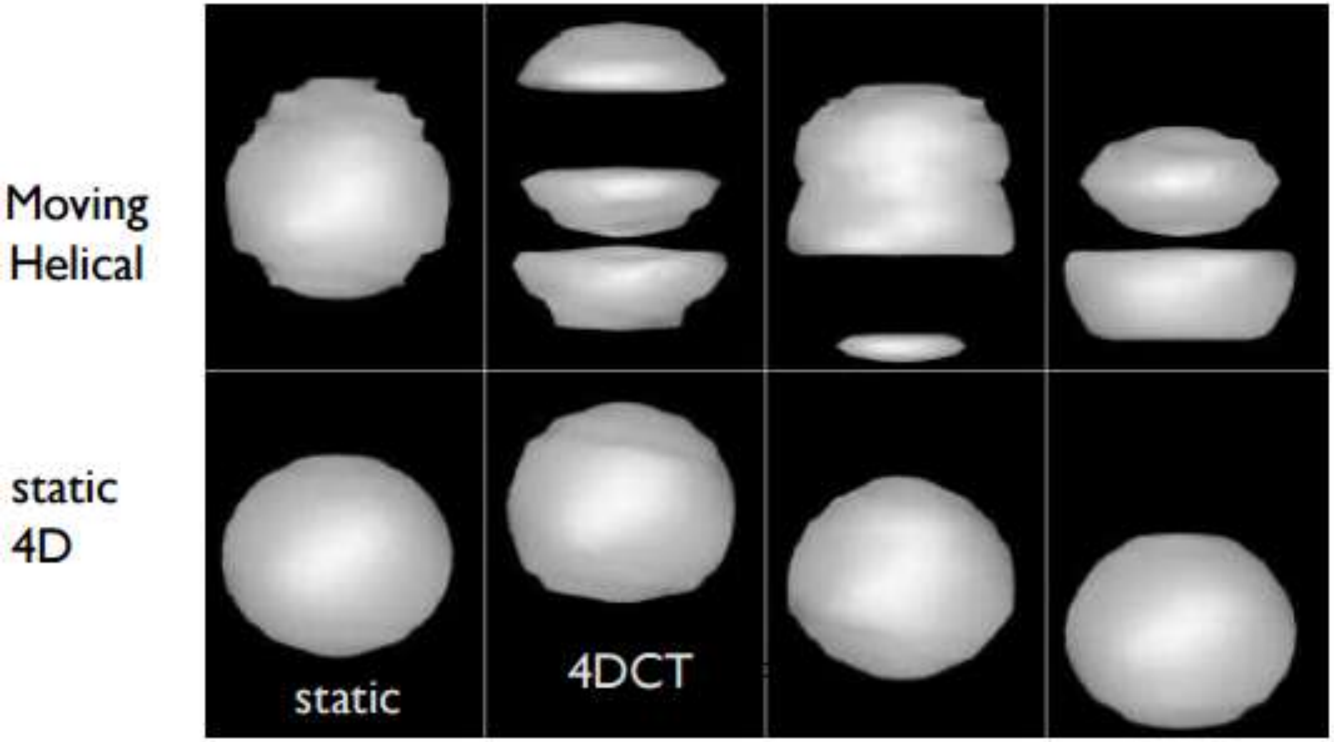
TG-132 Fusion Assessment Level

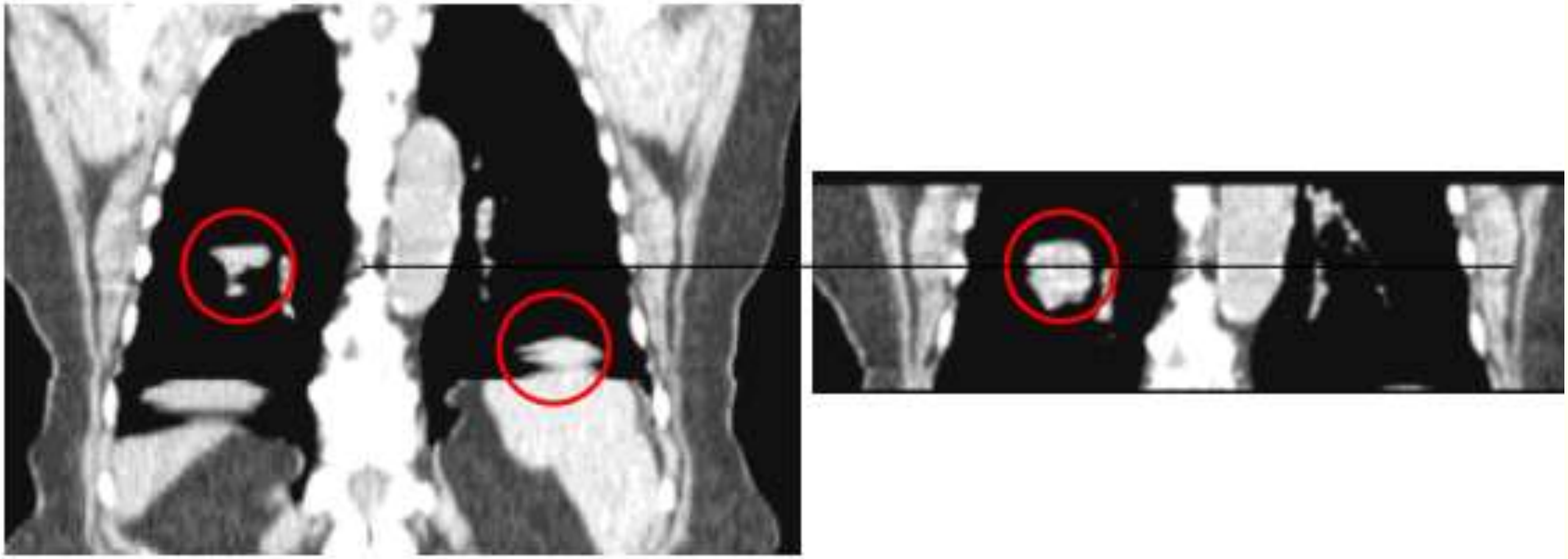
Uncertainty Assessment	Phrase	Description
0	Whole scan aligned	- Anatomy within 1 mm everywhere - Useful for structure definition everywhere - Ok for stereotactic localization
1	Locally aligned	- Anatomy local to the area of interest is un-distorted and aligned within 1mm - Useful for structure definition within the local region - Ok for localization provided target is in locally aligned region
2	Useable with risk of deformation	- Aligned locally, with mild anatomical variation - Acceptable registration required deformation which risks altering anatomy - Registered image shouldn't be used solely for target definition as target may be deformed - Increased reliance on additional information is highly recommended - Registered image information should be used in complimentary manner and no image should be used by itself
3	Useable for diagnosis only	- Registration not good enough to rely on geometric integrity - Possible use to identify general location of lesion (e.g. PET hot spot)
4	Alignment not acceptable	- Unable to align anatomy to acceptable levels - Patient position variation too great between scans (e.g. surgical resection of the anatomy of interest or dramatic weight change between scans)

4D: accurate shape / trajectory



Rietzel et al

4D can reduce shape artifacts



helical light breathing scan

4DCT dataset

PHYSICS CONTRIBUTION

RETROSPECTIVE ANALYSIS OF ARTIFACTS IN FOUR-DIMENSIONAL CT IMAGES OF 50 ABDOMINAL AND THORACIC RADIOTHERAPY PATIENTS

TOKIHIRO YAMAMOTO, PH.D., ULRICH LANGNER, PH.D., BILLY W. LOO, JR., M.D., PH.D., JOHN SHEN, B.S., AND PAUL J. KEALL, PH.D.

Department of Radiation Oncology, Stanford University School of Medicine, Stanford, CA

Purpose: To quantify the type, frequency, and magnitude of artifacts in four-dimensional (4D) CT images acquired using a multislice cine method.
Methods and Materials: Fifty consecutive patients who underwent 4D-CT scanning and radiotherapy for thoracic or abdominal cancers were included in this study. All the 4D-CT scans were performed on the GE multislice PET/CT scanner with the Varian Real-time Position Management system in cine mode. The GE Advantage 4D software was used to create 4D-CT data sets. The artifacts were then visually and quantitatively analyzed. We performed statistical analyses to evaluate the relationships between patient- or breathing-pattern-related parameters and the occurrence as well as magnitude of artifacts.
Results: It was found that 45 of 50 patients (90%) had at least one artifact (other than blurring) with a mean magnitude of 11.6 mm (range, 4.4–56.0 mm) in the diaphragm or heart. We also observed at least one artifact in 6 of 20 lung or mediastinal tumors (30%). Statistical analysis revealed that there were significant differences between several breathing-pattern-related parameters, including abdominal displacement ($p < 0.01$), for the subgroups of patients with and without artifacts. The magnitude of an artifact was found to be significantly but weakly correlated with the abdominal displacement difference between two adjacent couch positions ($R = 0.34$, $p < 0.01$).
Conclusions: This study has identified that the frequency and magnitude of artifacts in 4D-CT is alarmingly high. Significant improvement is needed in 4D-CT imaging.

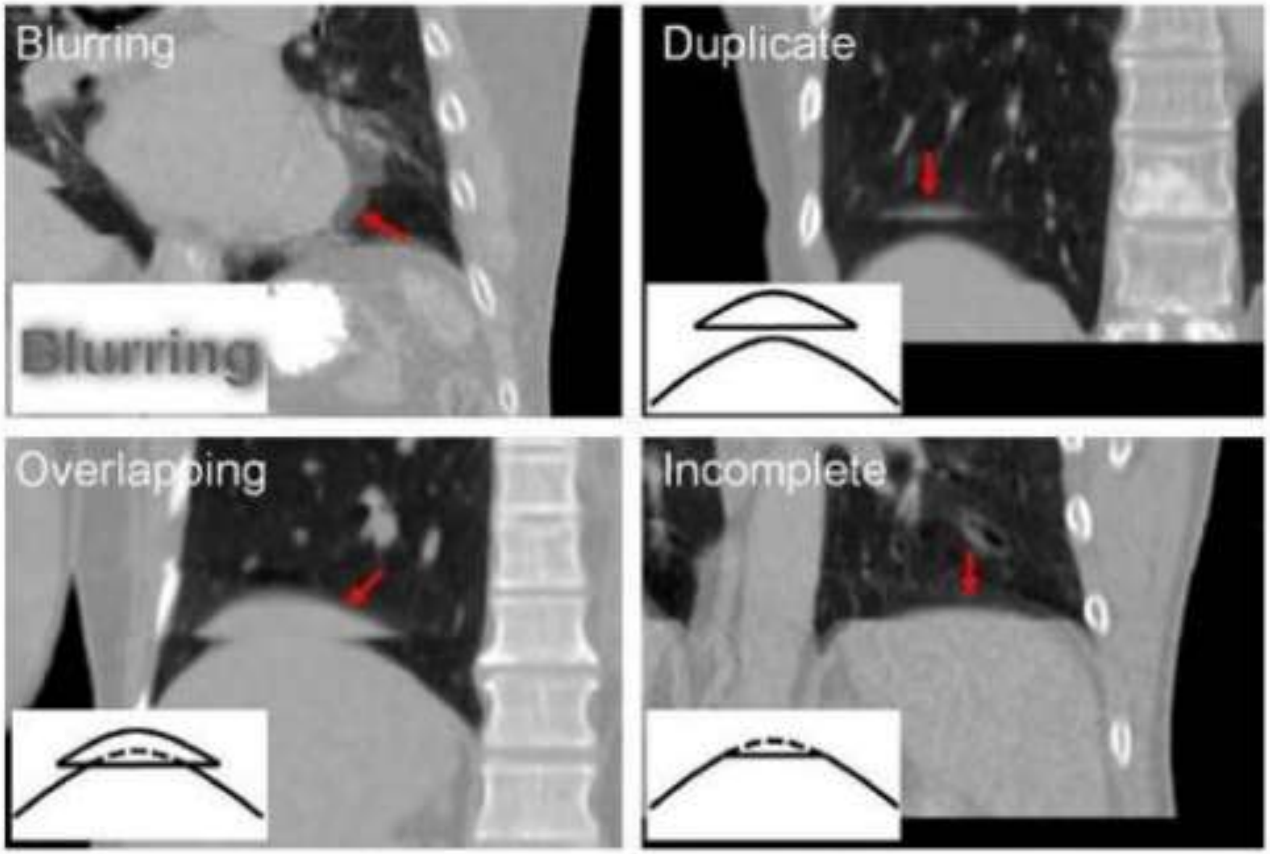


Fig. 2. Example four-dimensional CT images with schematic diagrams for the four types of artifacts: blurring, duplicate structure, overlapping structure, and incomplete structure. Corresponding artifacts are indicated by arrows in respective images. Note that other artifacts can also be observed in these images.

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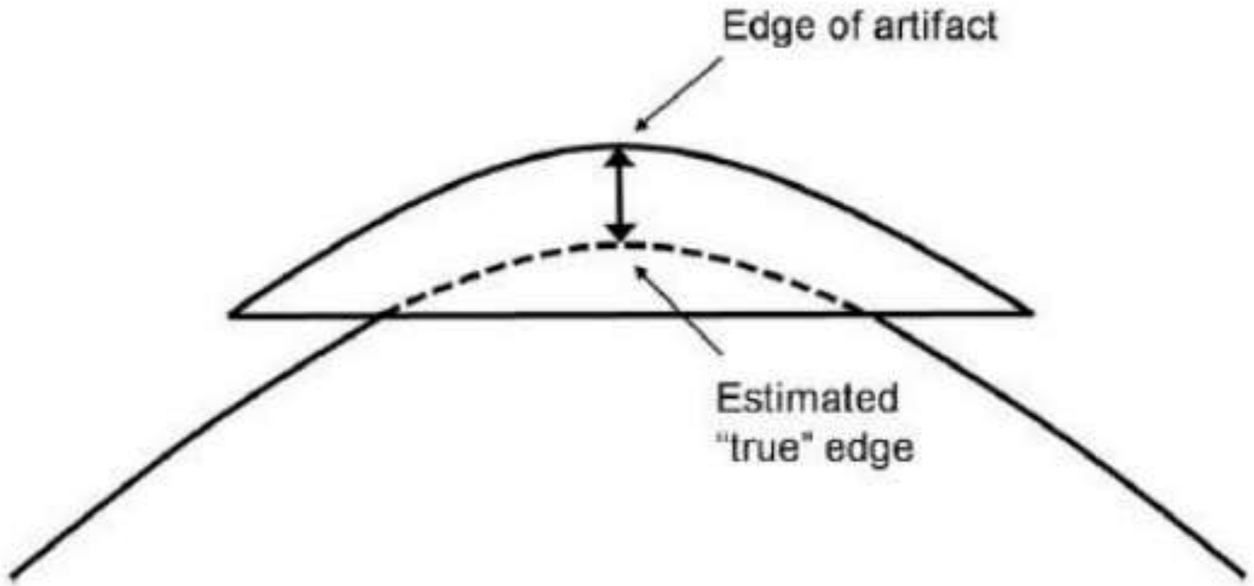

Fig. 3. A schematic diagram of the method to measure the artifact magnitude for the overlapping structure. The "true" edge was visually estimated by the observer. The distance in the superior-inferior direction between the edge of the artifact and the "true" edge of the organ was then measured. Duplicate and incomplete structure artifacts were also measured by the same method.

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- How prevalent are 4D artifacts?
- Examine retrospectively 50 patients with lung or abdominal tumors
- 90% of scans have at least one artifact!
- But this does not mean 90% of scans are not useful.

MR Image Distortion

- Magnetic field inhomogeneities and non-linear magnetic field gradients cause distortion
  - Distortion often worst in coronal sections; measuring Leksell fiducials can determine distortion severity

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- 1.8 ± 0.5 mm shift of MR images relative to

CT and delivered dose. Shifts occur in the

frequency encoding direction

- Y Watanabe, GM Perera, RB Mooij, "Image distortion in MRI-based polymer gel dosimetry of Gamma Knife stereotactic radiosurgery systems," Med. Phys. 29: 797-802, 2001

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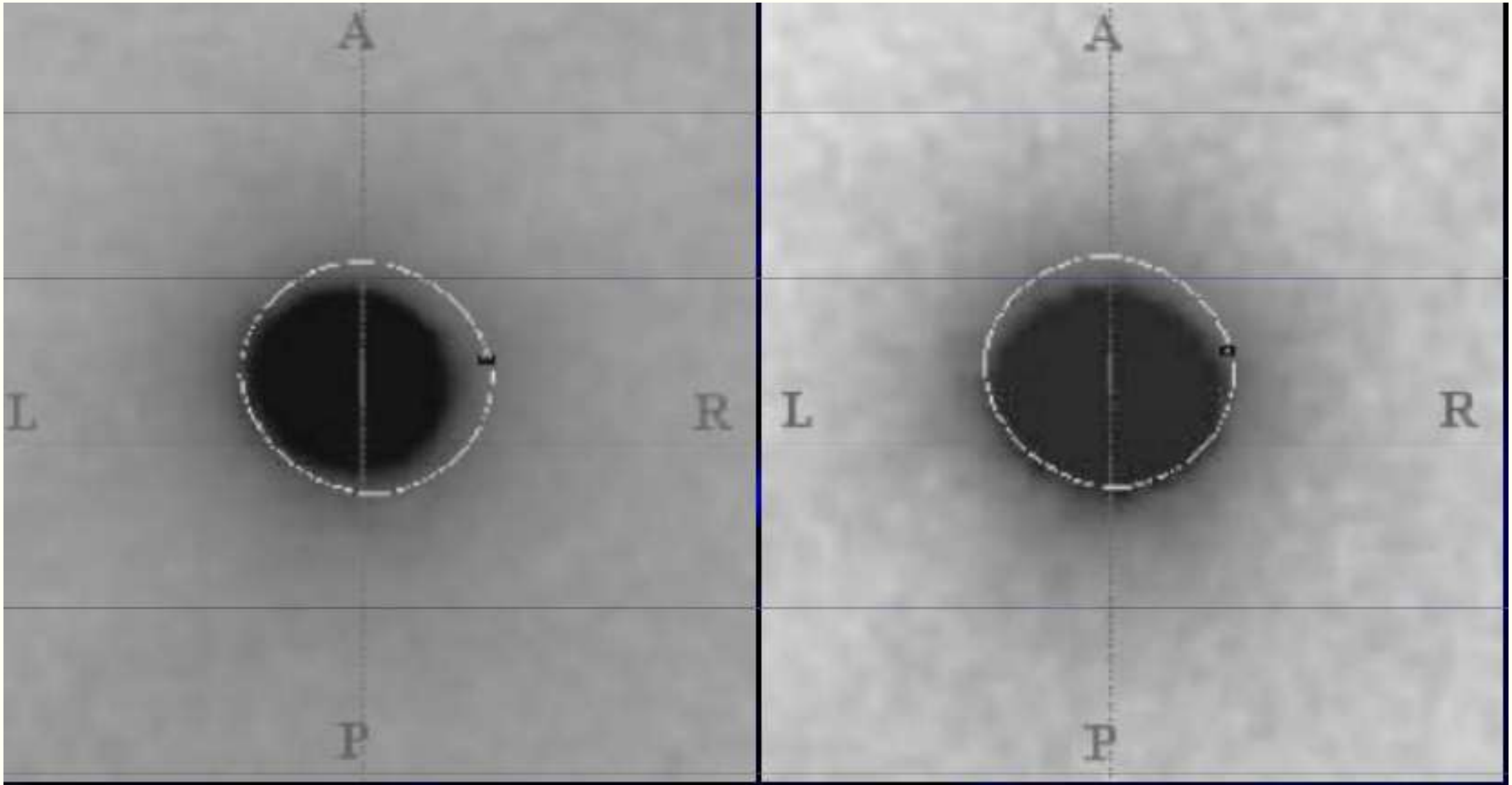

Frequency Encoding = L/R   **Frequency Encoding = A/P**

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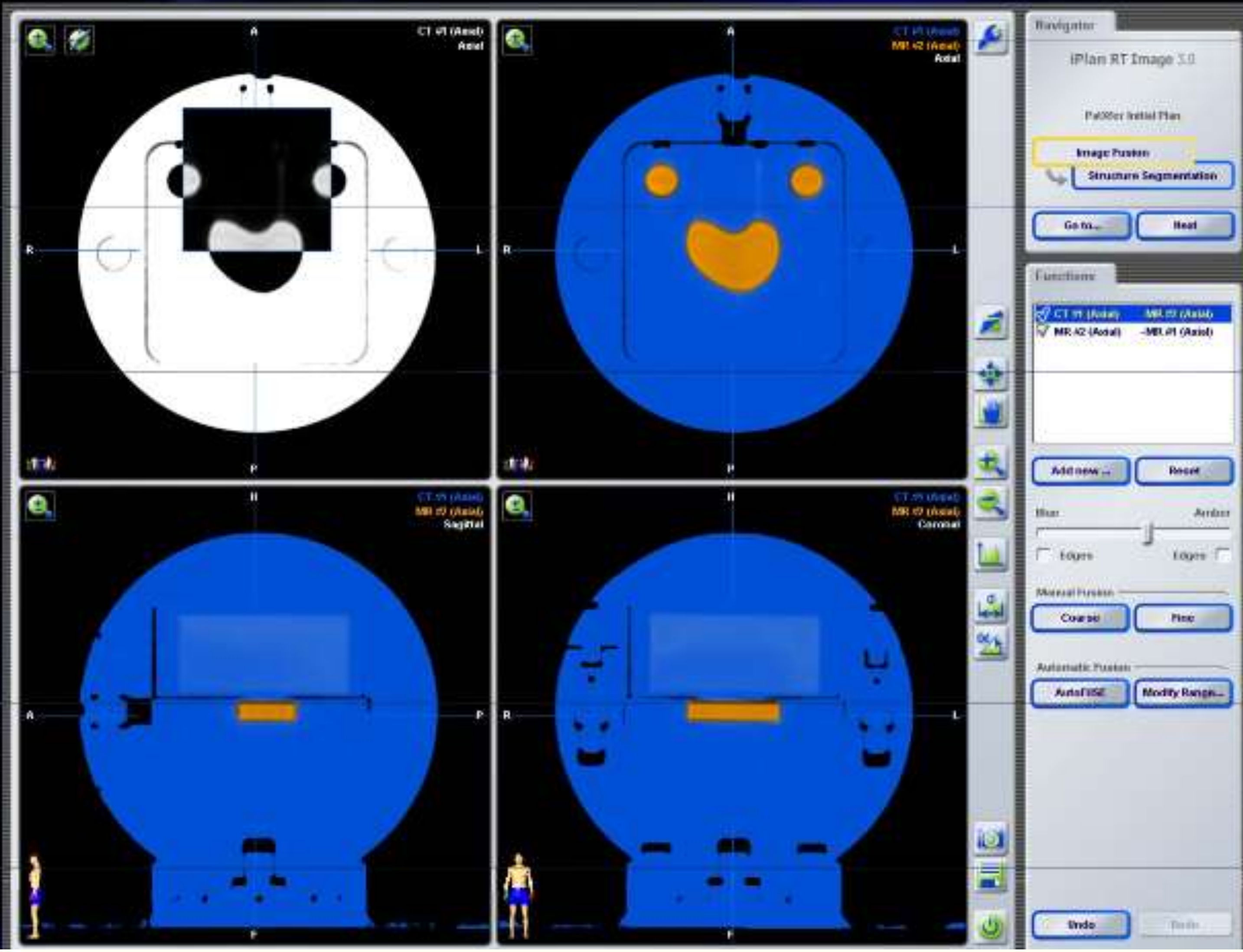
MR Fusion – Lucy Phantom



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LINAC REQUIREMENTS

History: Lars Leksell – 1968 - Gammaknife

Lars Leksell

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History of Linear Accelerator Based Radiosurgery

- Early reports of linac-based radiosurgery with stereotactic frames in 1980's
- Winston and Lutz published their results from Joint Center for Radiation Therapy in Boston in 1986
- Early linac treatments required attachment of circular collimators to standard linacs
- Radionics, Leibinger and Fischer, Philips, others began commercial distribution of add-on accessories in 1990s

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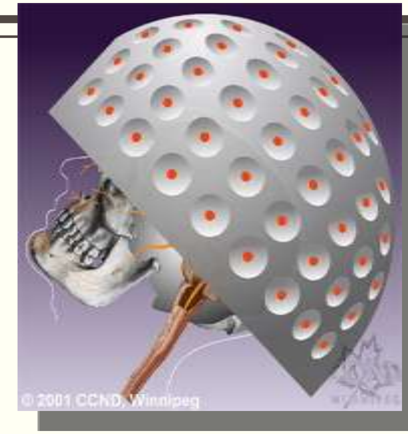
Current technology

- Gamma Knife® by Elekta
  - Uses 192 to 201 beams of highly-focused gamma rays
    - All beams aim at target region
- Linear accelerator (LINAC) machines
  - accelerate photons
    - Brainlab
    - CyberKnife® by Accuray
    - Elekta
    - Varian
    - ZAP
- Proton beam machine



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Traditional Linac Stereotactic Radiosurgery Equipment

Collimator set Typically ~5-60 mm diameter

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Varian Edge

- Multileaf Collimator

High-definition 120 Multileaf Collimator

Center 2.5 mm width x 32 pairs

Peripheral 5 mm width x 28 pairs

Maximum static field size 40 cm x 22 cm

6D Couch with KV imaging

Versa HD with Agility/APEX MLC

2.5mm resolution
12 cm x 14 cm Max Static field
6D Couch with KV imaging
Agility: 5mm up to 40 x 40 cm
giving Effective 1mm
using jaw modulation


ACCURAY

TABLE I. Daily.

Procedure	Machine-type tolerance		
	Non-IMRT	IMRT	SRS/SBRT
Dosimetry			
X-ray output constancy (all energies)			
Electron output constancy (weekly, except for machines with unique e-monitoring requiring daily)		3%	
Mechanical			
Laser localization	2 mm	1.5 mm	1 mm
Distance indicator (ODI) @ iso	2 mm	2 mm	2 mm
Collimator size indicator	2 mm	2 mm	1 mm
Safety			
Door interlock (beam off)		Functional	
Door closing safety		Functional	
Audiovisual monitor(s)		Functional	
Stereotactic interlocks (lockout)	NA	NA	Functional
Radiation area monitor (if used)		Functional	
Beam on indicator		Functional	

Table II. Monthly.

	Machine-type tolerance		
Procedure	Non-IMRT	IMRT	SRS/SBRT
Dosimetry			
X-ray output constancy			
Electron output constancy		2%	
Backup monitor chamber constancy			
Typical dose rate[a] output constancy	NA	2% (@ IMRT dose rate)	2% (@ stereo dose rate, MU)
Photon beam profile constancy		1%	
Electron beam profile constancy		1%	
Electron beam energy constancy		2%/2 mm	
Mechanical			
Light/radiation field coincidence[b]		2 mm or 1% on a side	
Light/radiation field coincidence[b] (asymmetric)		1 mm or 1% on a side	
Distance check device for lasers compared with front pointer		1mm	
Gantry/collimator angle indicators (@ cardinal angles) (digital only)		1.0°	
Accessory trays (i.e., port film graticle tray)		2 mm	
Jaw position indicators (symmetric)[c]		2 mm	
Jaw position indicators (asymmetric)[d]		1 mm	
Cross-hair centering (walkout)		1 mm	
Treatment couch position indicators[e]	2 mm/1°	2 mm/1°	1 mm/0.5°
Wedge placement accuracy		2 mm	
Compensator placement accuracy[f]		1 mm	
Latching of wedges, blocking tray[g]		Functional	
Localizing lasers	±2 mm	±1 mm	<±1 mm
Safety			
Laser guard-interlock test		Functional	
Respiratory gating			
Beam output constancy		2%	
Phase, amplitude beam control		Functional	
In-room respiratory monitoring system		Functional	
Gating interlock		Functional	

[a]Dose monitoring as a function of dose rate.
[b]Light/radiation field coincidence need only be checked monthly if light field is used for clinical setups.
[c]Tolerance is summation of total for each width or length.
[d]Asymmetric jaws should be checked at settings of 0.0 and 10.0.
[e]Lateral, longitudinal, and rotational.

Table III. Annual.

Procedure	Machine-type tolerance		
	Non-IMRT	IMRT	SRS/SBRT
Dosimetry			
X-ray flatness change from baseline		1%	
X-ray symmetry change from baseline		±1%	
Electron flatness change from baseline		1%	
Electron symmetry change from baseline		±1%	
SRS arc rotation mode (range: 0.5–10 MU/deg)	NA	NA	Monitor units set vs delivered: 1.0 MU or 2% (whichever is greater) Gantry arc set vs delivered: 1.0° or 2% (whichever is greater)
X-ray/electron output calibration (TG-51)		±1% (absolute)	
Spot check of field size dependent output factors for x ray (two or more FSs)		2% for field size $<4\times4$ cm^2, 1% $\geq4\times4$ cm^2	
Output factors for electron applicators (spot check of one applicator/energy)		±2% from baseline	
X-ray beam quality (PDD_{10} or TMR_{10}^{20})		±1% from baseline	
Electron beam quality (R_{50})		±1 mm	
Physical wedge transmission factor constancy		±2%	
X-ray monitor unit linearity (output constancy)	±2% ≥5 MU	±5% (2–4 MU), ±2% ≥5 MU	±5% (2–4 MU), ±2% ≥5 MU
Electron monitor unit linearity (output constancy)		±2% ≥5 MU	
X-ray output constancy vs dose rate		±2% from baseline	
X-ray output constancy vs gantry angle		±1% from baseline	
Electron output constancy vs gantry angle		±1% from baseline	
Electron and x-ray off-axis factor constancy vs gantry angle		±1% from baseline	
Arc mode (expected MU, degrees)		±1% from baseline	
TBI/TSET mode		Functional	
PDD or TMR and OAF constancy		1% (TBI) or 1 mm PDD shift (TSET) from baseline	
TBI/TSET output calibration		2% from baseline	
TBI/TSET accessories		2% from baseline	
Mechanical			
Collimator rotation isocenter		±1 mm from baseline	

Mechanical			
Collimator rotation isocenter		±1 mm from baseline	
Gantry rotation isocenter		±1 mm from baseline	
Couch rotation isocenter		±1 mm from baseline	
Electron applicator interlocks		Functional	
Coincidence of radiation and mechanical isocenter	±2 mm from baseline	±2 mm from baseline	±1 mm from baselin
Table top sag		2 mm from baseline	
Table angle		1°	
Table travel maximum range movement in all directions		±2 mm	
Stereotactic accessories, lockouts, etc.	NA	NA	Functional

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
Monthly		
Planar MV imaging (EPID)		
Imaging and treatment coordinate coincidence (four cardinal angles)	≤2 mm	≤1 mm
Scaling[b]	≤2 mm	≤2 mm
Spatial resolution	Baseline[c]	Baseline
Contrast	Baseline	Baseline
Uniformity and noise	Baseline	Baseline
Planar kV imaging[d]		
Imaging and treatment coordinate coincidence (four cardinal angles)	≤2 mm	≤1 mm
Scaling	≤2 mm	≤1 mm
Spatial resolution	Baseline	Baseline
Contrast	Baseline	Baseline
Uniformity and noise	Baseline	Baseline
Cone-beam CT (kV and MV)		
Geometric distortion	≤2 mm	≤1 mm
Spatial resolution	Baseline	Baseline
Contrast	Baseline	Baseline
HU constancy	Baseline	Baseline
Uniformity and noise	Baseline	Baseline

	Annual (A)	
Planar MV imaging (EPID)		
Full range of travel SDD	±5 mm	±5 mm
Imaging dose[e]	Baseline	Baseline
Planar kV imaging		
Beam quality/energy	Baseline	Baseline
Imaging dose	Baseline	Baseline
Cone-beam CT (kV and MV)		
Imaging dose	Baseline	Baseline

[a]Or at a minimum when devices are to be used during treatment day.
[b]Scaling measured at SSD typically used for imaging.
[c]Baseline means that the measured data are consistent with or better than ATP data.
[d]kV imaging refers to both 2D fluoroscopic and radiographic imaging.
[e]Imaging dose to be reported as effective dose for measured doses per TG 75[36].

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Summery of the Tolerances

Procedure	SRS/SBRT Tolerance
Radiation/Mechanical Isocenter	±1 mm from baseline
Collimator Rotation Isocenter	±1 mm from baseline
Gantry Rotation Isocenter	±1 mm from baseline
Couch Rotation Isocenter	±1 mm from baseline
Laser Localization	1 mm
Collimator Size Indicator	1mm
Couch Position	1mm/0.5°
Table Top Sag	1 mm

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Treatment Planning

- After commissioning has identified appropriate uses and limitations for the TPS, the goal is to detect deviations
  - RPC (now IROC) data suggests ~80% of institutions can achieve dosimetric accuracy of ~7%
  - TG-53 provides comprehensive guidelines for QA
  - Treatment process should standardize parameters such as beam arrangements, calc. grid size, jaw tracking
- TPS upgrades are a source of changes, so re-testing is required after upgrades

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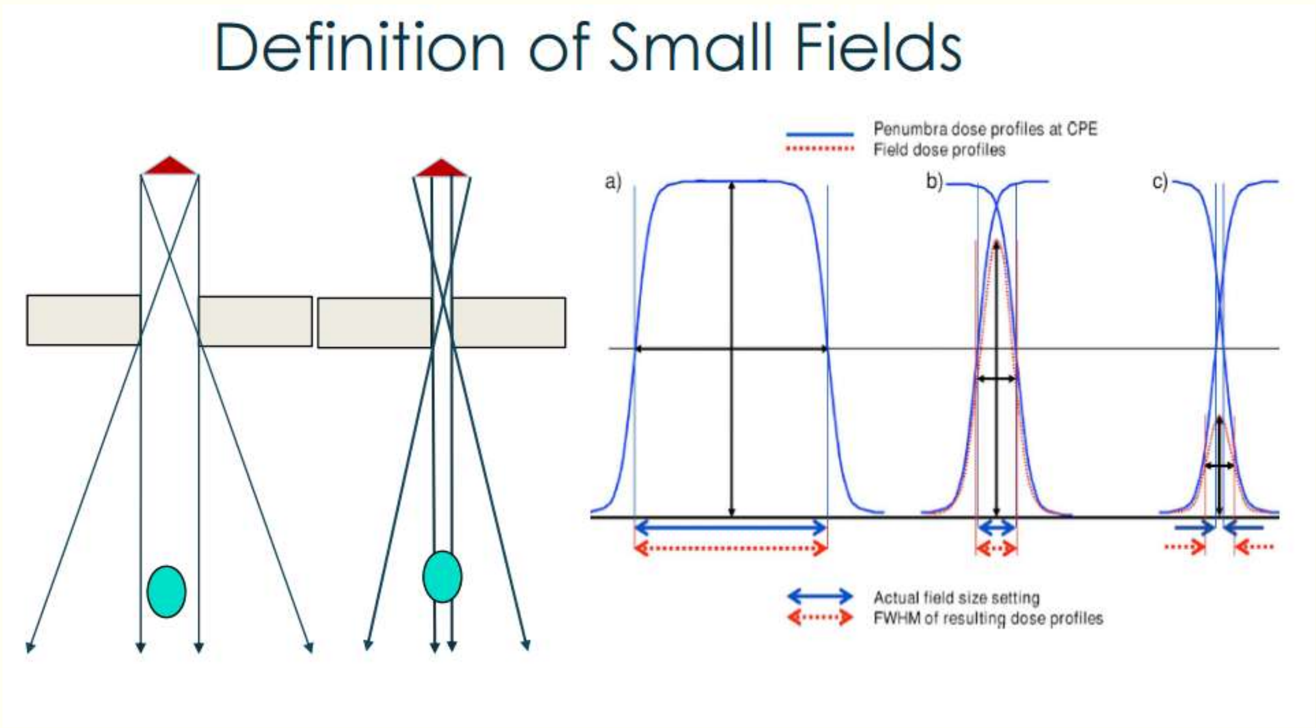
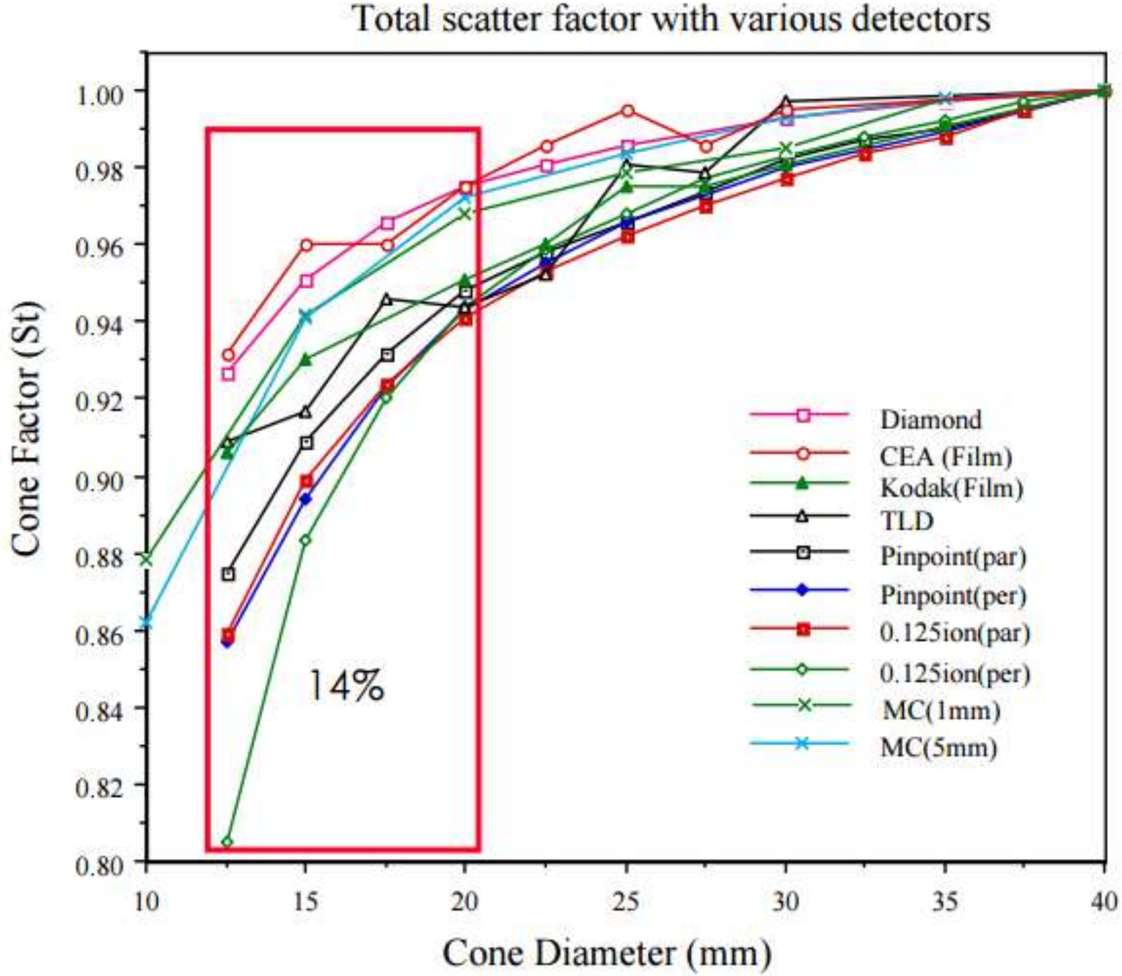
Treatment Planning commissioning

- Small Field Dosimetry – Data Collection and Modeling



Dosimetric Variation with Detectors



Das et al, J Radiosurgery, 3, 177-186, 2000

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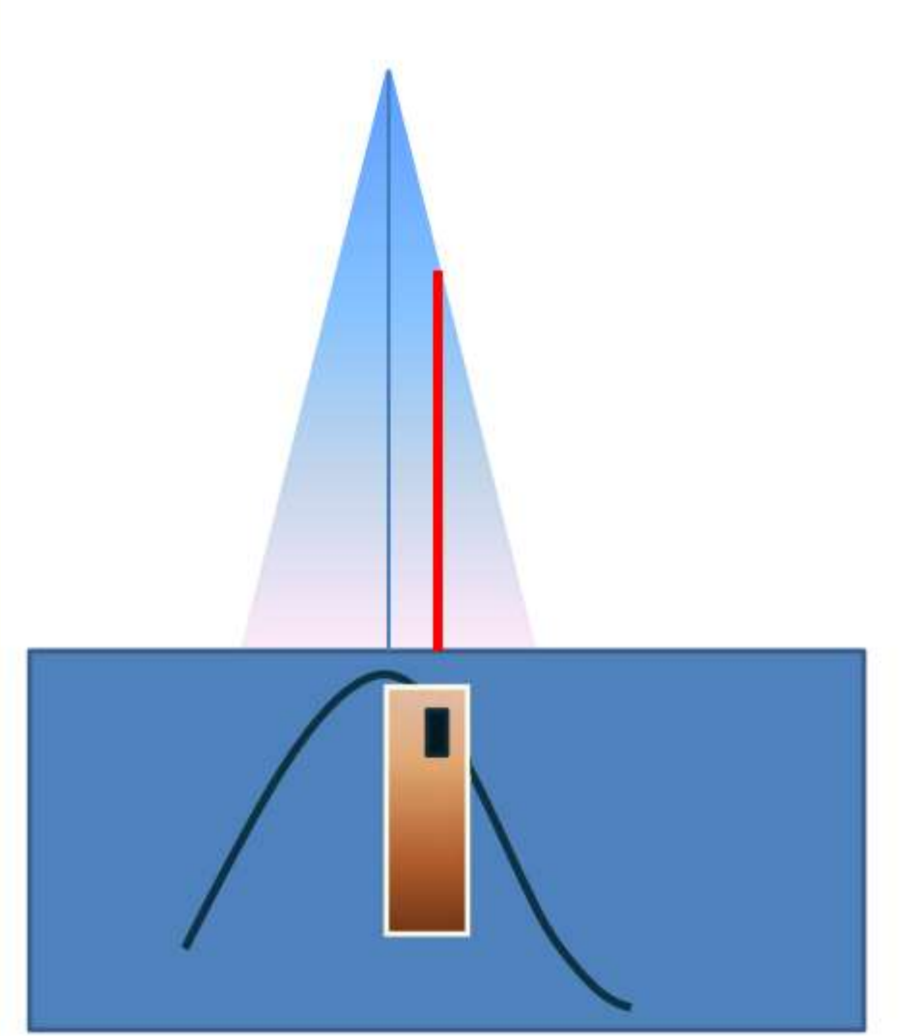
Small field Detector Selection

- Experimental Setup Consistency



OF Correction

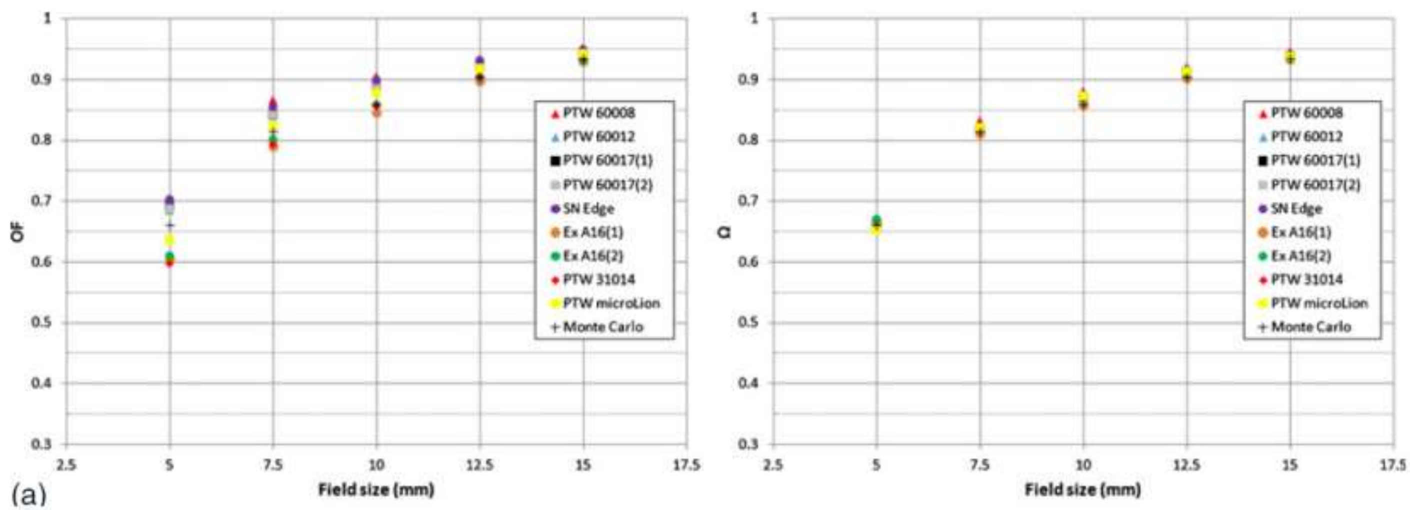
- **MC differs from TRS-398**
- **Effects of correction for several collimator systems**

Francescon et al, PMB 57 (2012) 3741

Table 1. Values of k_{Q_{msr},Q_0} calculated by Monte Carlo simulation of the CyberKnife system an a reference Co-60 beam. For comparison, $k_{Q,Q0}$ extracted from TRS-398 using a hypothetic 100 × 100 mm^2 TPR20/10 converted using the method of Sauer (2009) from the measure TPR20/10 at 60 mm circular field size is shown, together with the difference between these tw calculations.

Chamber	k_{Q_{msr},Q_0}	$k_{Q,Q0}$ (TRS-398)	Difference (%)
PTW 30006 Farmer	1.000	0.993	+0.7%
PTW 31014 PinPoint	0.990	0.995	−0.5%
Exradin A12 Farmer	1.006	0.997	+0.9%
NE 2571 Farmer	1.003	0.995	+0.8%
PTW 31010 Semiflex	0.990	–	–

Correction factors for CyberKnife dosimetry 3753



Is the OF Measurement Correct?

- CyberKnife has reference data set available in commissioning tool.
- "Golden" beam data sets
- Literature

		10 x 10	6 x 6	4 x 4	3 x 3	2 x 2	1 x 1	.5 x .5
Elekta *	MLC	1	0.930	0.878	0.842	0.790	N/A	N/A
Varian *	MLC	1	0.921	0.865	0.828	0.786	N/A	N/A
BrainLab	mMLC	See Next Slide						
BrainLab	Cone	1	N/A	N/A	0.969	0.926	0.85	0.711
CK	Cone	N/A	1	0.997	0.993	0.974	0.911	0.709

- *JACMP Vol 13 (5) 2012:

Independent Output Check

- Absolutely necessary before treating a patient!
- Too many misadministrations based on reference dosimetry gone wrong
- E.g. use TLD/OSLD service
- Peer review

Understand the detectors available

Attribute	Ionization chamber	Micro Chambers	Stereotactic Diodes	Diamond detector	Plastic Scintillator	Gels
Field size	≥ 2 cm x 2 cm	≥ 3 mm x 3 mm	≥ 3 mm x 3 mm	≥ 3 mm x 3 mm	≥ 3 mm x 3 mm	≥ 3 mm x 3 mm
Energy dependence	Use k_Q to correct energy dependence	Use k_Q to correct energy dependence	Normalize at 4 cm^2 for energy dependence	Almost none	Almost none	Depends on gel material
Drawbacks	Volume effect	Stem and cable effect, S/N ratio	Some models: Aging, dose rate	Weak dose rate dependence; availability	S/N ratio; temperature dependence; cable irradiation	Availability
Advantage	Familiarity/ Availability	Spatial resolution	Small size, availability	Near ideal	Small size	Spatial resolution

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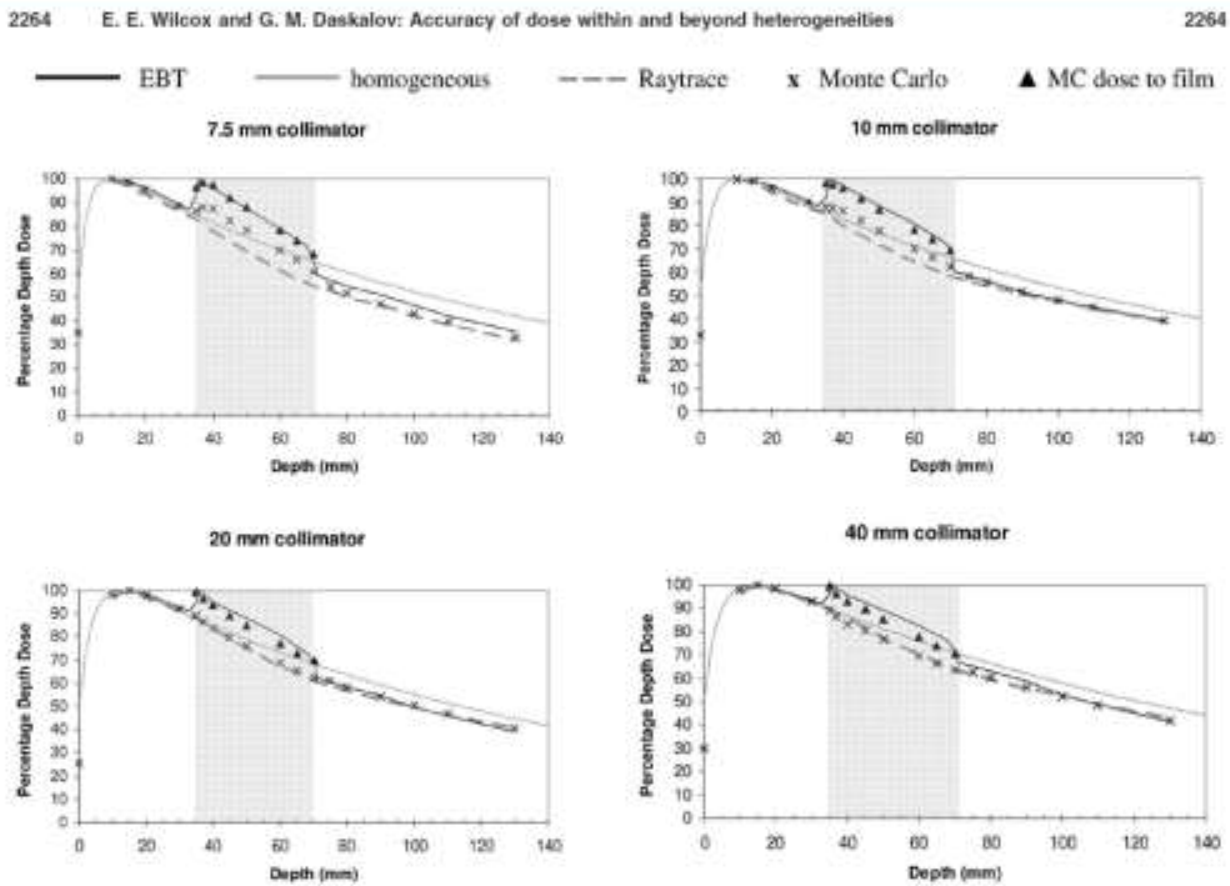
Dosimetry: Dose Calculation Algorithm



Common MC uncertainty setting: 2% at maximum dose

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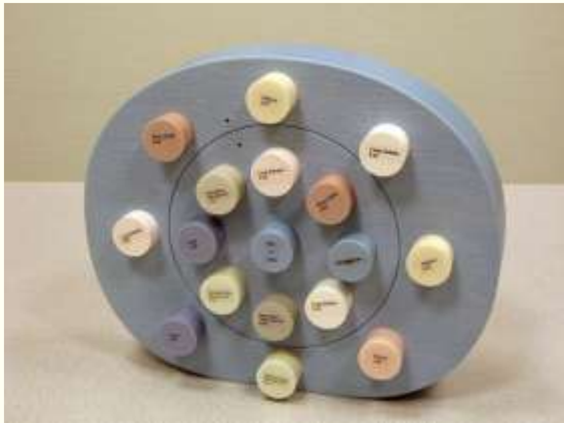
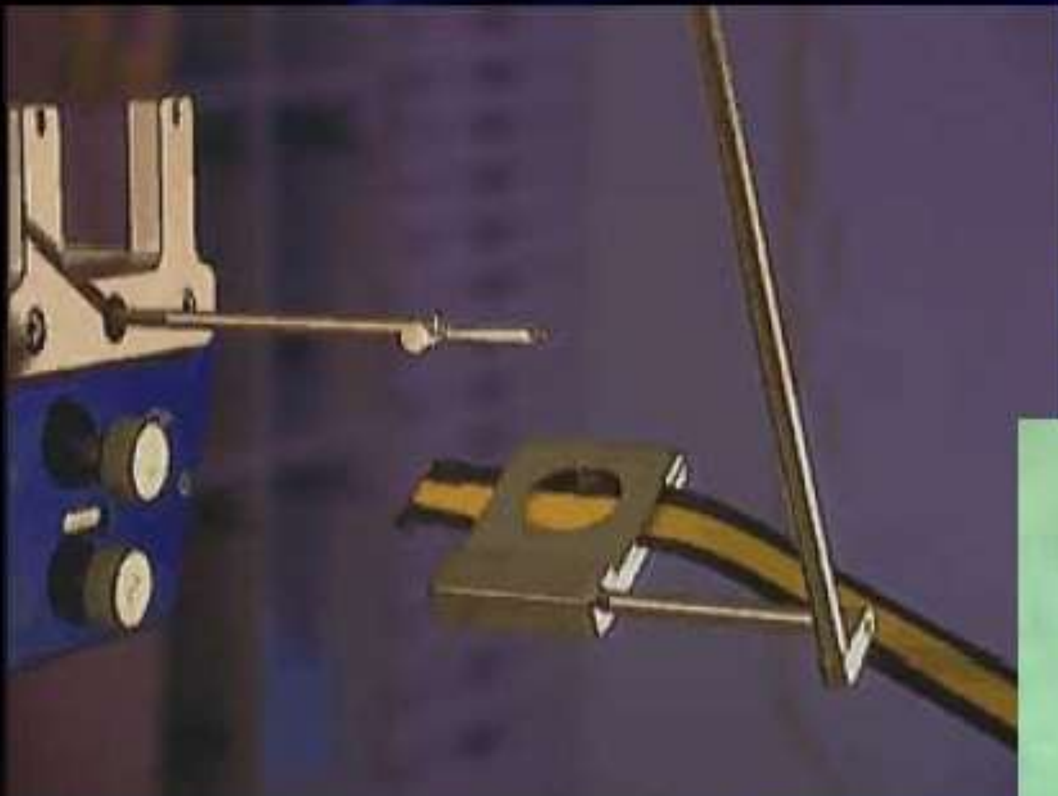
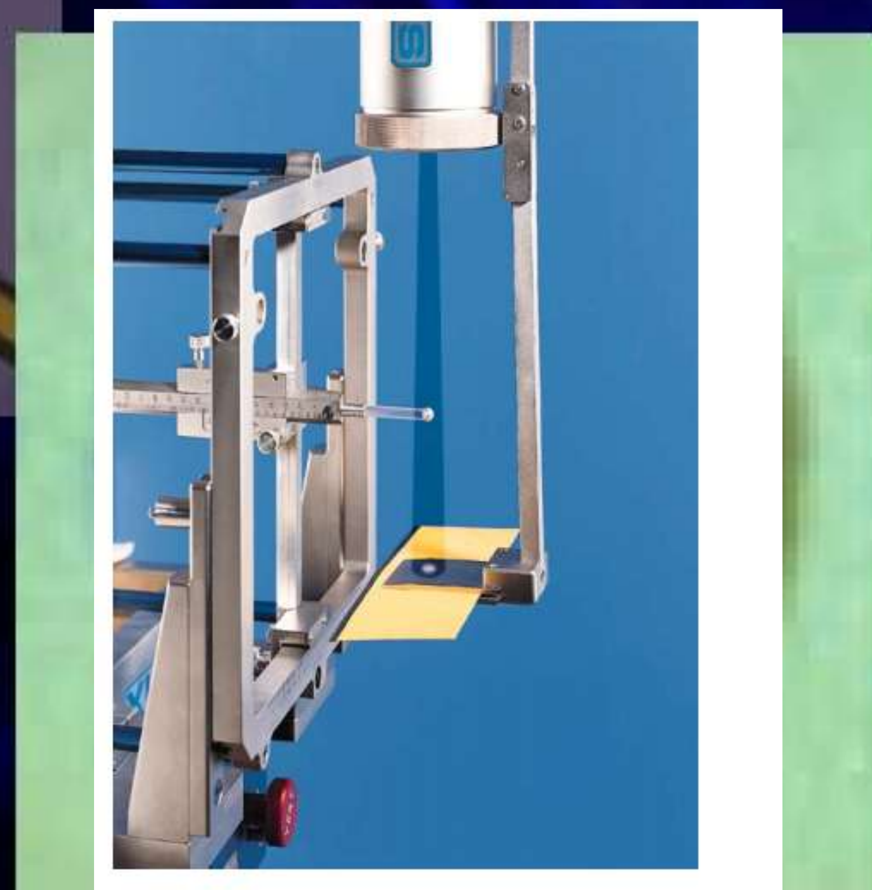
Challenges in CT-to-material conversions

- Can result in errors in dose estimations
- Dose errors up to 10% **for** 6 & 15 MV photons
- Go up to 30% for 18 MeV electrons
- Conversion techniques based purely on mass density is discouraged
- Artifacts are potentially important in MC dose calculations



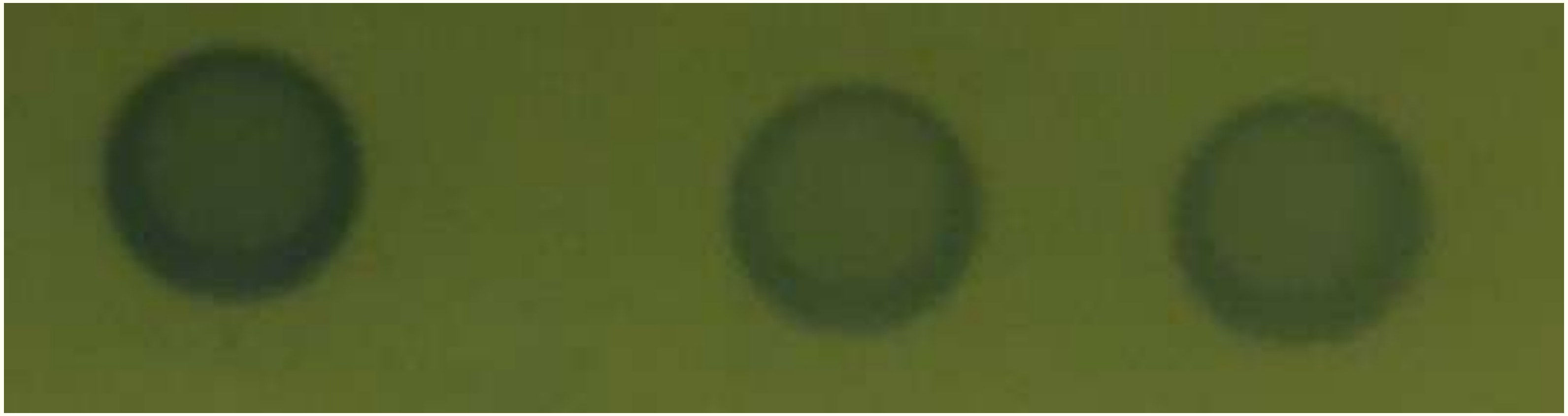
Isocentric Accuracy





Is the projection of the ball centered within the field?

Test results



Max Tolerances: 1mm

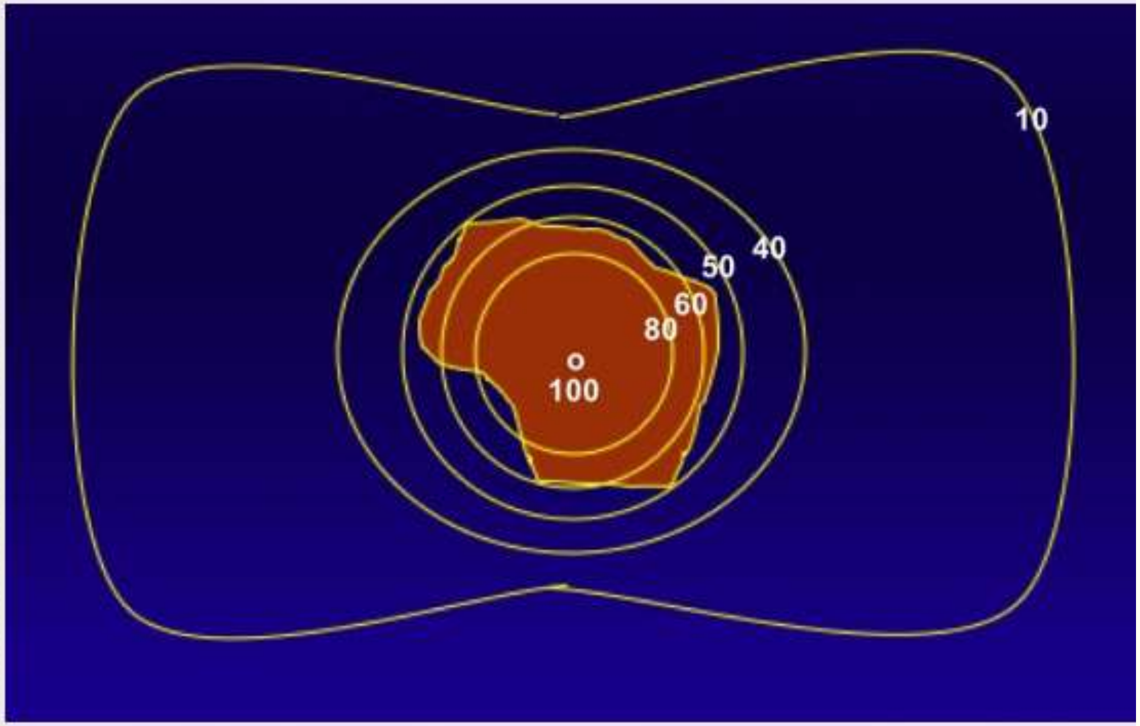
End To End Test

Treatment Planning

- Multiple non-coplanar converging arcs technique:
- Target dose is delivered through a series of gantry arcs, each arc with a different stationary position of the treatment couch or chair.
- Arc angles are usually smaller than 180^o to avoid parallel-opposed beams in the plane of the arc.
- Typical number of arcs used ranges from 4 to 11.

Target coverage with various isodose surfaces:

The 50 % isodose surface covers the target well but also irradiates much of healthy surrounding tissue.



If the dose is prescribed to the 50 % isodose surface, target dose inhomogeneity is very large, but the dose conformity to the target is optimized.

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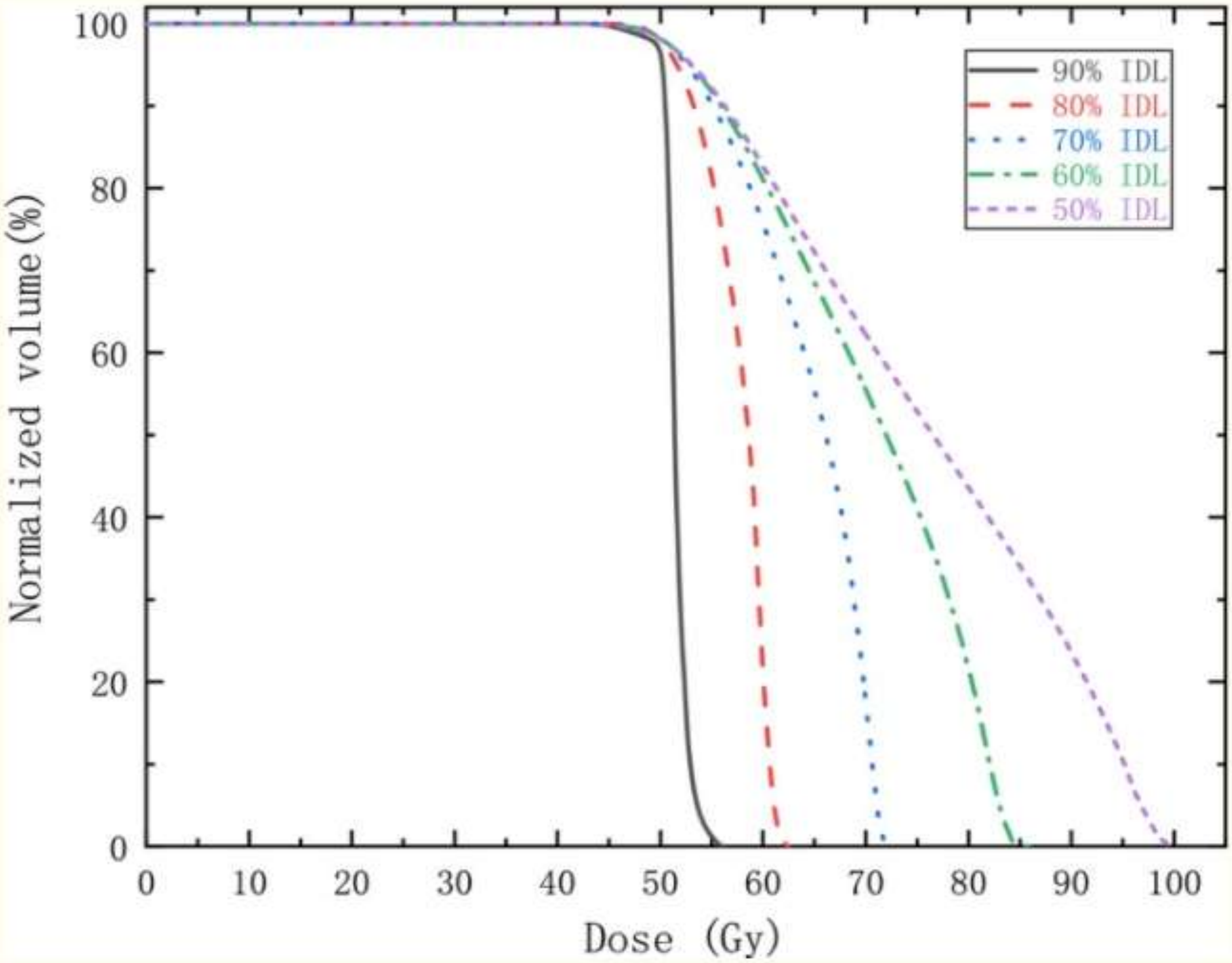

Xu, Y., Ma, P., Xu, Y., & Dai, J. (2019). Selection of prescription isodose line for brain metastases treated with volumetric modulated arc radiotherapy. *Journal of applied clinical medical physics*, *20*(12), 63–69. https://doi.org/10.1002/acm2.12761

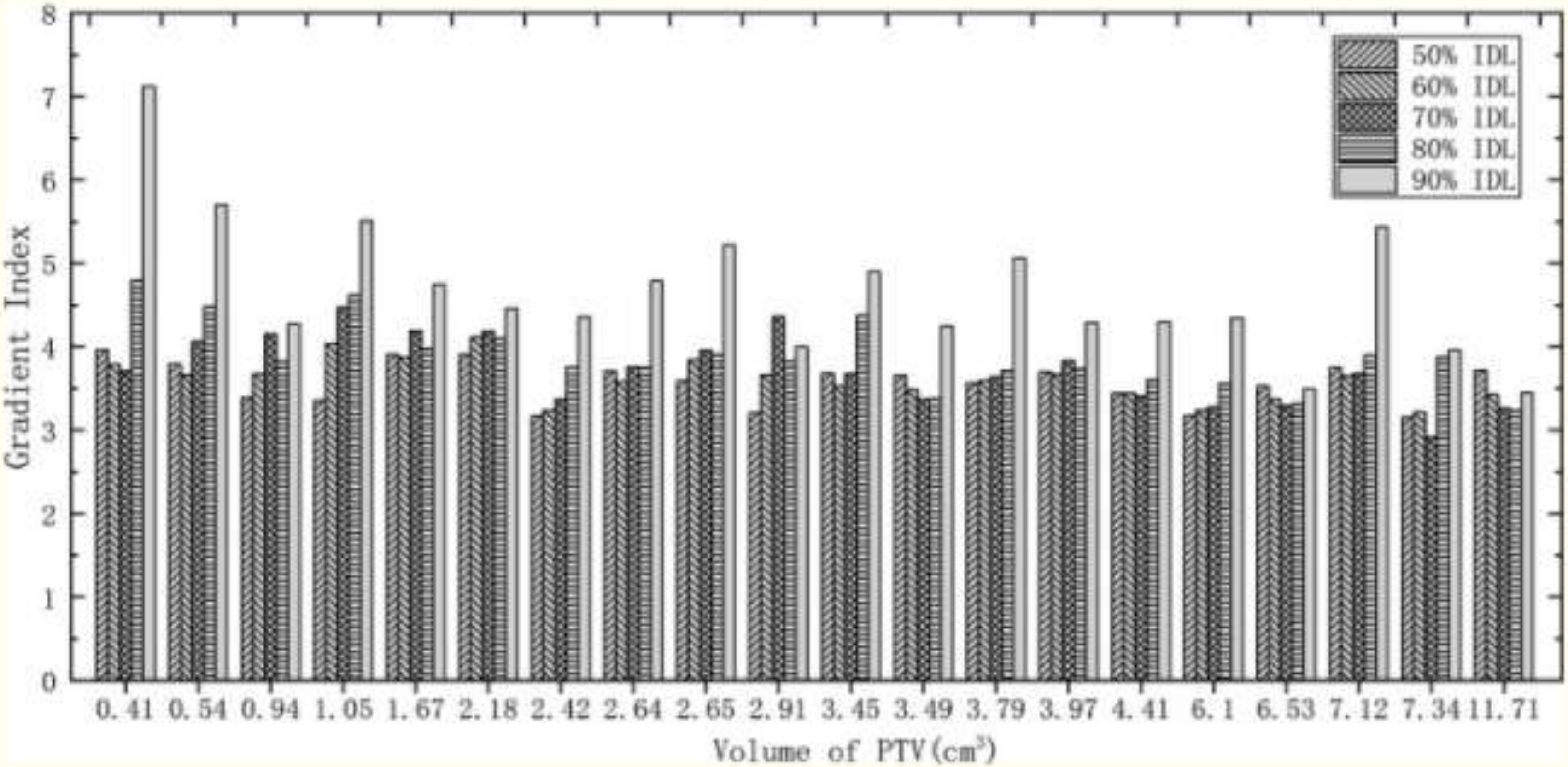

Figure 2

The gradient index for individual lesions sorted to size.

Xu, Y., Ma, P., Xu, Y., & Dai, J. (2019). Selection of prescription isodose line for brain metastases treated with volumetric modulated arc radiotherapy. *Journal of applied clinical medical physics*, *20*(12), 63–69. https://doi.org/10.1002/acm2.12761

Evaluation – Conformity Index

$$CI = \frac{\text{Volume of target covered by PI}}{\text{Volume of PI}} \times \frac{\text{Volume of target covered by PI}}{\text{Volume of Target}}$$

First factor ↓ Overtreatment Ratio

Second factor ↓ Undertreatment Ratio

CI = 1.0 represents perfect conformity

Paddick, *J Neurosurg* **93** Suppl. 3 (2000), pp. 219–222

Evaluation – Gradient Index

$$GI = \frac{\text{Volume of isodose that is ½ of PI}}{\text{Volume of PI}}$$

Measures how quickly dose is dropping outside of target:

Example: If prescription isodose is at 60%, measure volume of 30% / 60%

GI < 3.0 is "good" dose falloff

Paddick, et. al., *J Neurosurg* **105** Suppl. 7 (2006), pp. 194-201

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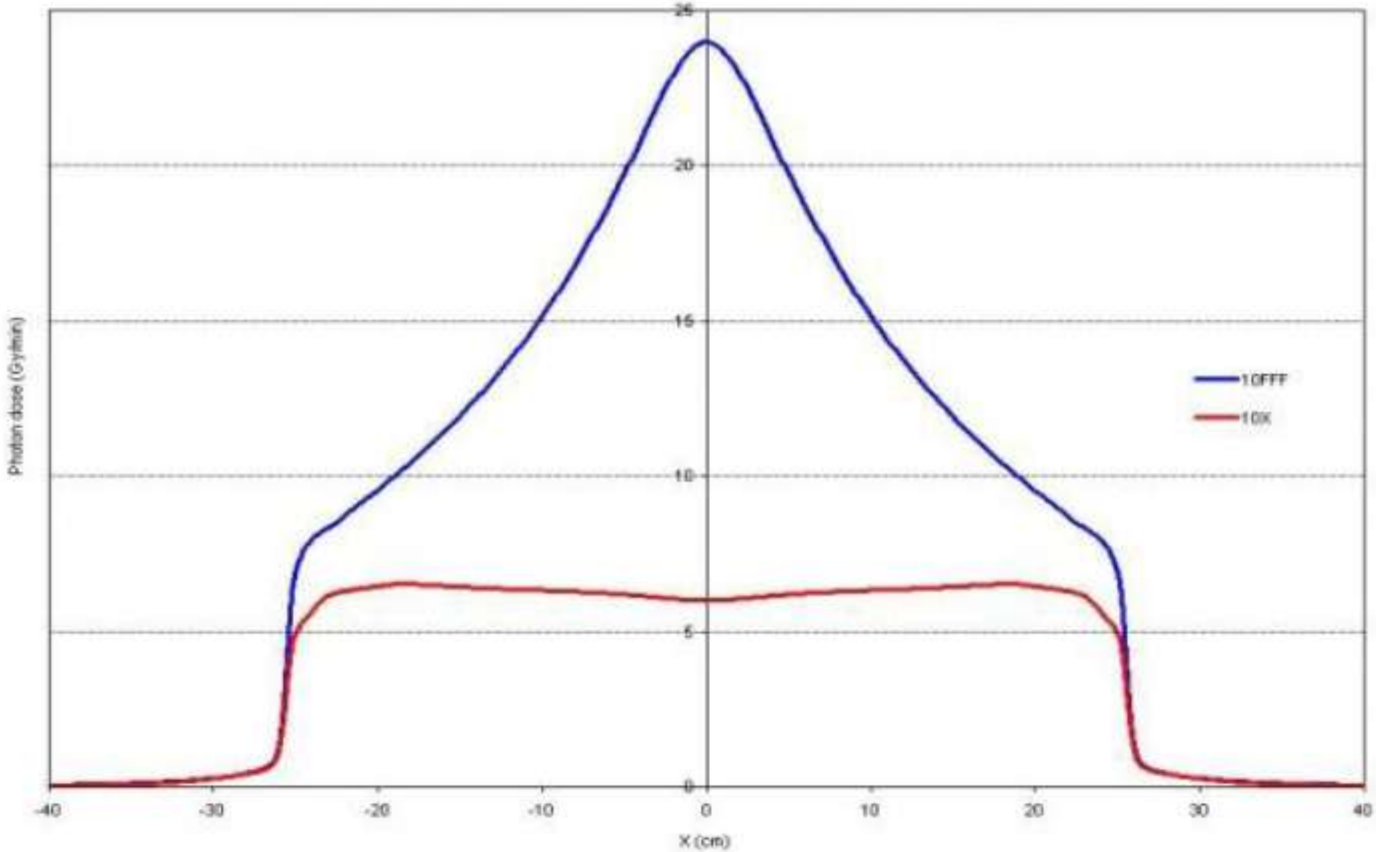
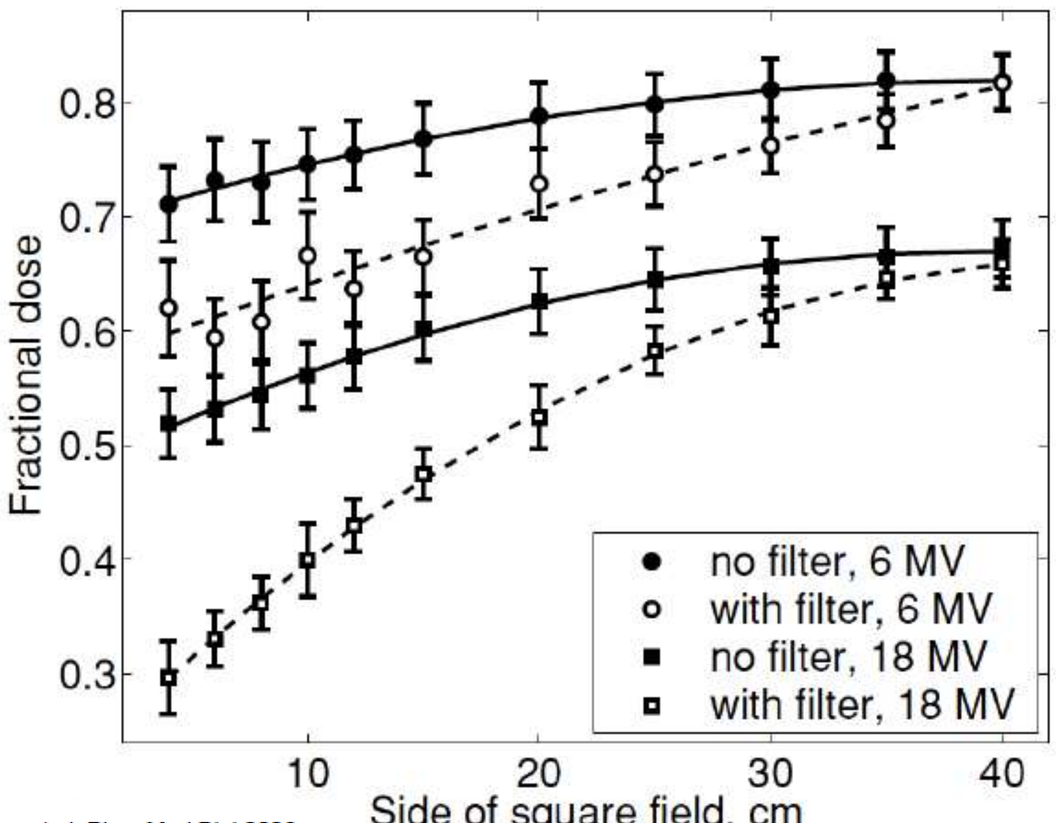
Beam Profile – Flattening Filter



Relative to a flattened beam of the same energy, the surface dose for a flattening filter free beam is higher for small field sizes and comparable at 40x40 cm2



Vassiliev et al. Phys Med Biol 2006

Reference: Vassiliev ON, Titt U, Pönisch F, Kry SF, Mohan R, Gillin MT. Dosimetric properties of photon beams from a flattening filter free clinical accelerator. Phys Med Biol. 2006 Apr 7;51(7):1907-17

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Delivery QA -DEPTH HELMET

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AMRITA INSTITUTE OF MEDICAL SCIENCES & RESEARCH CENTER,
DEPARTMENT OF MEDICAL PHYSICS & RADIATION SAFETY,

SRS DEPTH HELMET MEASUREMENT SHEET

PATIENT DETAILS

Name	Aminath Ali	Physicist(s)	SS
M.R.NO.	1774432	Date	15/12/16
RT NO	16RT1355	SITE	AVM

Hole No	Scale reading		
	Before CT	Before treatment	
0	83	83	
A1	84	84	
A3	80	80	
A5	73	73	
A7	98	99	+1
B2	78	78	
B4	69	69	
B6	88	88	
B8	104	104	
C5	58	59	+1
C6	81	81	
C7	104	105	+1
C1	73	73	
C8	101	101	

Collision test

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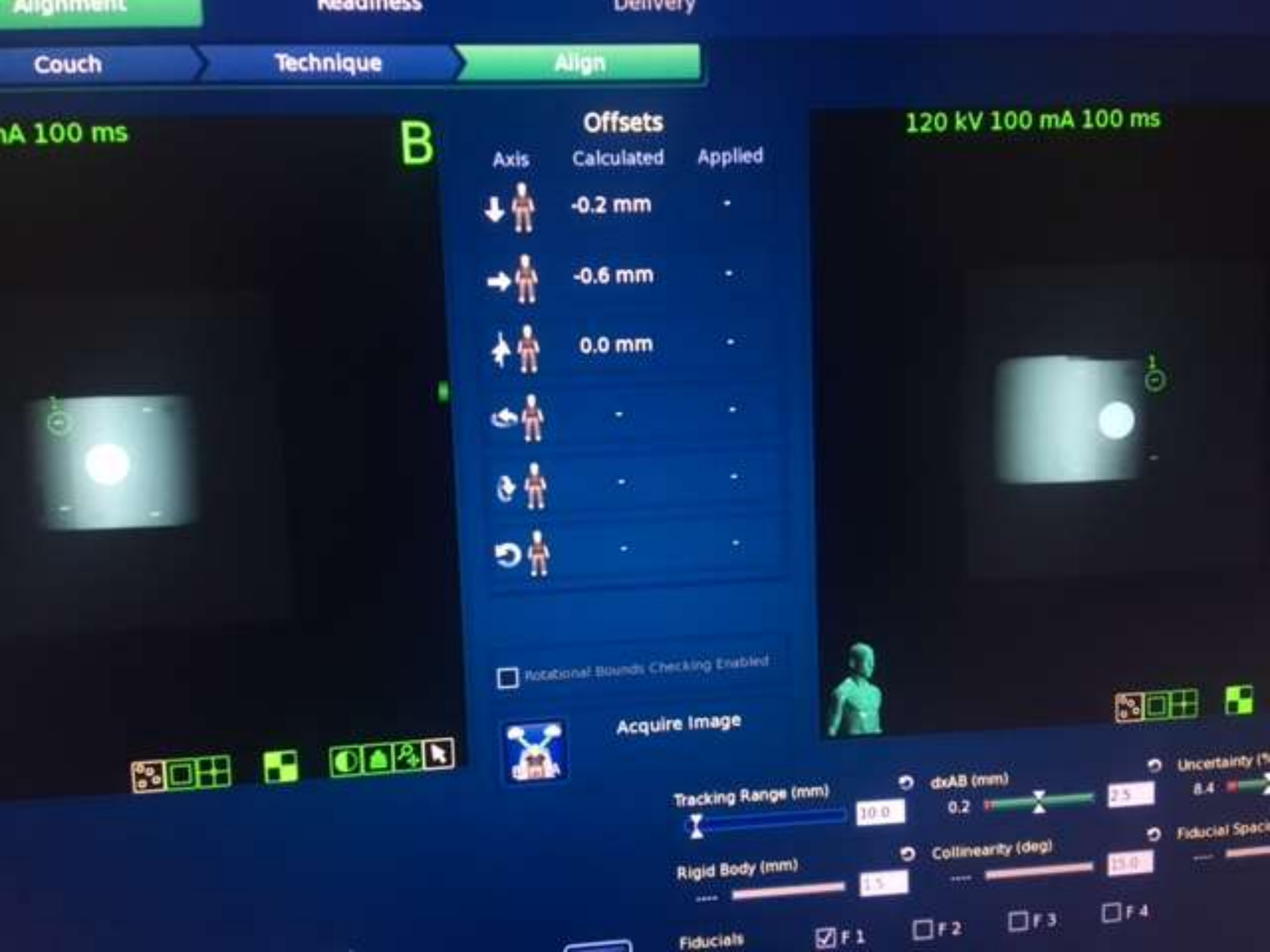
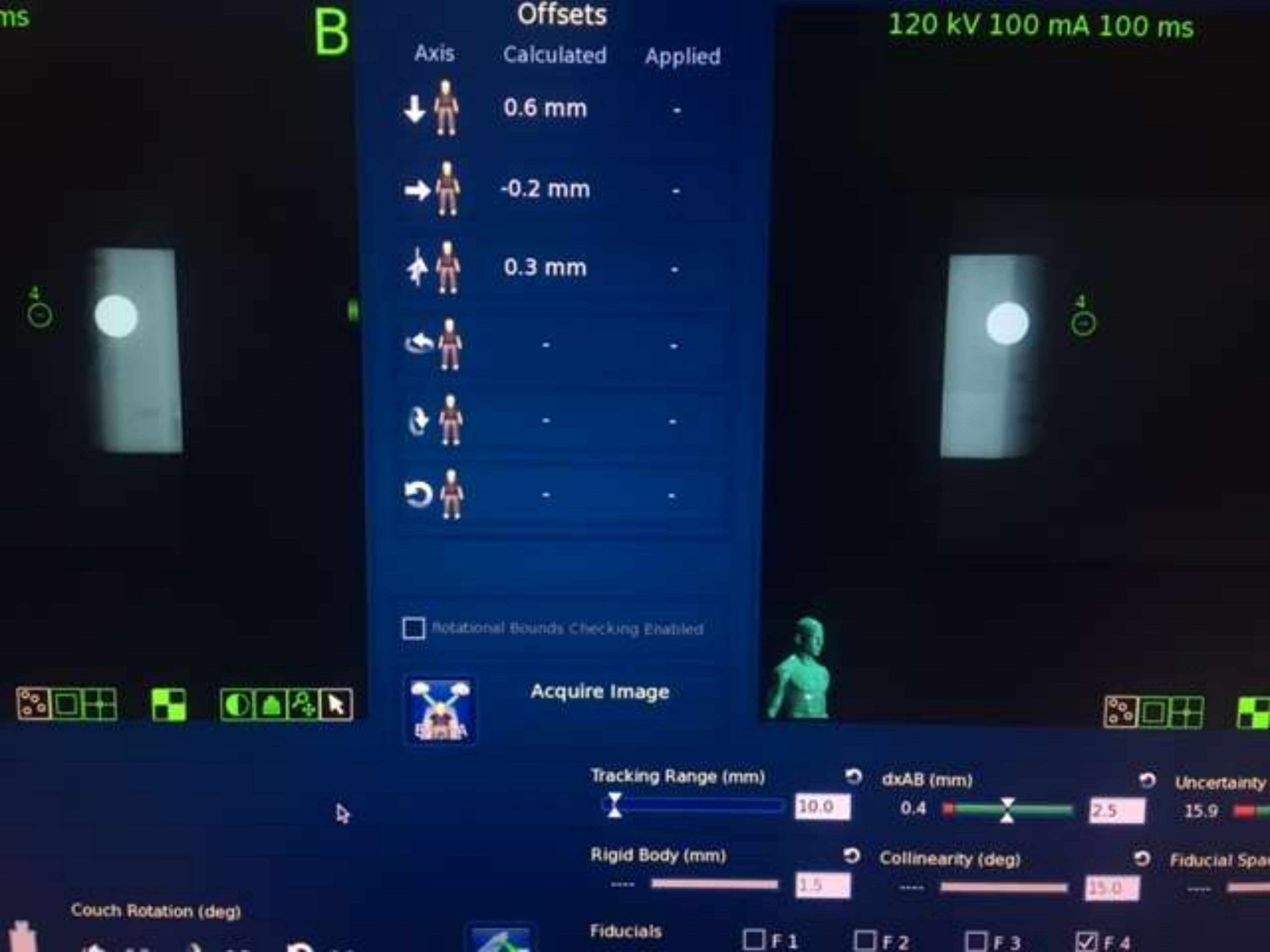
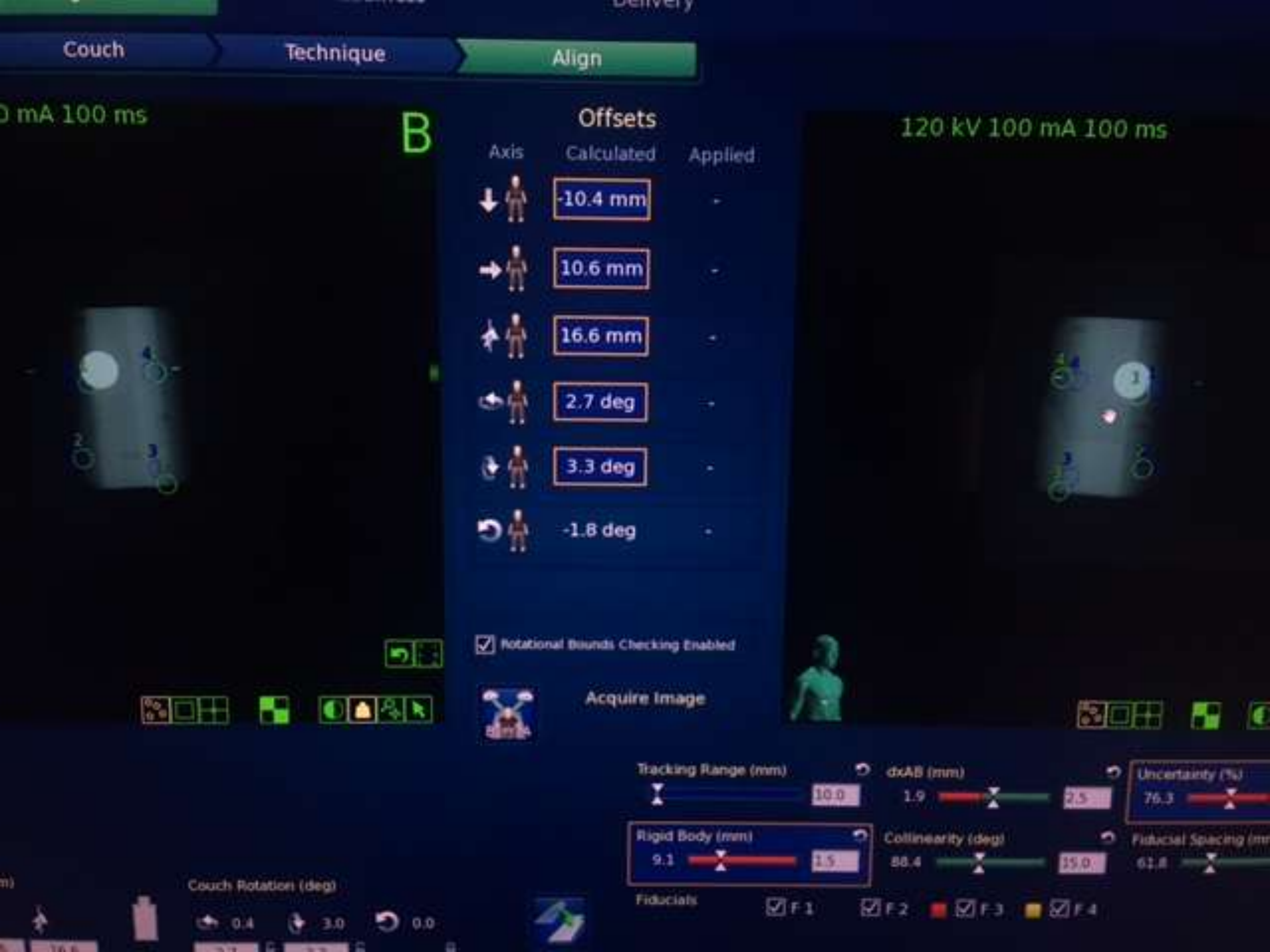
Challenges during Trt Delivery - How many Fiducials??


Alignment
Readiness
Delivery
Couch
Technique
Align
mA 100 ms
B
Offsets
Axis
Calculated
Applied
-0.2 mm
-0.6 mm
0.0 mm
120 kV 100 mA 100 ms
Rotational Bounds Checking Enabled
Acquire Image
Tracking Range (mm)
10.0
dxAB (mm)
0.2
2.5
Uncertainty
8.4
Rigid Body (mm)
1.5
Collinearity (deg)
15.0
Fiducial Spac
Fiducials
F 1
F 2
F 3
F 4

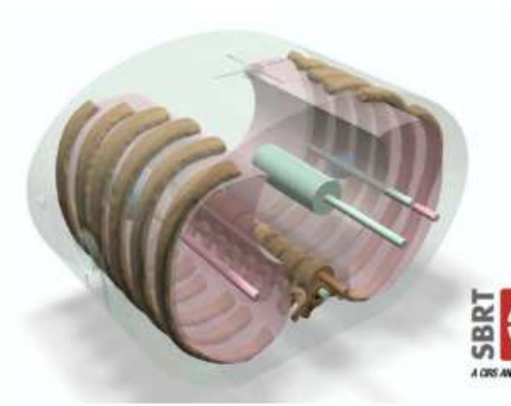


ms
B
Offsets
Axis
Calculated
Applied
0.6 mm
-
-0.2 mm
-
0.3 mm
-
-
-
-
-
-
-
120 kV 100 mA 100 ms
4
4
Rotational Bounds Checking Enabled
Acquire Image
Tracking Range (mm)
10.0
dxAB (mm)
0.4
2.5
Uncertainty
15.9
Rigid Body (mm)
1.5
Collinearity (deg)
15.0
Couch Rotation (deg)
Fiducials
F 1
F 2
F 3
F 4

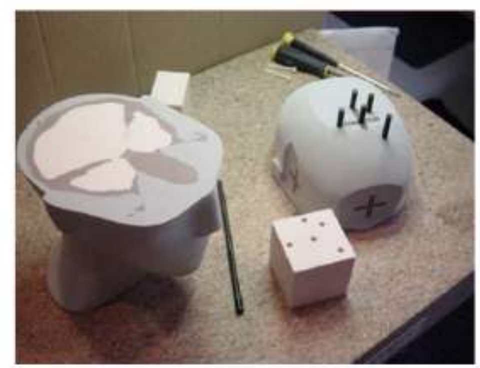

Couch
Technique
Align
mA 100 ms
B
Offsets
Axis
Calculated
Applied
-10.4 mm
10.6 mm
16.6 mm
2.7 deg
3.3 deg
-1.8 deg
120 kV 100 mA 100 ms
Rotational Bounds Checking Enabled
Acquire Image
Tracking Range (mm)
10.0
dxAB (mm)
1.9
2.5
Uncertainty (%)
76.3
Rigid Body (mm)
9.1
1.5
Collinearity (deg)
88.4
15.0
Fiducial Spacing
61.8
Couch Rotation (deg)
0.4
3.0
0.0
Fiducials
F1
F2
F3
F4

E2E testing

- Specialized SBRT/ SRS phantoms
  - End-to-end testing **crucial**
    - Spatial accuracy (hidden target)
    - Dosimetric accuracy
  - ***E2E needs to incorporate imaging***



SBRT e2e SCAN PLAN LOCALIZE TREAT
A CIRS AND IMT JOINT DEVELOPMENT PROJECT



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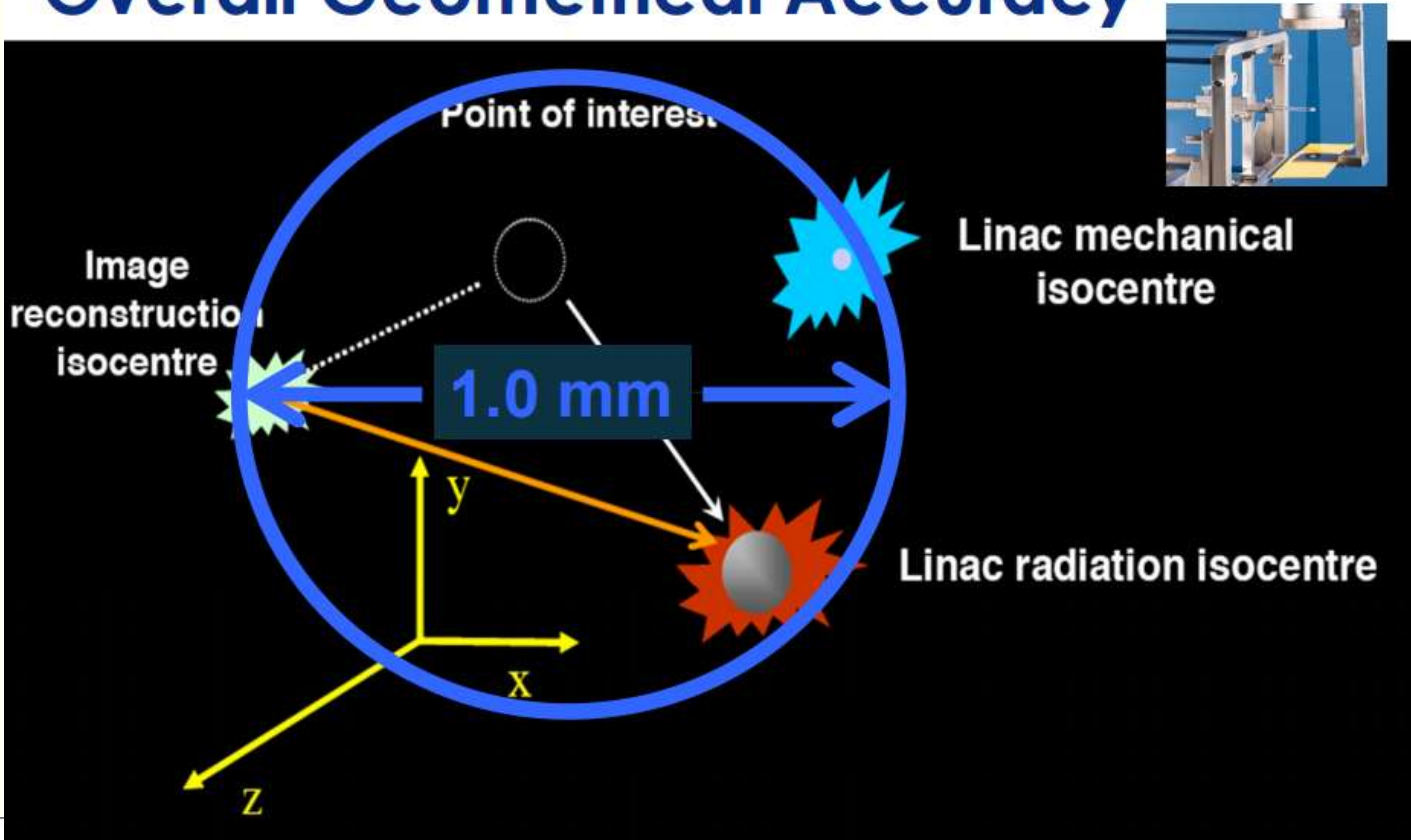
How accurate is radiosurgery?

TABLE II. Achievable Uncertainties in SRS

Stereotactic Frame	1.0 mm	1.0 mm
Isocentric Alignment	1.0 mm	1.0 mm
CT Image Resolution	1.7 mm	3.2 mm
Tissue Motion	1.0 mm	1.0 mm
Angio (Point Identification)	0.3 mm	0.3 mm
Standard Deviation of Position Uncertainty (by Quadrature)	2.4 mm	3.7 mm

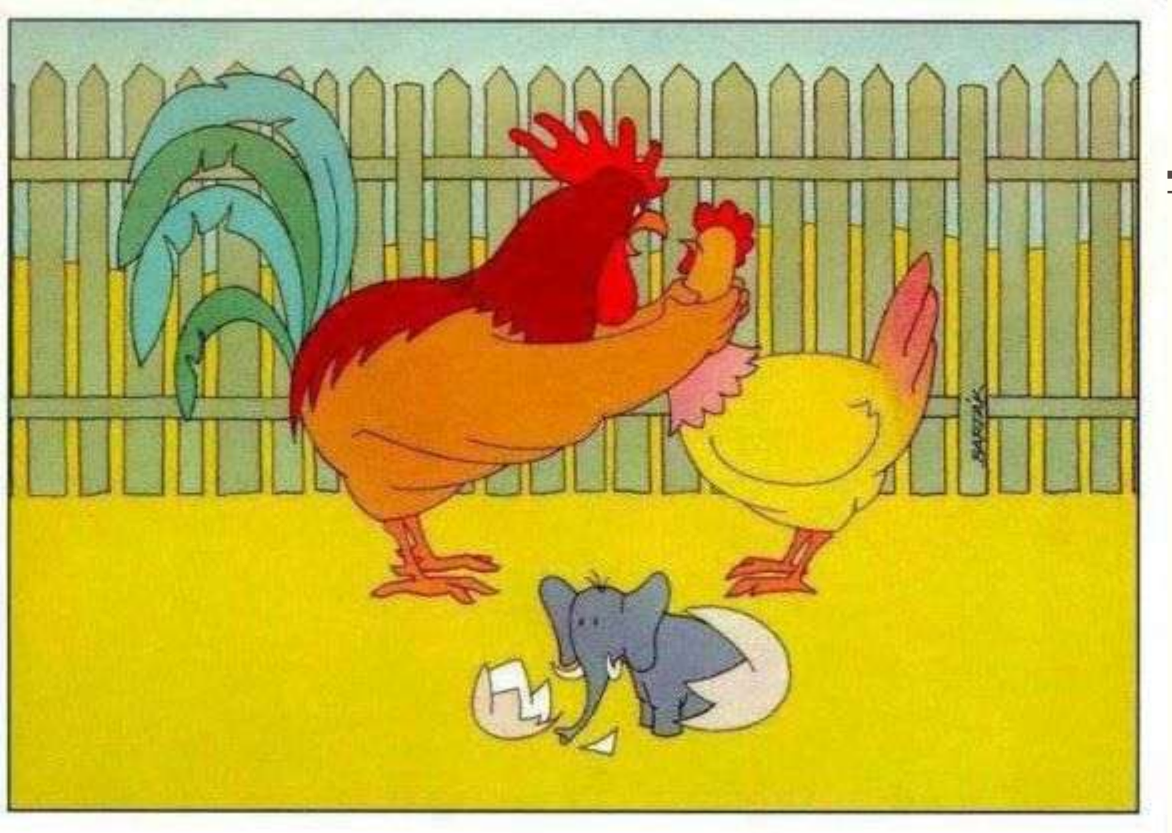
Stereotactic Radiosurgery, AAPM Report No. 54, 1995

Overall Geometrical Accuracy



Recommendation for Treatment - AAPM TG101

- At least one qualified physicist be present from the beginning to end of the first treatment fraction.
- For subsequent fractions, it is recommended that a qualified physicist be available, particularly for patient setup in order to verify immobilization, imaging, registration, gating, and setup correction.
- Radiation therapists be well-trained in SRS/SBRT procedures.
- A radiation oncologist approve the result of the image guidance and verify the port films before every fraction of the SBRT treatment.



THANK YOU

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