Quality Assurance in Stereotactic Radiosurgery and Fractionated Stereotactic Radiotherapy

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Quality Assurance in Linac SRS/SBRT

Outline

- Mechanical aspects
  - Linac
  - Frames
- Beam data acquisition
- Commissioning of TP system
- End-to-end evaluation
- Imaging and Image Fusion
- Frameless Radiosurgery
- References and Guidelines

How accurate is radiosurgery?

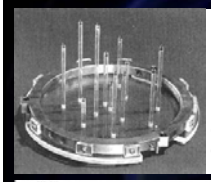
TABLE II. Achievable Uncertainties in SRS

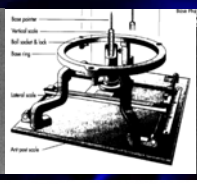
Stereotactic Frame	1.0 mm	1.0 mm
Isocentric Alignment	1.0 mm	1.0 mm
CT Image Resolution	1.7 mm	3.2 mm
Tissue Motion	1.0 mm	1.0 mm
Angio (Point Identification)	0.3 mm	0.3 mm
Standard Deviation of Position Uncertainty (by Quadrature)	2.4 mm	3.7 mm

Stereotactic Radiosurgery, AAPM Report No. 54, 1995

Other sources: MRI Distortion
Image Fusion
Relocatable frames
Dosimetric
……

Frames & CT



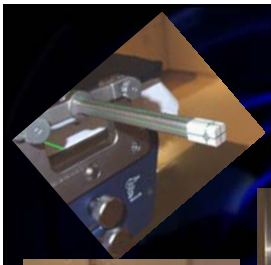


CT Slice Thickness (mm)	Measurement	BRW (mm)	CRW (mm)	COMPASS (mm)	Leksell (mm)
1	Mean ± 3 SE_{xx}	1.9 ± 0.10	1.8 ± 0.11	1.2 ± 0.06	1.7 ± 0.10
	99% CI for the mean	1.80 to 2.00	1.69 to 1.91	1.04 to 1.26	1.60 to 1.80
1 canted	Mean ± 3 SE_{xx}	2.5 ± 0.11	2.2 ± 0.11	2.1 ± 0.10	N/A
	99% CI for the mean	2.39 to 2.61	2.09 to 2.31	2.00 to 2.20	N/A
4	Mean ± 3 SE_{xx}	2.7 ± 0.13	2.6 ± 0.15	2.5 ± 0.12	2.6 ± 0.14
	99% CI for the mean	2.57 to 2.83	2.45 to 2.75	2.38 to 2.62	2.46 to 2.74
8	Mean ± 3 SE_{xx}	6.6 ± 0.31	6.6 ± 0.30	5.1 ± 0.23	5.4 ± 0.24
	99% CI for the mean	6.29 to 6.91	6.30 to 6.90	4.87 to 5.33	5.16 to 5.64

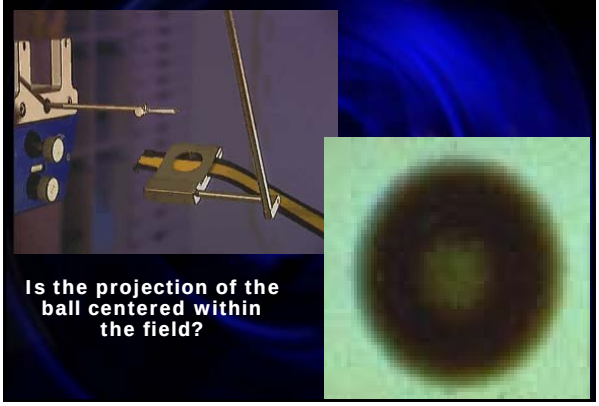
* The large numbers of measurements yielded small standard errors of the means and a resultant high confidence in these experimentally derived means as being representative of the true means of application accuracy for these stereotactic frame systems. SE_{xx}, standard error of the means; N/A, not available; CT, computed tomography; BRW, Brown-Roberts-Wells; CRW, Cosman-Roberts-Wells; CI, confidence interval.

Maciunas et al, Neurosurgery 35:682-695, 1995

Isocentric Accuracy: The Winston-Lutz Test

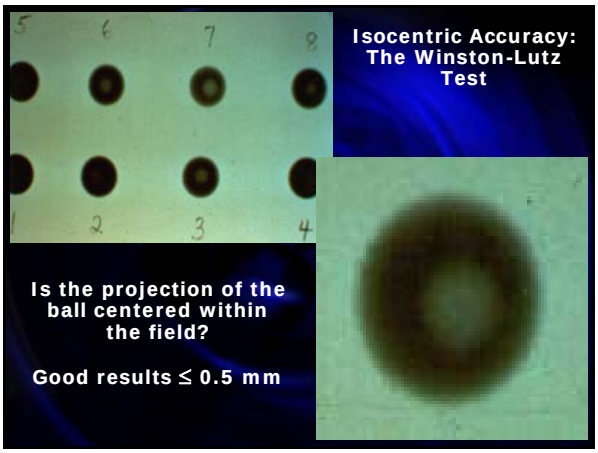


Mechanical Uncertainties



Is the projection of the ball centered within the field?

Isocentric Accuracy: The Winston-Lutz Test

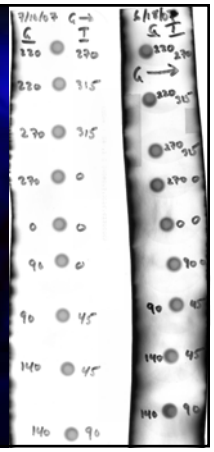


Is the projection of the ball centered within the field?

Good results ≤ 0.5 mm

A daily Lutz test is extremely important because:

- The mechanical isocenter can shift over time
- The AMC board in Varian couches can fail
- The cone or MLC may not be repositioned perfectly after service



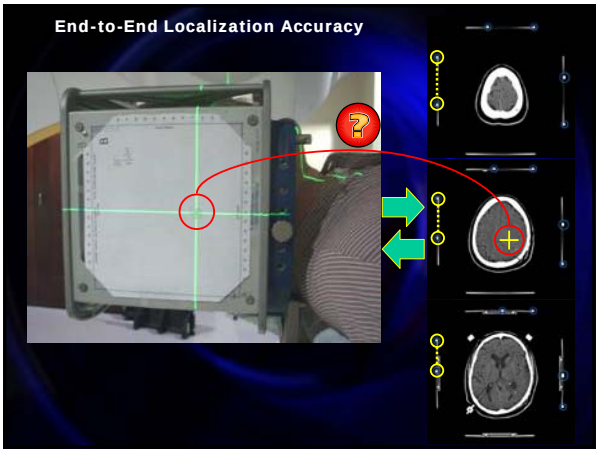
Before (right) and After (left) relatively simple couch adjustment

A Lutz test with the MLC is also important because:

- The Cone-based Lutz test does not tell you anything about the mechanical isocenter of the MLC
- The MLC may not be repositioned perfectly after service

Lutz test with 12 x 12 mm MLC field

End-to-End Localization Accuracy



End-to-End Localization Accuracy (Surely my vendor has checked this)

YAHOO! FINANCE

Welcome [Sign In]

Financial News

Press Release

Source: BrainLAB

Specific Mechanical Component/Software Incompatibility Resulted in 1.25 mm Shift in Target Area Alignment in Radiosurgery Treatment

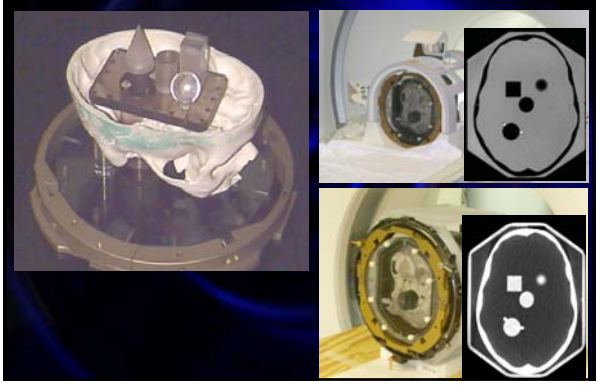
Friday June 15, 3:00 pm ET

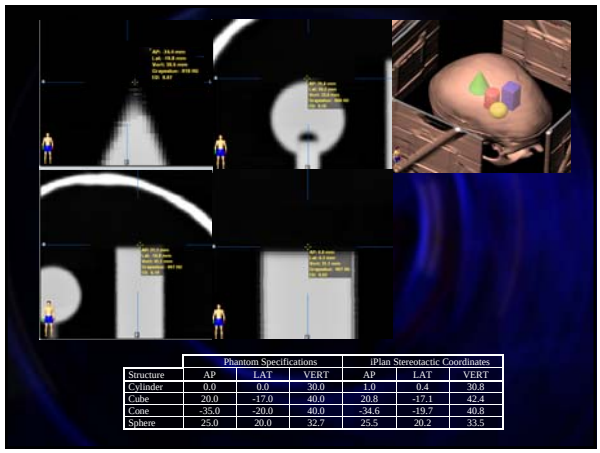
MUNICH, Germany, June 15 /PRNewswire/ -- A mechanical component/software incompatibility caused by a specific combination of the BrainLAB Target Positioner version 40700-3A for Leksell headrings and BrainLAB planning software resulted in a 1.25 mm shift in target area alignment during radiosurgery treatment. Two hospitals in the US were performing radiosurgery using this specific configuration. Seven hospitals have purchased this configuration worldwide, six of which were in clinical use -- two are located in the US, four in France.

The shift in target area alignment for this specific configuration of mechanical components and software used in radiosurgery was discovered by a BrainLAB support engineer and a customer during an installation procedure. A custom-made test, performed in addition to the normal tests for commissioning a system, detected a shift in alignment from the intended target treatment area of 1.25 mm. This alignment shift falls within accepted safety margins and known deviations published in the field of radiosurgery and for this reason was not discovered earlier during routine product test and customer commissioning procedures.

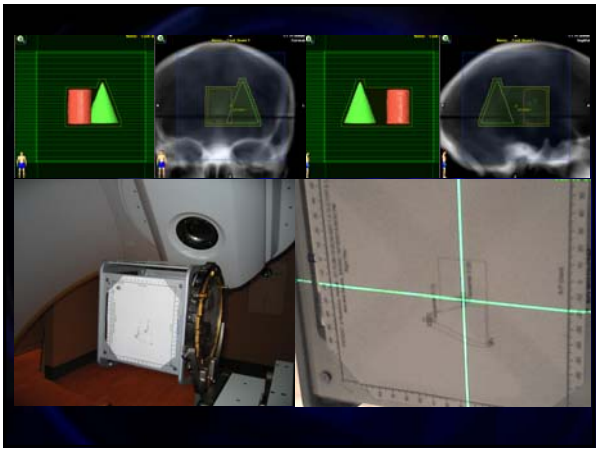
Investigation has shown the cause to be a mechanical component/software incompatibility for one specific BrainLAB configuration. The shift in target area alignment only occurs through the combination of the BrainLAB Target Positioner version 40700-3A for Leksell headrings and BrainLAB software. All other BrainLAB configurations of mechanical components and software were also tested during the investigation and it was confirmed that the problem is limited to this specific configuration.

End-to-end localization evaluation

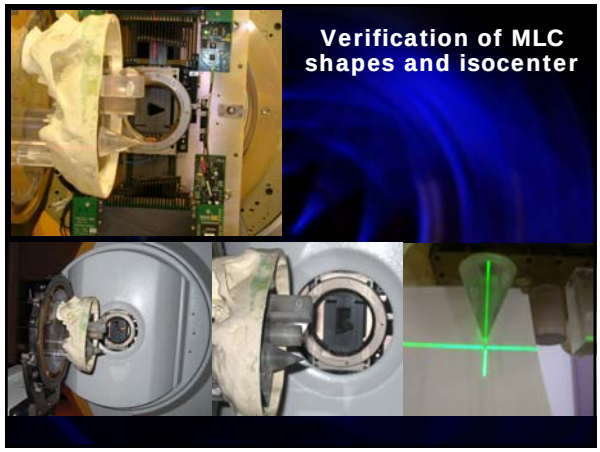




	Phantom Specifications			iPlan Stereotactic Coordinates		
Structure	AP	LAT	VERT	AP	LAT	VERT
Cylinder	0.0	0.0	30.0	1.0	0.4	30.8
Cube	20.0	-27.0	40.0	20.8	-17.1	42.4
Cone	-35.0	-20.0	40.0	-34.6	-19.7	40.8
Sphere	25.0	20.0	32.7	25.5	20.2	33.5

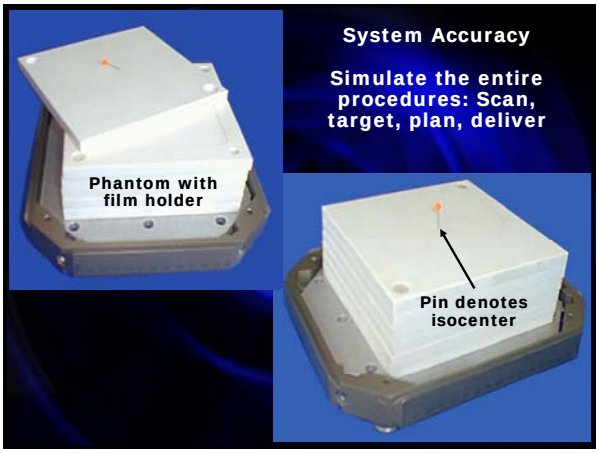


Verification of MLC shapes and isocenter

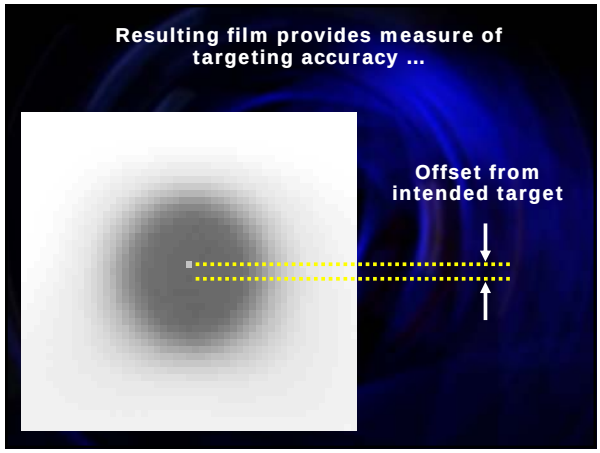


System Accuracy

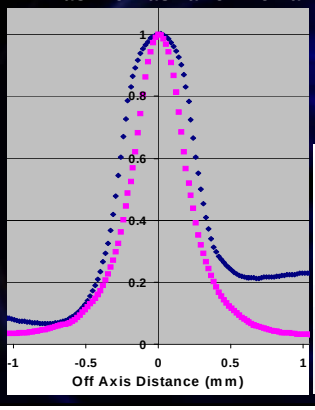
Simulate the entire procedures: Scan, target, plan, deliver

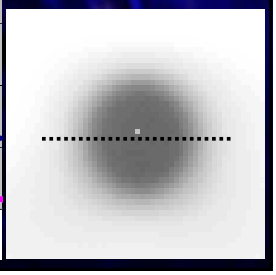


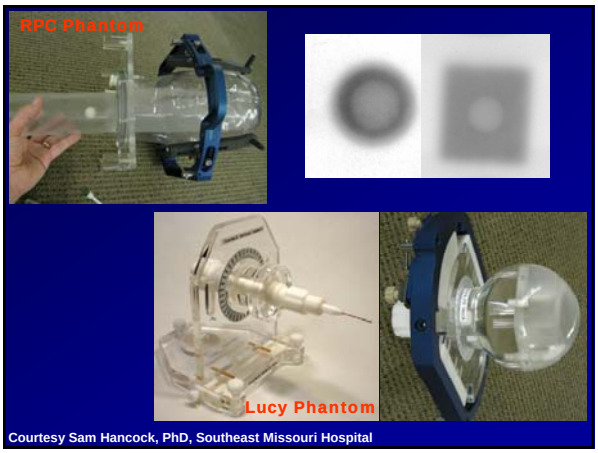
Resulting film provides measure of targeting accuracy ...



... as well as falloff for a multiple arc delivery







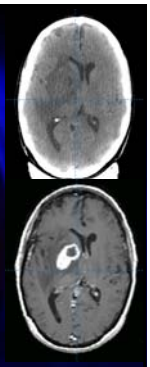
Courtesy Sam Hancock, PhD, Southeast Missouri Hospital

Imaging Uncertainties

- Use CT for geometric accuracy
- Use MR for target delineation

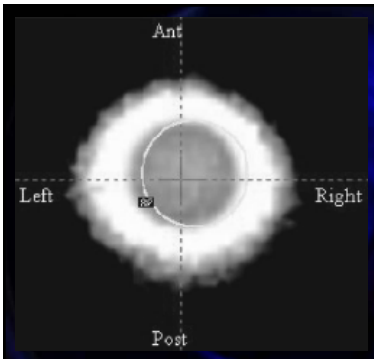
"MRI contains distortions which impede direct correlation with CT data at the level required for SRS"

Stereotactic Radiosurgery – AAPM Report No. 54



Other References

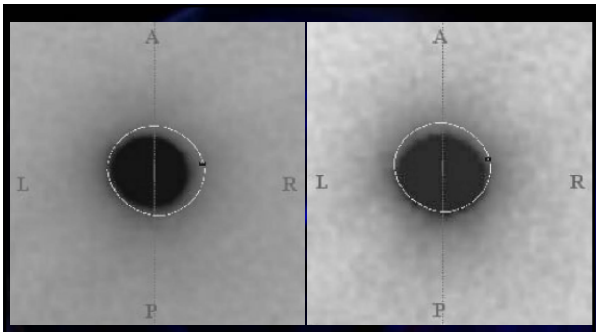
TS Sumanaweera, JR Adler, S Napel, et al., Characterization of spatial distortion in magnet resonance imaging and its implications for stereotactic surgery," Neurosurgery 35: 696-704, 1994.



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.

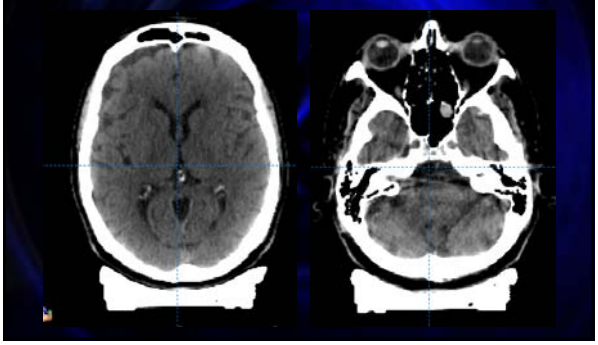


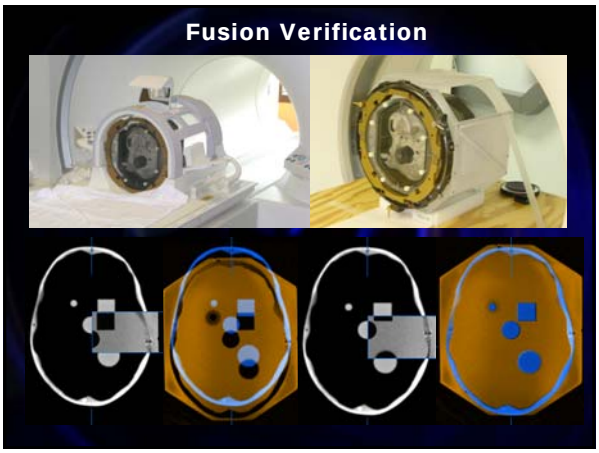
Frequency Encoding = L/R Frequency Encoding = A/P

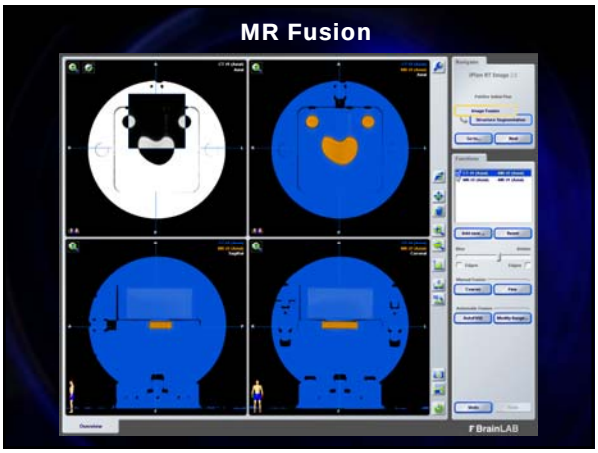
Y Watanabe, GM Perera, RB Mooij, "Image distortion in MRI-based polymer gel dosimetry of Gamma Knife stereotactic radiosurgery systems," Med. Phys. 29: 797-802, 2001.

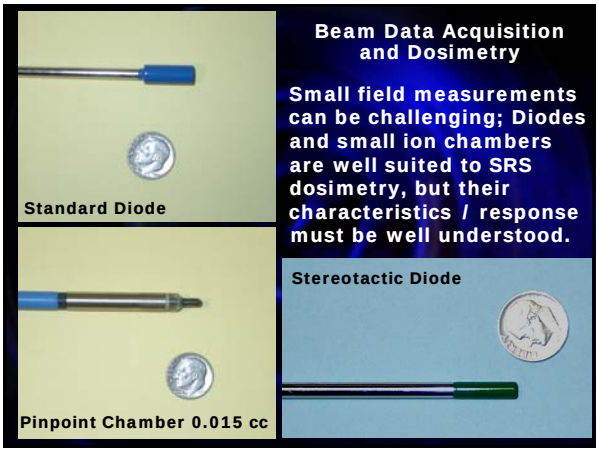
What do we do about MR spatial distortion?

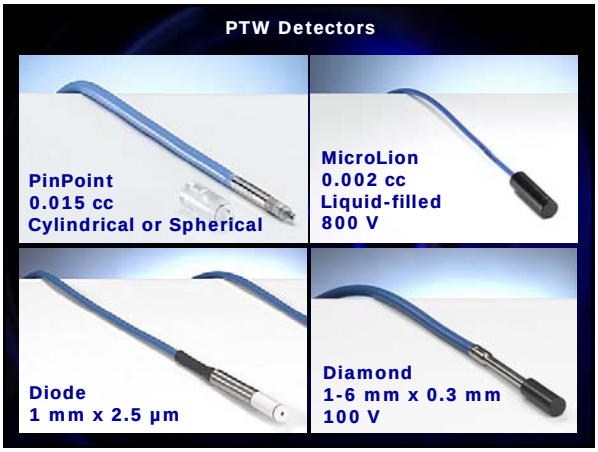
Use Image Fusion



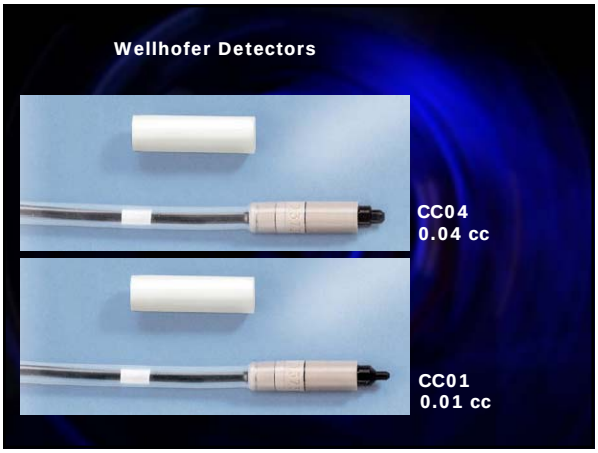

Fusion Verification

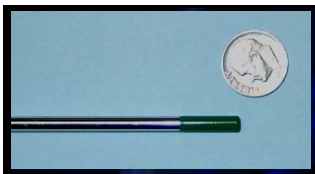

MR Fusion
BrainLAB


Beam Data Acquisition and Dosimetry
Small field measurements can be challenging; Diodes and small ion chambers are well suited to SRS dosimetry, but their characteristics / response must be well understood.
Standard Diode
Pinpoint Chamber 0.015 cc
Stereotactic Diode


PTW Detectors
PinPoint
0.015 cc
Cylindrical or Spherical
MicroLion
0.002 cc
Liquid-filled
800 V
Diode
1 mm x 2.5 µm
Diamond
1-6 mm x 0.3 mm
100 V


A14
0.016 cc
A16
0.007 cc
A14SL
0.016 cc
Exradin Detectors


Wellhofer Detectors
CC04
0.04 cc
CC01
0.01 cc



Diode Warnings!!!

1) Diode response will drift over time

   Re-measure reference between each chance in field size

2) Diodes exhibit enough energy dependence that ratios between large and small field measurements are inaccurate at the level required for radiosurgery

Use an intermediate reference field appropriate for both diodes and ion chambers

Reference diode output to an intermediate field size

$$\text{Output Factor} = \frac{\text{Reading (FS)}_{diode}}{\text{Reading (Ref')}_{diode}} \times \frac{\text{Reading (Ref')}_{IC}}{\text{Reading (Ref)}_{IC}}$$

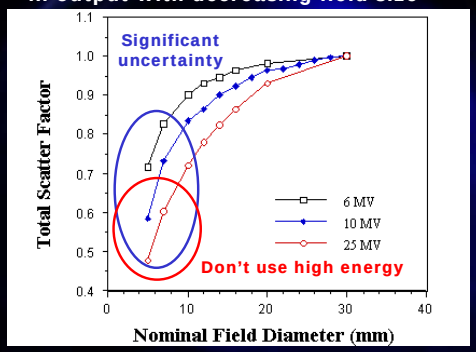
NO!

$$\frac{\text{Reading (6 mm)}_{diode}}{\text{Reading (100 mm)}_{diode}}$$

YES!

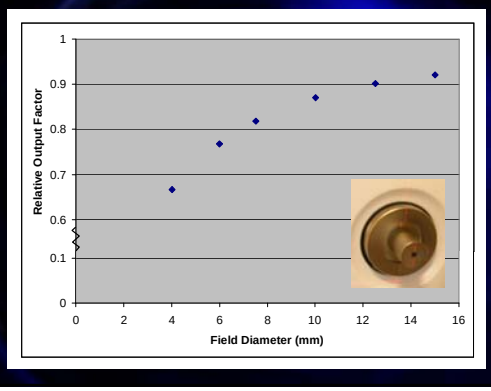
$$\frac{\text{Reading (6 mm)}_{diode}}{\text{Reading (24 mm)}_{diode}} \times \frac{\text{Reading (24 mm)}_{IC}}{\text{Reading (100 mm)}_{IC}}$$

Radiosurgery beams exhibit a sharp decrease in output with decreasing field size

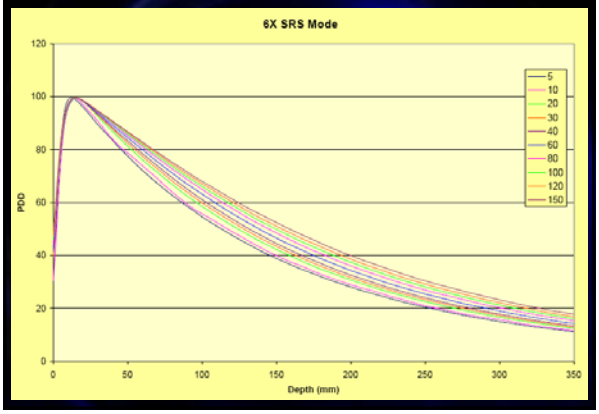


This means that with small collimators, treatment times can be long

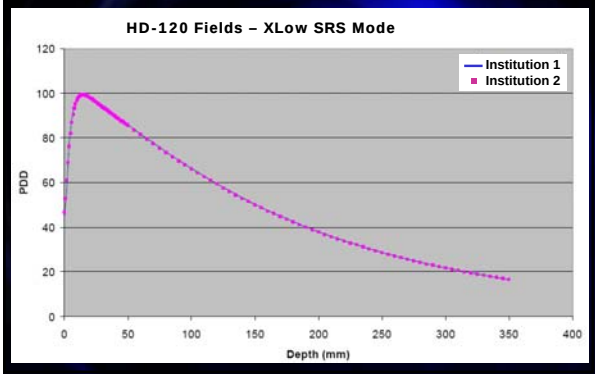
6X Output Factors – Circular Cones



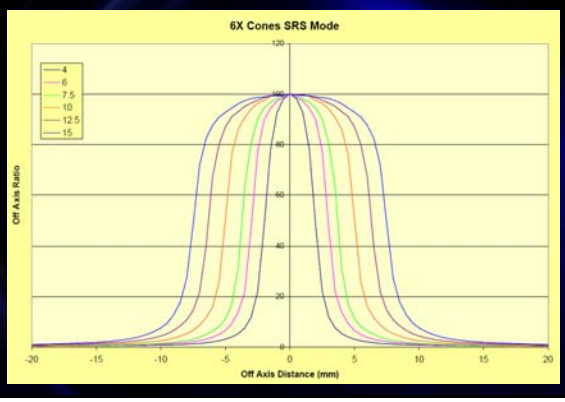
Small field depth dose show familiar trends



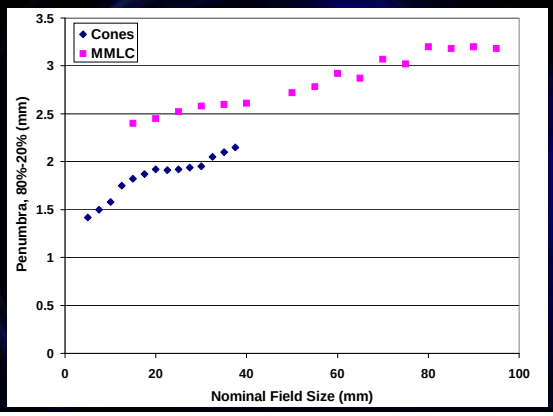
Novalis Tx



Off Axis Profiles – Cones



Penumbra: Cones versus MMLC



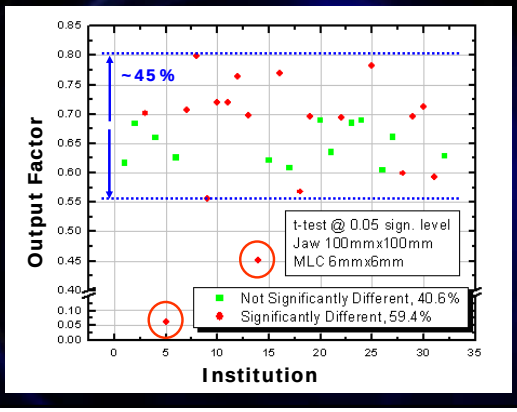
Need proof that beam data acquisition for small fields is difficult?

Surveyed Beam Data from 40 identical treatment units:

- **Percent Depth Dose**
- **Relative Scatter Factors**
- **Absolute Dose-to-Monitor Unit CF**
- **Reference Condition**

Applied statistical methods to compare data

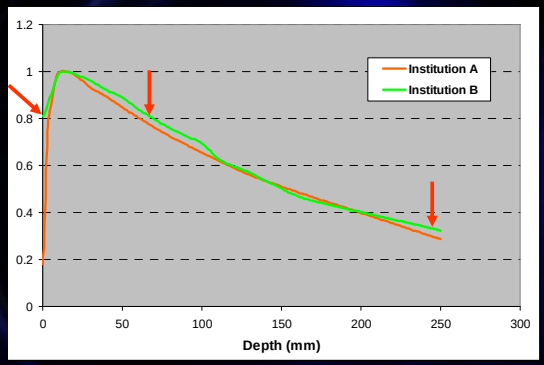
Relative Output Factor: 6 mm x 6 mm MLC



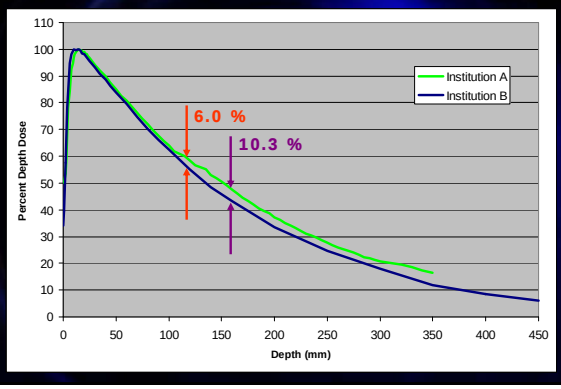
Even people in the U.S have problems

Cone size (mm)	Original Output Factor	Re-measured Output Factor
4.0	0.312	0.699
7.5	0.610	0.797
10.0	0.741	0.835
12.5	0.823	0.871
15.0	0.862	0.890
17.5	0.888	0.904
20.0	0.903	0.913
25.0	0.920	0.930
30.0	0.928	0.940

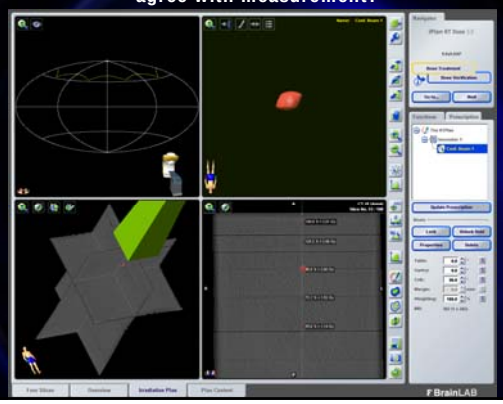
A different institution in the U.S



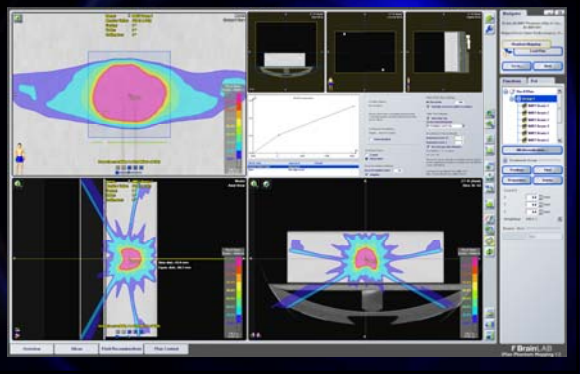
And still another institution in the U.S



Commissioning your system: Does calculation agree with measurement?

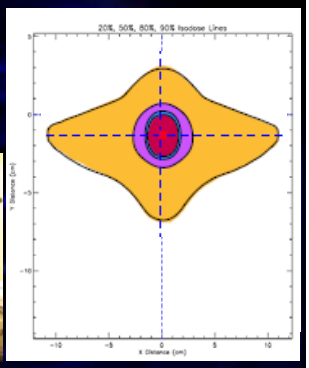


Phantom Plans



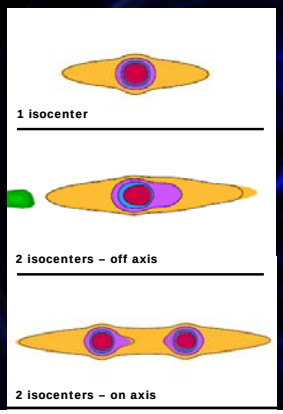
End-to-end testing

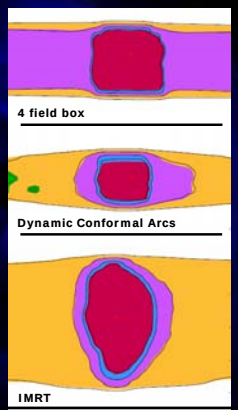
Dosimetric uncertainty



Relative Dosimetry

Start simple, and increase complexity

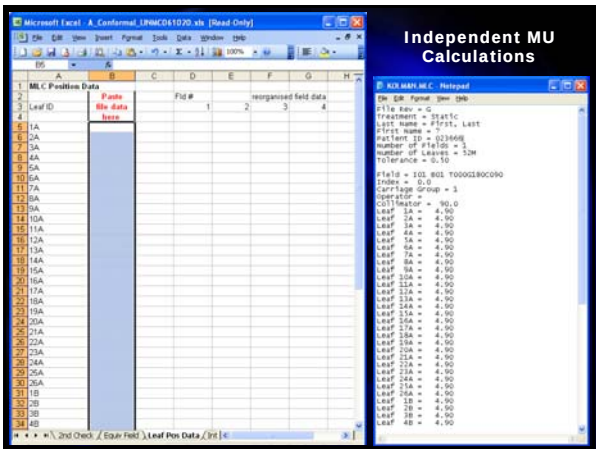




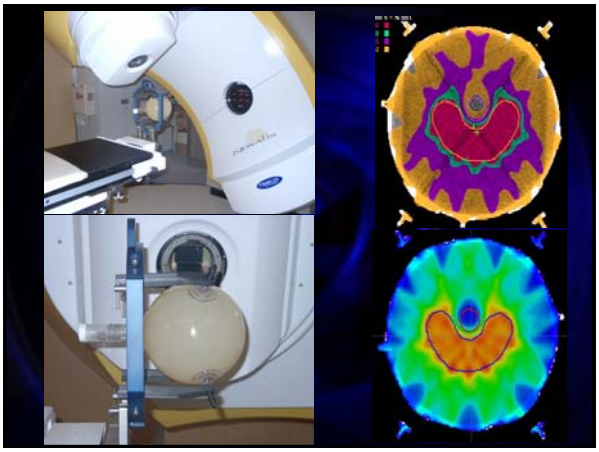
End-to-end testing

Dosimetric uncertainty

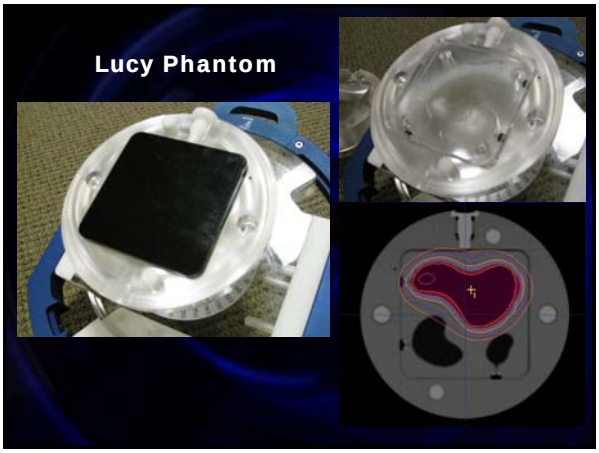
Absolute Dosimetry

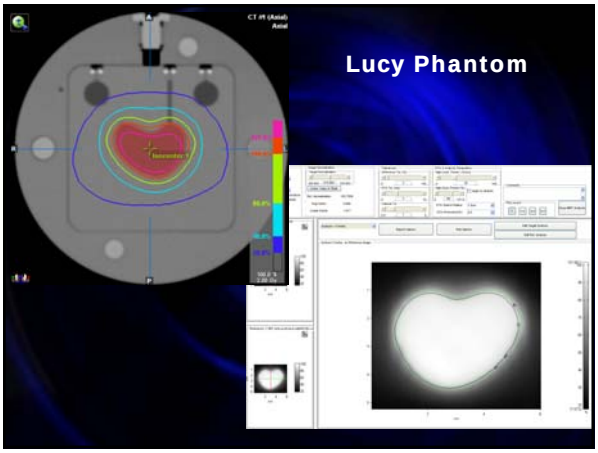

Independent MU Calculations


End-to-end dosimetric evaluation




Lucy Phantom


Lucy Phantom


Lucy Phantom

What about "Frameless Systems?"

A "frameless" stereotactic system provides localization accuracy consistent with the safe delivery of a therapeutic dose of radiation given in one or few fractions, without the aid of an external reference frame, and in a manner that is non-invasive.

Frameless stereotaxis is inherently image guided

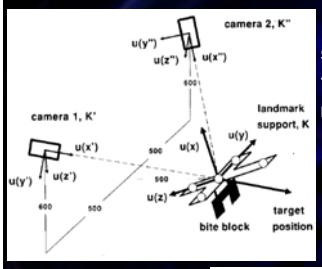
Also required:

Immobilization – need not be linked to localization

Ability to periodically monitor / verify

(Stereo)photogrammetry - the principle behind frameless technologies

Stereophotogrammetry in Radiotherapy

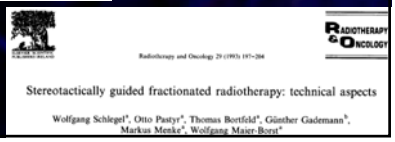


Spatial Resolution: 0.05 mm

Temporal Resolution: 0.03 s

Localization Accuracy: 0.2 mm

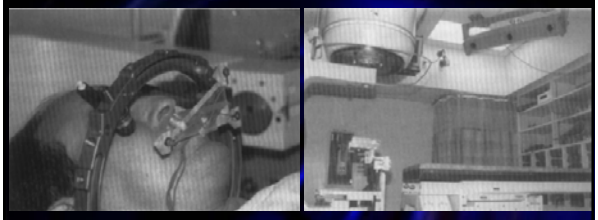
Optical Photogrammetry


Radiotherapy and Oncology 29 (1993) 197–204

Stereotactically guided fractionated radiotherapy: technical aspects

Wolfgang Schlegel[a], Otto Pastyr[a], Thomas Bortfeld[a], Günther Gademann[b], Markus Menke[a], Wolfgang Maier-Borst[a]

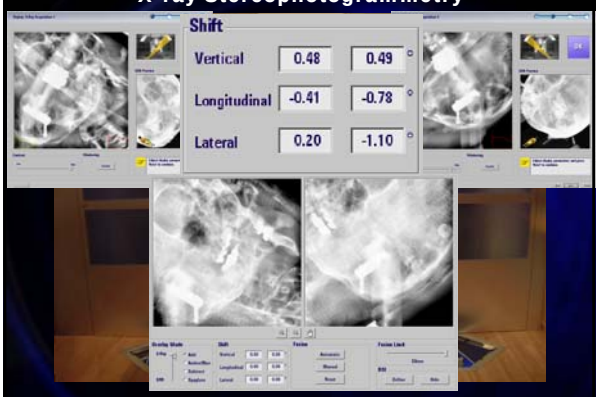
Stereophotogrammetry in Radiotherapy



Condition	Stereotactic subsystem position AP (mm)	Lat (mm)	Axial (mm)	IRLED reading position AP (mm)	Lat (mm)	Axial (mm)	Difference AP (mm)	Lat (mm)	Axial (mm)
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	100.0	0.0	0.0	100.0	0.0	−0.1	0.0	0.0	0.1
3	−100.0	0.0	0.0	−100.1	0.0	0.1	0.1	0.0	−0.1
4	0.0	100.0	0.0	−0.1	100.0	0.0	0.0	0.0	0.0
5	0.0	−100.0	0.0	0.0	−100.0	0.0	0.0	0.0	0.0
6	0.0	0.0	100.0	0.1	0.0	100.1	−0.1	0.0	−0.1
7	0.0	0.0	−45.0	0.0	0.0	−45.0	0.0	0.0	0.0

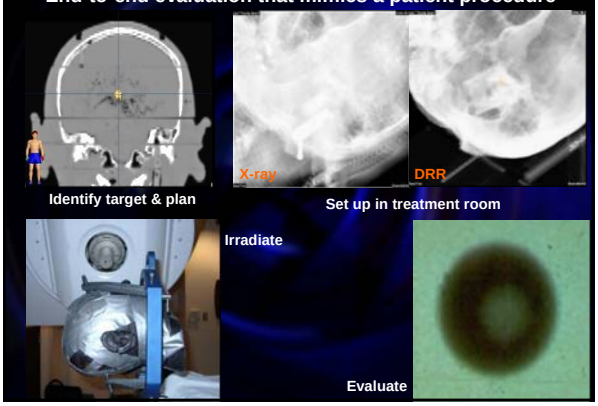
Bova et al, IJROBP, 1999

X-ray Stereophotogrammetry



Frameless (Image Guided) Radiosurgery

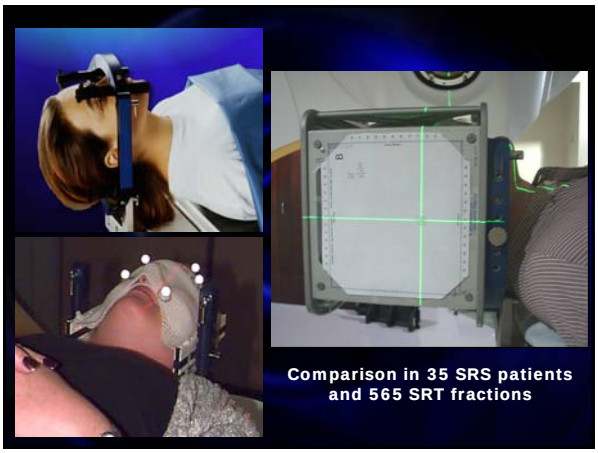
How do we know the system is targeting properly? End-to-end evaluation that mimics a patient procedure



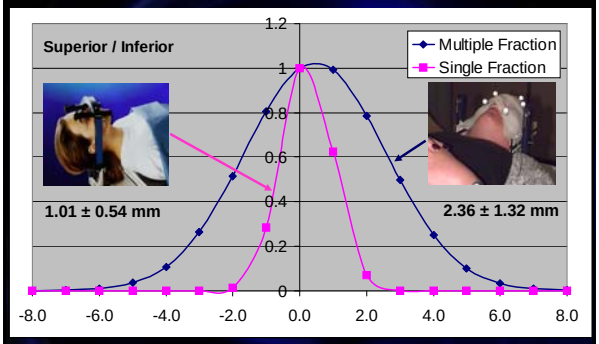
Results of Phantom Data

(mm)	Lat.	Long.	Vert.	3D vector
Average	-0.06	-0.01	0.05	1.11
Standard Deviation	0.56	0.32	0.82	0.42

- Sample size = 50 trials (justified to 95% confidence level, +/- 0.12mm)

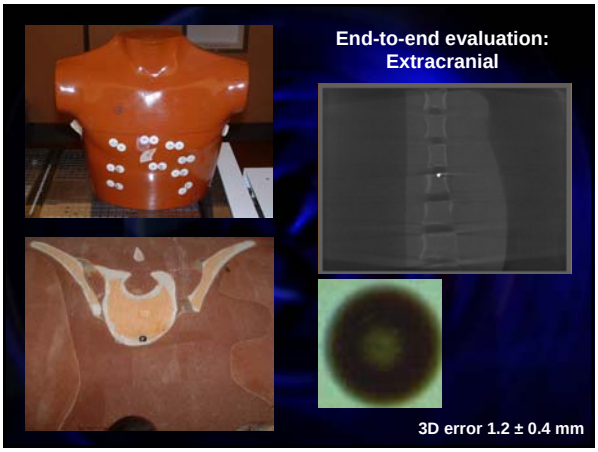


Difference Between conventional and frameless localization

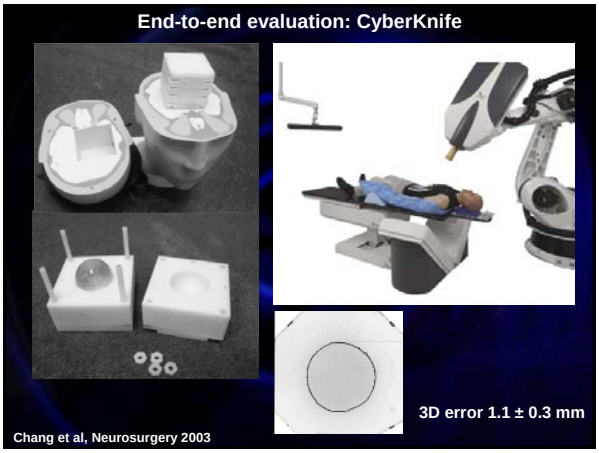


- Frameless localization is equivalent to frame-based rigid fixation
- Frameless localization improves accuracy of relocatable frames

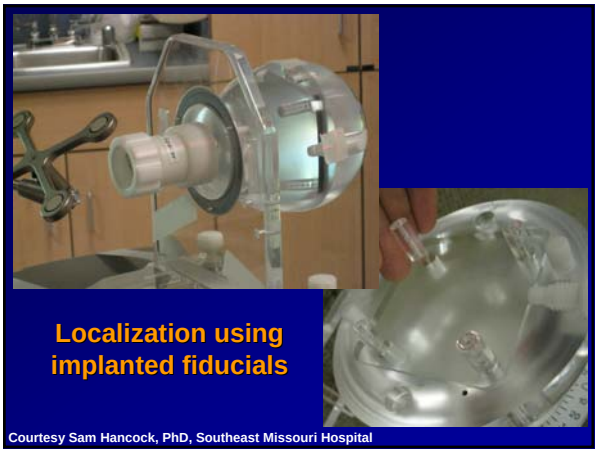
End-to-end evaluation: Extracranial



End-to-end evaluation: CyberKnife



Chang et al, Neurosurgery 2003



Courtesy Sam Hancock, PhD, Southeast Missouri Hospital

Localization using implanted fiducials

Radiosurgery Guidelines

- ACR / ASTRO Practice Guidelines

PRACTICE GUIDELINE FOR THE PERFORMANCE OF STEREOTACTIC RADIOSURGERY

PRACTICE GUIDELINE FOR THE PERFORMANCE OF STEREOTACTIC BODY RADIATION THERAPY

- What do they cover?
  - Personnel Qualifications / Responsibilities
  - Procedure Specifications
  - Quality Control / Verification / Validation
  - Follow-up

Radiosurgery Guidelines

- Task Group Reports

AAPM Report #54 – Stereotactic Radiosurgery
AAPM Report #91 – The Management of Motion in Radiation Oncology (TG 76)
TG 68 – Intracranial Stereotactic Positioning Systems

TG 101 – Stereotactic Body Radiotherapy
TG 104 – kV Localization in Therapy
TG 117 – Use of MRI in Treatment Planning and Stereotactic Procedures
TG 132 – Use of Image Registration and Data Fusion Algorithms and Techniques in Radiotherapy Treatment Planning
TG 135 – QA for Robotic Radiosurgery
TG 147 – QA for Non-Radiographic Radiotherapy Localization and Positioning Systems
TG 155 – Small Fields and Non-Equilibrium Condition Photon Beam Dosimetry
TG 176 – Task Group on Dosimetric Effects of Immobilization Devices
TG 178 – Gamma Stereotactic Radiosurgery Dosimetry and QA
TG 179 – QA for Image-Guided Radiation Therapy Utilizing CT-Based Technologies

Radiosurgery Guidelines

- RTOG Protocols

RTOG 9005 – Single Dose Radiosurgical Treatment of Recurrent Previously Irradiated Primary Brain Tumors and Brain Metastases

RTOG 9305 – Randomized Prospective Comparison Of Stereotactic Radiosurgery (SRS) Followed By Conventional Radiotherapy (RT) With BCNU To RT With BCNU Alone For Selected Patients With Supratentorial Glioblastoma Multiforme (GBM)

RTOG 9508 – A Phase III Trial Comparing Whole Brain Irradiation Alone Versus Whole Brain Irradiation Plus Stereotactic Radiosurgery for Patients with Two or Three Unresected Brain Metastases

RTOG 0236 – A phase II trial of SBRT in the treatment of patients with medically inoperable stage I/II non-small cell lung cancer

RTOG 0618 – A phase II trial of SBRT in the treatment of patients with operable stage I/II non-small cell lung cancer

RTOG 0813 – Seamless phase I/II study of SBRT for early stage, centrally located, non-small cell lung cancer in medically operable patients

Other Documents

ASTRO/AANS Consensus Statement on stereotactic radiosurgery quality improvement, 1993

RTOG Radiosurgery QA Guidelines, 1993

European Quality Assurance Program on Stereotactic Radiosurgery, 1995

DIN 6875-1 (Germany) Quality Assurance in Stereotactic Radiosurgery/Radiotherapy, 2004

... and read the literature

... and talk with your colleagues