Quality Assurance in Stereotactic Radiosurgery and Fractionated Stereotactic Radiotherapy

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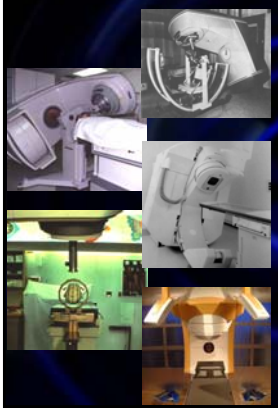
Quality Assurance in Linac SRS/SBRT

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

LOTS of variation in Linac SRS technologies …



Betti OO, Derechinsky VE, Hyperselective encephalic irradiation with linear accelerator, Acta Neurochir. 33: 385, 1984

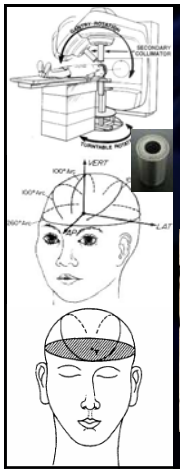
Siddon RL, Barth NH, Stereotaxic localization of intracranial targets, Int J Radiat Oncol Biol Phys. 1987 13(8):1241-6, 1987

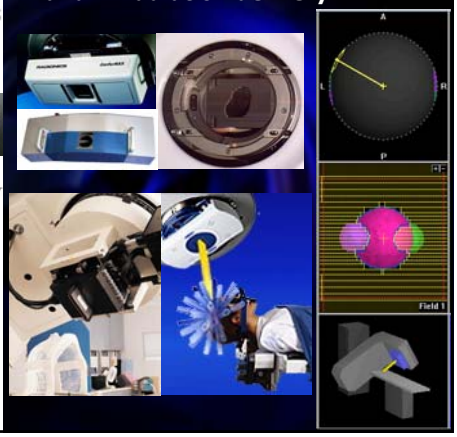
Lutz W, Winston KR, Maleki N, A system for stereotactic radiosurgery with a linear accelerator, Int J Radiat Oncol Biol Phys. 14(2):373-81, 1988

Podgorsak EB, Olivier A, Pla M, et al, Dynamic rotation stereotactic radiosurgery, Int J Radiat Oncol Biol Phys. 11: 1185-1192, 1988

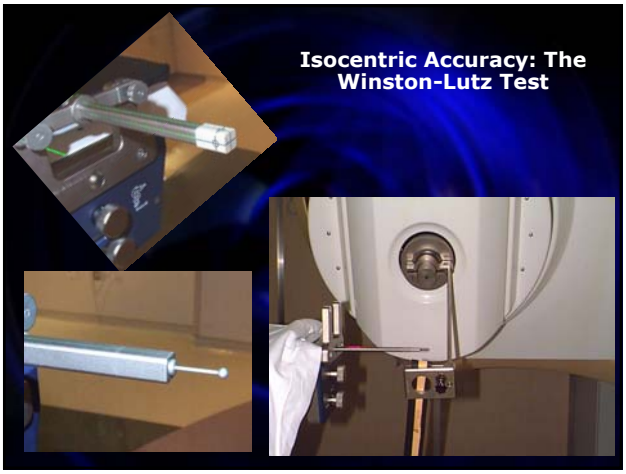
Friedman WA, Bova FJ, The University of Florida radiosurgery system, Surg Neurol. 32(5):334-42, 1989

… and in radiation delivery

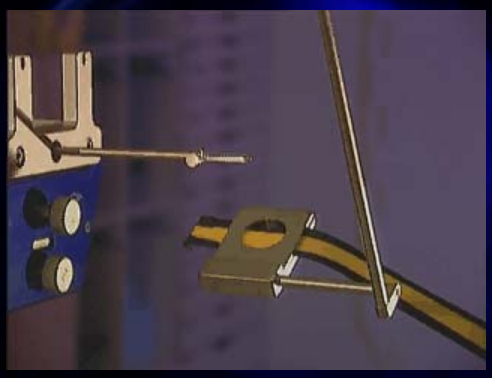




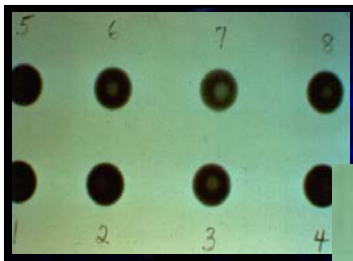
Isocentric Accuracy: The Winston-Lutz Test

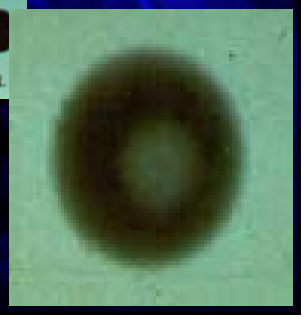


Isocentric Accuracy: The Winston-Lutz Test



Isocentric Accuracy: The Winston-Lutz Test



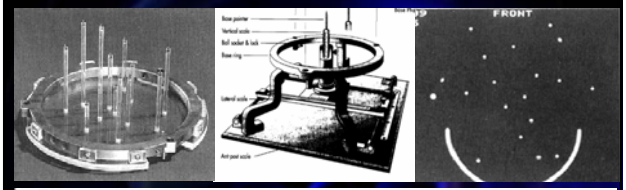


Is the projection of the ball centered within the field?

Good results: $\bar{x} \leq 0.5$ mm

What can you expect and what can you do about it?

Localization Accuracy of Stereotactic Frames



CT Slice Thickness (mm)	Measurement	BRW (mm)	CRW (mm)	COMPASS (mm)	Leksell (mm)
1	Mean ± 3 SE_M	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_M	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_M	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_M	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_M, standard error of the mean; N/A, not available; CT, computed tomography; BRW, Brown-Roberts-Wells; CRW, Cosman-Roberts-Wells; CI, confidence interval.

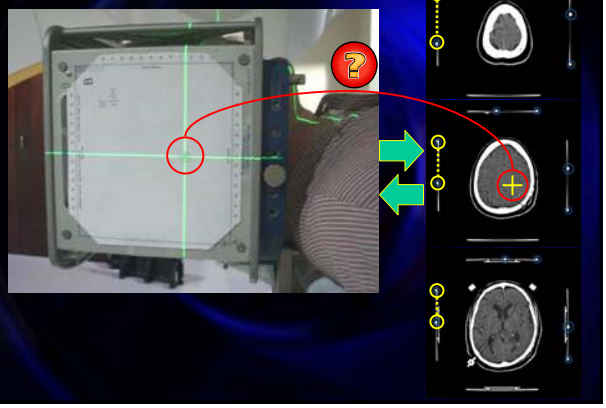
Maciunas et al, Neurosurgery 35:682-695, 1995

For SRT, it is essential to ensure daily reproducibility of frames

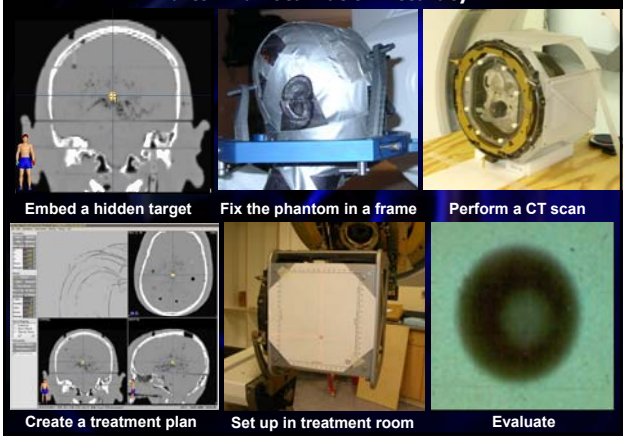
σ = 0.4 mm (n=2000), but "The frame is not appropriate for single fraction radiosurgery, as a large setup error (> 2 mm) for a single treatment cannot be excluded.

Kooy et al, IJROBP 30:685-691, 1994

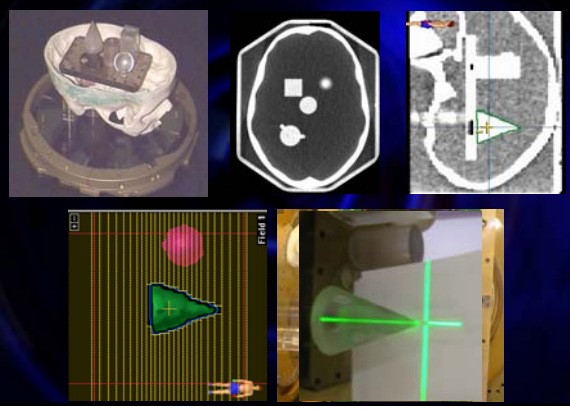
End-to-End Localization Accuracy



End-to-End Localization Accuracy



End-to-End Localization Accuracy
(with verification of MLC shapes, orientation, etc.)



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

YAHOO! FINANCE

Sign In
New User? Sign Up

Finance Home - Help

Welcome [Sign In]

To track stocks & more, Register

Financial News

Enter symbol(s) Basic Get Symbol Lookup

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.

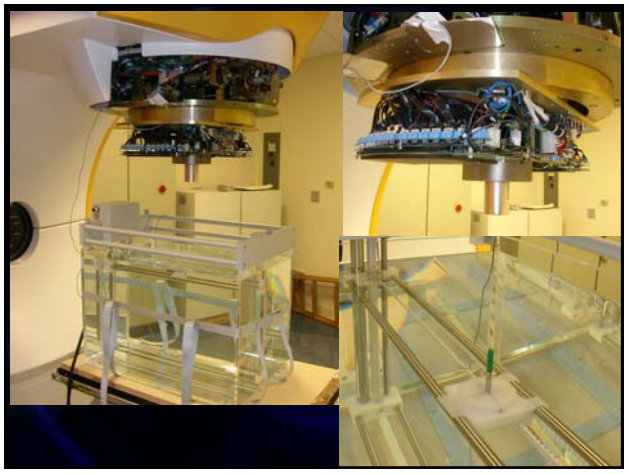
Beam Data Acquisition and Dose Computation

Traditional radiosurgery dose algorithms are quite simple, with dose specified by the product of measured beam parameters:

$$\text{Dose} = \overline{\text{TMR}} \bullet \text{OAR} \bullet \text{Output} \bullet \text{MU}$$

Corrections for tissue heterogeneities, surface irregularities, etc. are generally neglected.

But accurate measurement of beam data is difficult

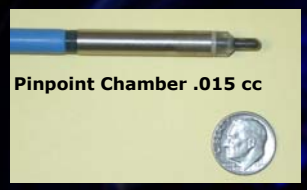


Beam Data

Beam characterization is best performed in water. Diodes are well suited to small field dosimetry though other dosimeters can certainly be used.

Measurement	Device
Depth Dose (PDD or TMR)	Diode / Ion Chamber
Off Axis Ratios	Diode / Ion Chamber
Relative Output	Diode / Ion Chamber
Absolute Dose	Ion Chamber

Dosimetry Equipment

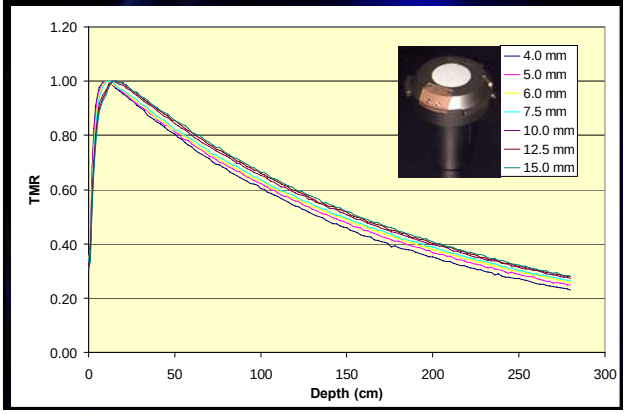


DIODE WARNING: Diodes exhibit enough energy dependence that ratios between large and small field measurements are inaccurate at the level required for radiosurgery

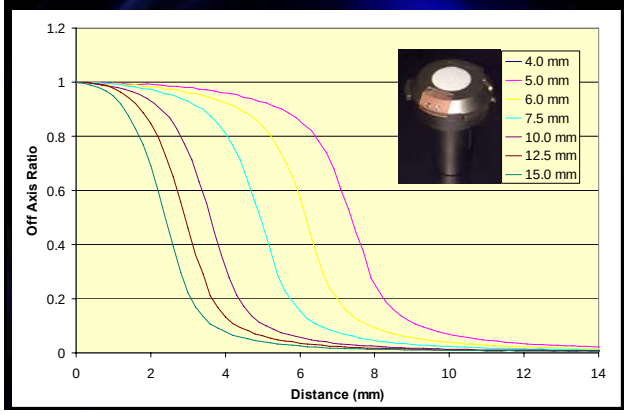
What to do?

Measure output factors ≤ 2x2 cm² using diode
≥ 2x2 and ≤ 4x4 cm² using diode & chamber
≥ 4x4 cm² using chamber

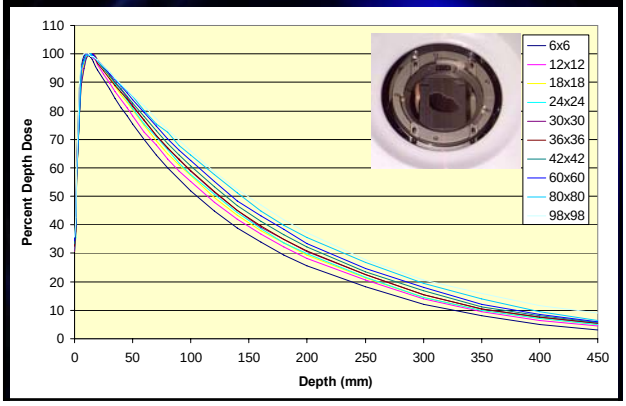
Depth Dose Data: Circular Cones



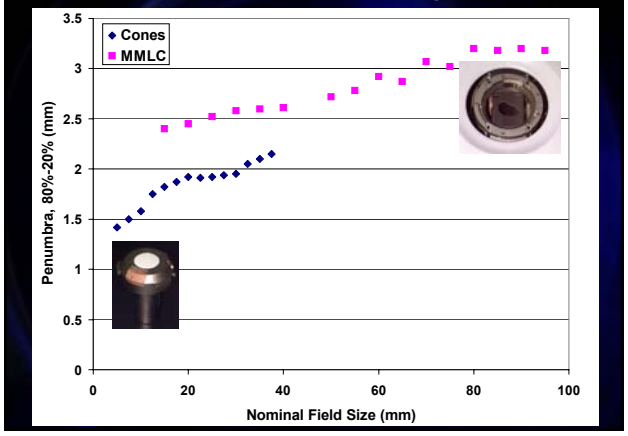
Profiles: Circular Cones



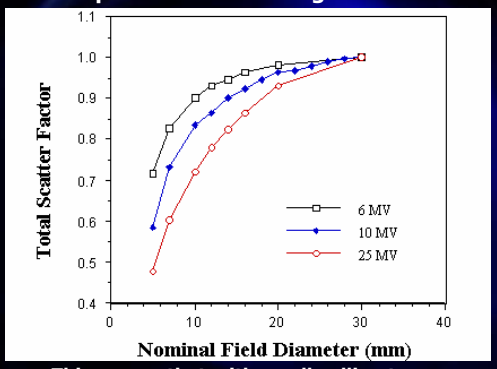
Depth Dose Data: μMLC



Penumbra: Cones versus μMLC

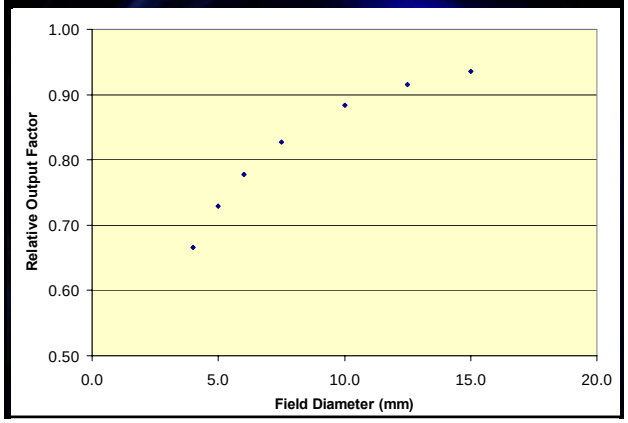


Radiosurgery beams exhibit a sharp decrease in output with decreasing field size

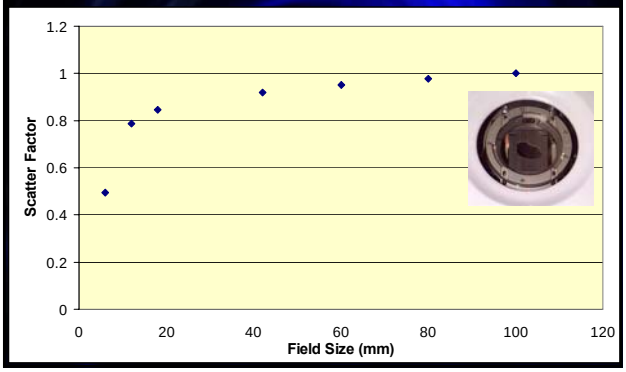


This means that with small collimators, treatment times can be long

Output Factors: Circular Collimators



Scatter Factors: µMLC



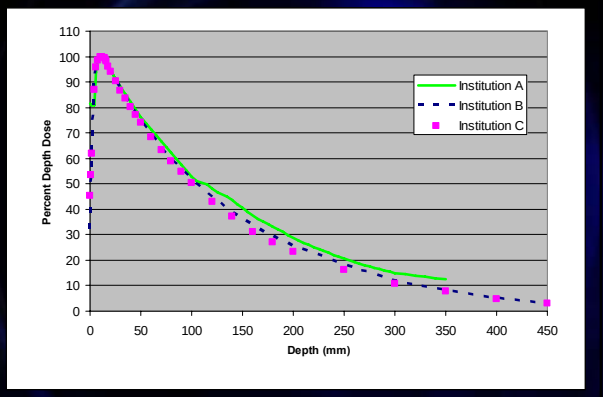
Seems Simple Enough ....

Surveyed beam data from 40 identical Linac SRS Units:

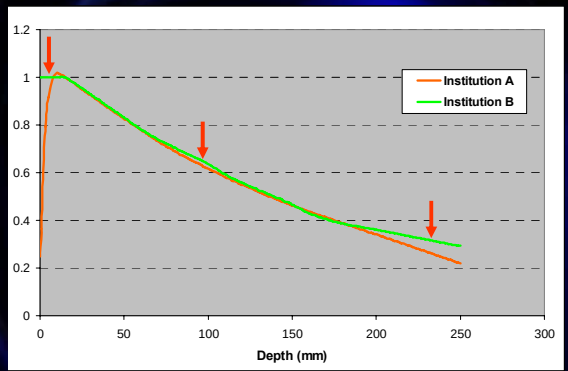
- **Percent Depth Dose**
- **Relative Scatter Factors**
- **Absolute Dose-to-Monitor Unit CF**
- **Reference Condition**

Applied statistical methods to compare data

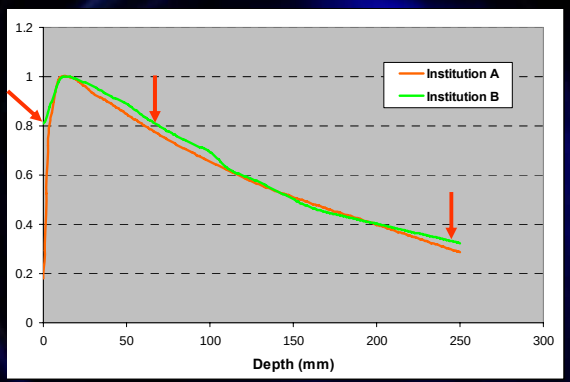
Observations of some treatment units: 6 mm x 6 mm MLC

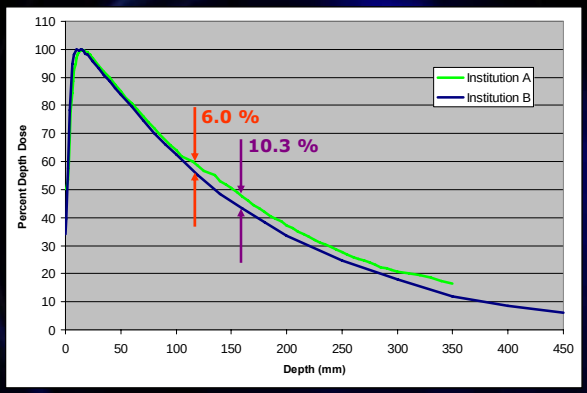


Observations of some treatment units: 5 mm collimator

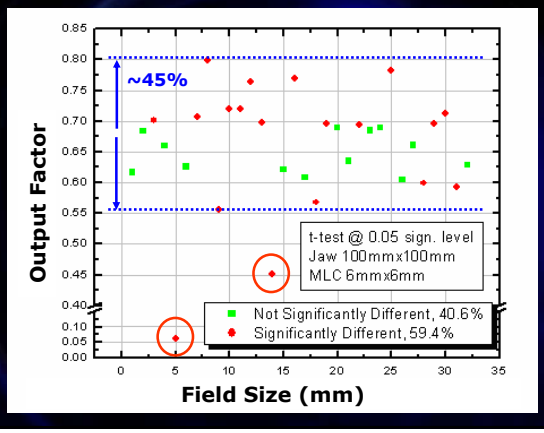


Observations of some treatment units: 15 mm collimator

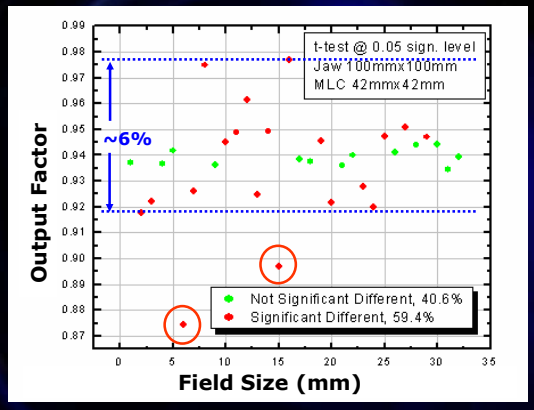




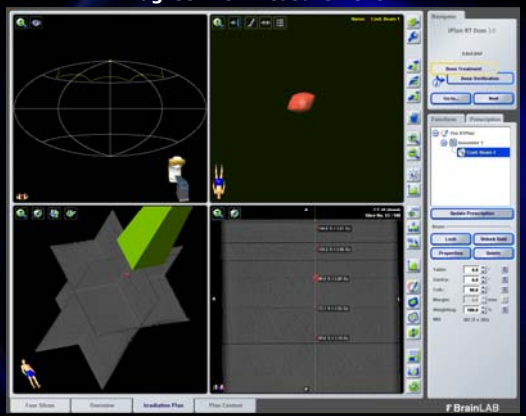
Relative Output Factor: 6 mm x 6 mm MLC

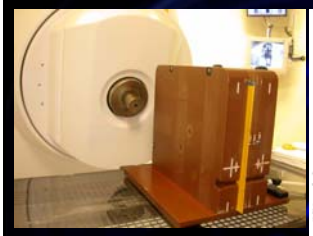


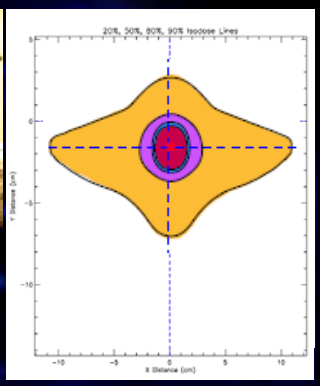
Relative Output Factor: 42 mm x 42 mm MLC



Commissioning your system: Does calculation agree with measurement?

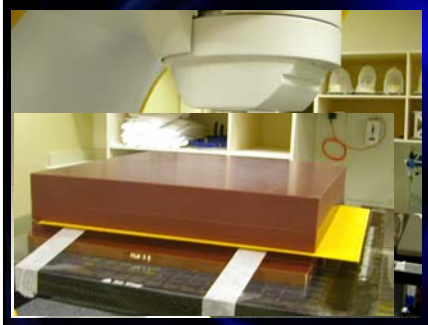


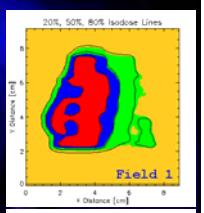


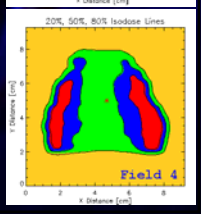


Directly verify the delivered distribution

Relative Dosimetry for individual fields



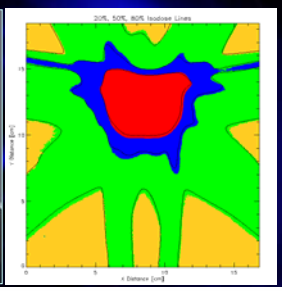




80, 50, 20% isodose lines of calculation and measurement

Relative Dosimetry for composite plan

80, 50, 20% isodose lines of calculation and measurement



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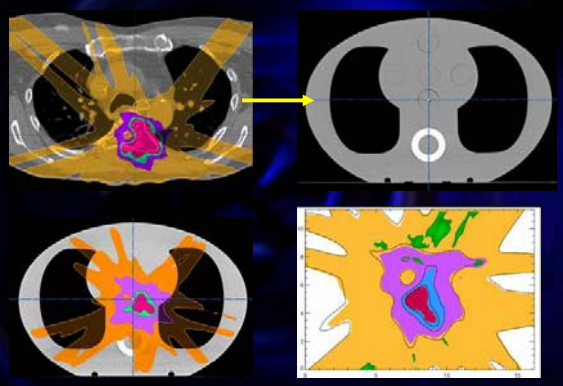
Patient specific quality assurance for the delivery of intensity modulated radiotherapy

Nzhde Agazaryan,* Timothy D. Solberg,† and John J. DeMarco‡
Department of Radiation Oncology, UCLA School of Medicine, 200 UCLA Medical Plaza, Suite B265, Los Angeles, California 90095-6951

Use an appropriate phantom



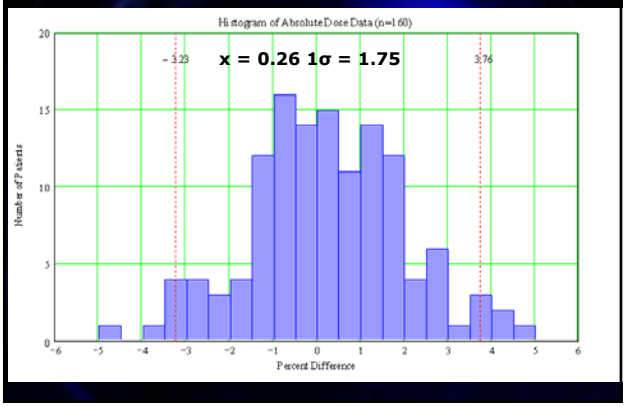
Absolute dosimetry

Med. Phys. 30 (7), July 2003

Segmental and dynamic intensity-modulated radiotherapy delivery techniques for micro-multileaf collimator

Nzhde Agazaryan[a)] and Timothy D. Solberg

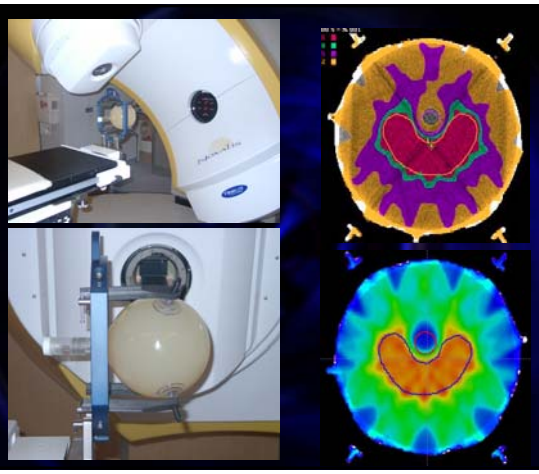
Difference between calculation and measurement: the first 160 IMRT patients



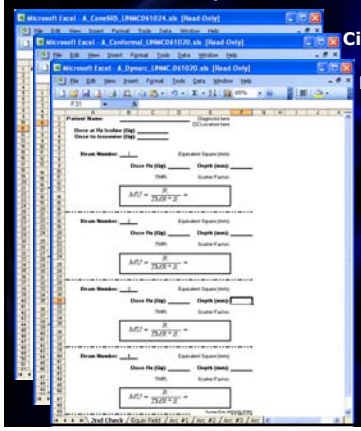
System Commissioning

End-to-end dosimetry is essential

Directly verify the delivered dose



What about independent verification of monitor units?

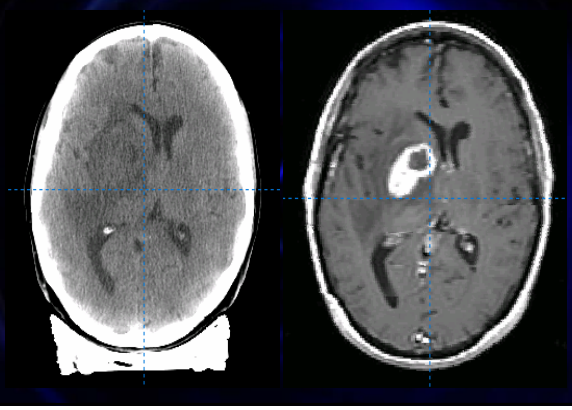


Circular Collimators

Micro-MLC

Dynamic Conformal Arc

Imaging: We need MR



Why do we need CT?

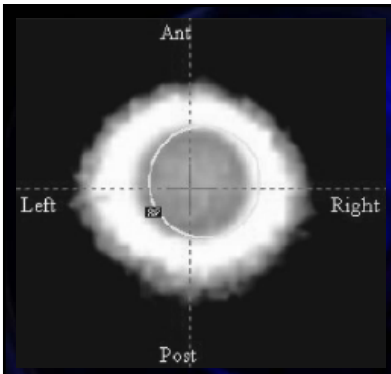
- Use CT for geometric accuracy
- Use MR for target delineation

"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.

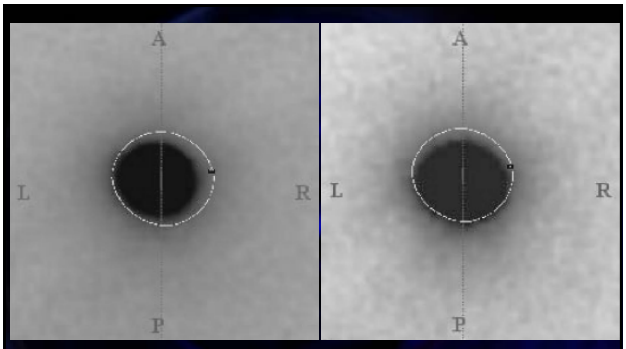


1.8 ± 0.5 mm shift of MR images relative to CT and delivered dose

Shifts occur in the frequency encoding direction

Due to susceptibility artifacts between the phantom and fiducial markers of the Leksell localization box

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?

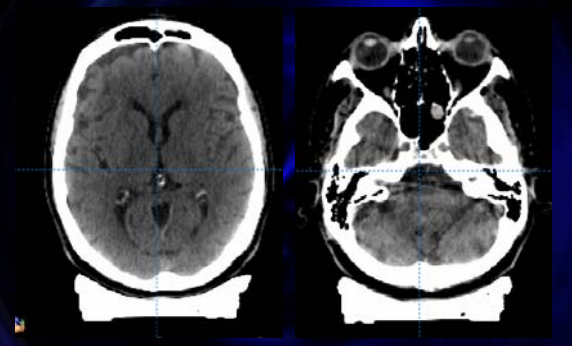
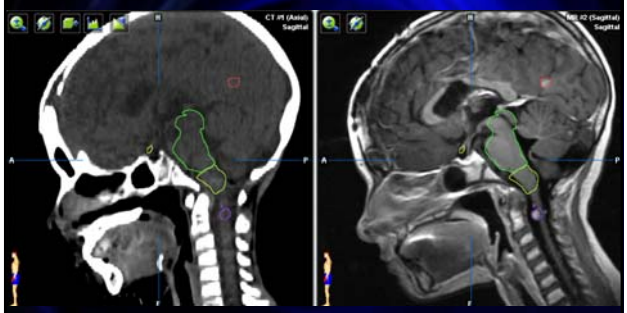


Image Fusion

Automatic Image Fusion for Extracranial Anatomy

DOESNT WORK!

Image Fusion for Extracranial Anatomy



So, how accurate is (frame-based) linac 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

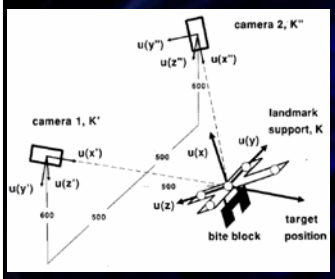
Stereotactic Radiosurgery, AAPM Report No. 54, 1995

Other sources not evaluated:

MRI, relocatable frames, …

Can we do better?

Stereophotogrammetry in Radiotherapy

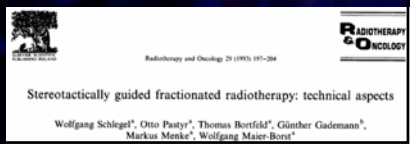


Spatial Resolution: 0.05 mm

Temporal Resolution: 0.03 s

Localization Accuracy: 0.2 mm

Optical Photogrammetry

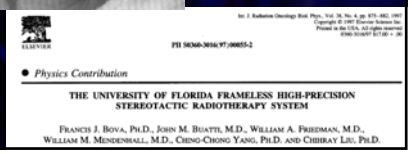

Radiotherapy and Oncology 29 (1993) 197–204

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

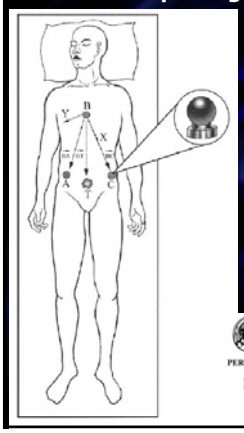
(Active) Infrared Photogrammetry

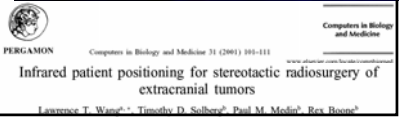

Physics Contribution

THE UNIVERSITY OF FLORIDA FRAMELESS HIGH-PRECISION STEREOTACTIC RADIOTHERAPY SYSTEM

Francis J. Bova, Ph.D., John M. Buatti, M.D., William A. Friedman, M.D., William M. Mendenhall, M.D., Cheng-Chong Yang, Ph.D. and Chihray Liu, Ph.D.

Stereophotogrammetry in Radiotherapy




PERGAMON

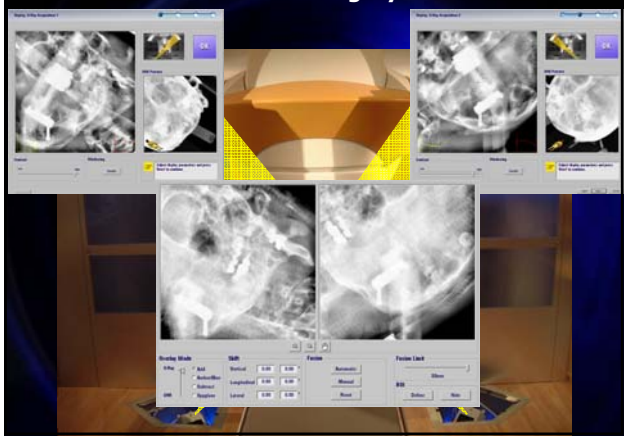
Computers in Biology and Medicine 31 (2001) 101–111

Computers in Biology and Medicine

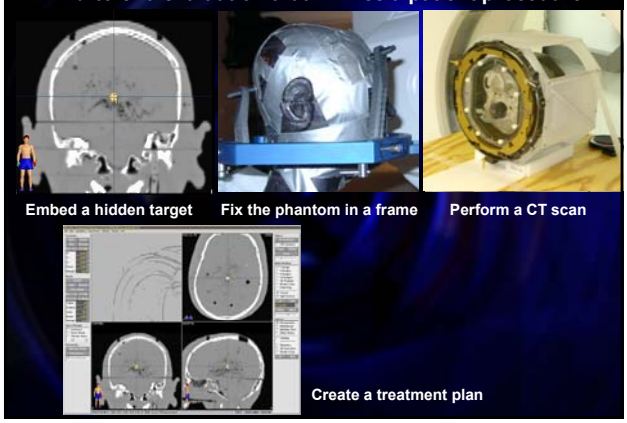
Infrared patient positioning for stereotactic radiosurgery of extracranial tumors

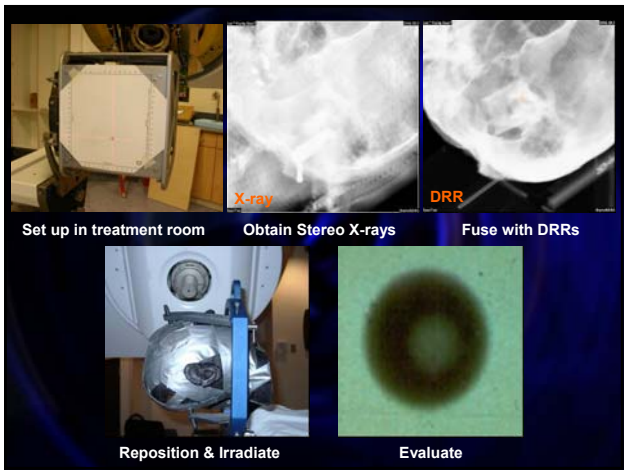
Lawrence T. Wang[a,*], Timothy D. Solberg[a], Paul M. Medin[b], Rex Boone[b]

Frameless Radiosurgery an UNMC



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

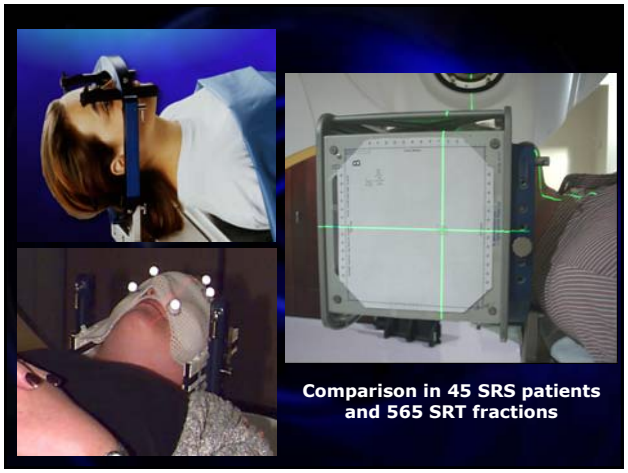




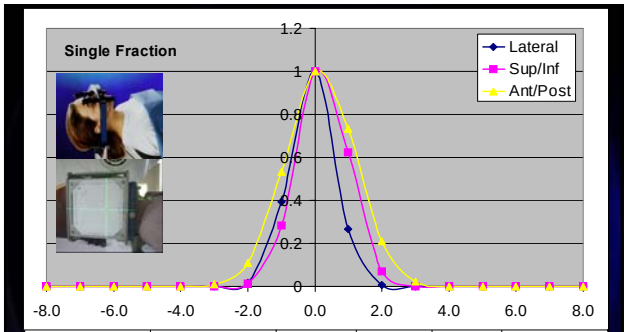
Results of Phantom Data

(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

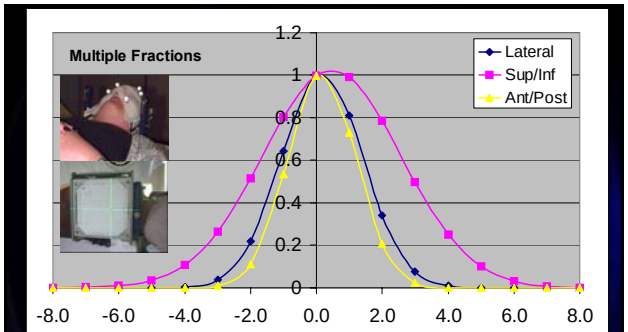
- Sample size = 50 trials (justified to 95% confidence level, +/- 0.12mm)



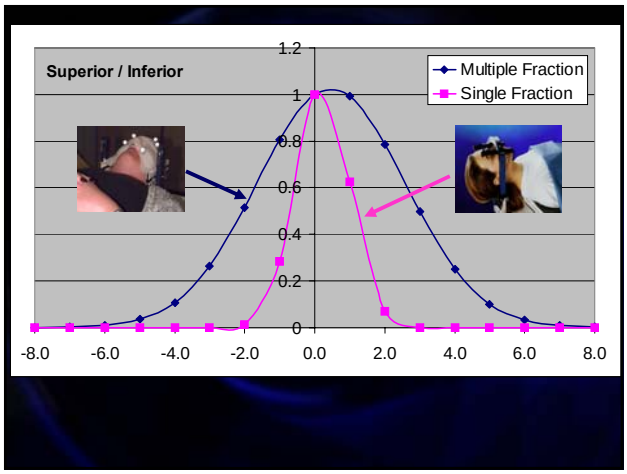
Comparison in 45 SRS patients and 565 SRT fractions



	(mm)	Lat.	Long.	Vert.	3D vector
Single Fraction	Average	-0.02	0.04	0.25	1.00
	Standard Deviation	0.66	0.55	0.72	0.55

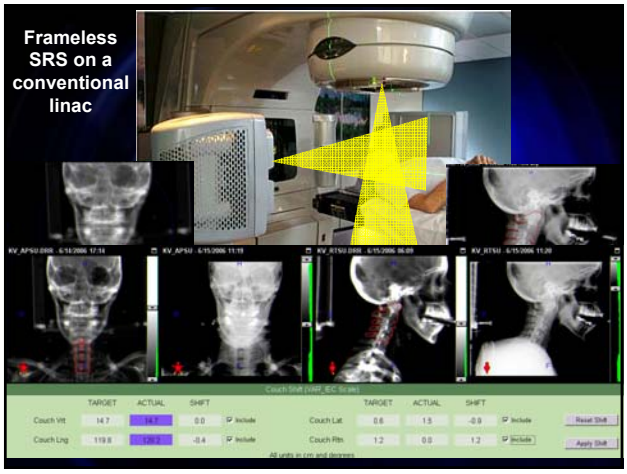


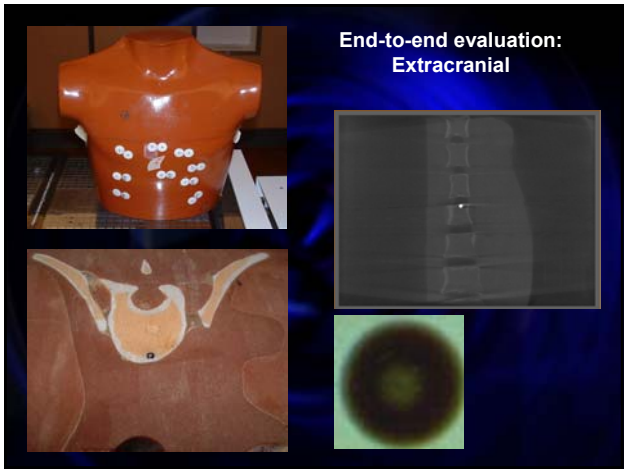
	(mm)	Lat.	Long.	Vert.	3D vector
Multiple Fraction	Average	0.17	0.47	0.17	2.36
	Standard Deviation	1.24	2.11	1.03	1.32



Comparative Patient Shift Data for Cranial Cases

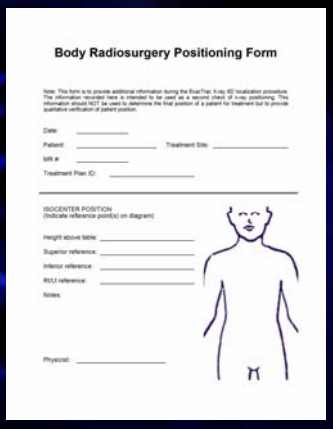
	(mm)	Lat.	Long.	Vert.	3D vector
Single Fraction	Average	-0.02	0.04	0.25	1.00
	Standard Deviation	0.66	0.55	0.72	0.55
Multiple Fraction	Average	0.17	0.47	0.17	2.36
	Standard Deviation	1.24	2.11	1.03	1.32





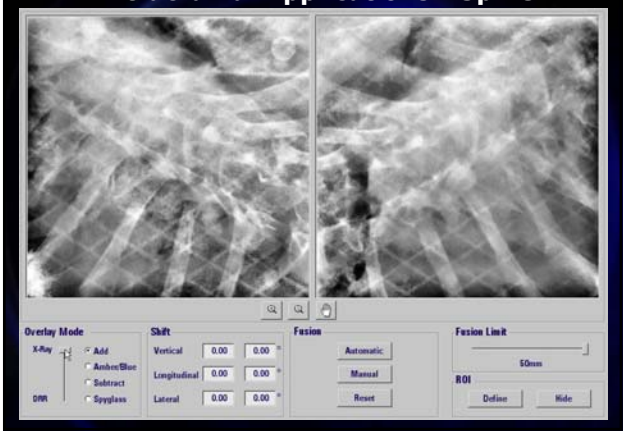
Lots of redundancy

- Patient is marked
- Immobilization device is marked
- Location of IR markers is recorded
- Table heights and shifts are provided



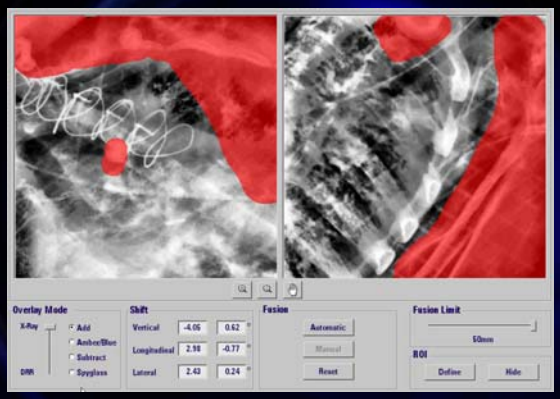
Extracranial Applications - Spine

Extracranial Applications - Spine



Extracranial Applications - Lung

Extracranial Applications - Lung



Radiosurgery Guidelines

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

RTOG Radiosurgery QA Guidelines, 1993

AAPM Task Group Report 54, 1995

European Quality Assurance Program on Stereotactic Radiosurgery, 1995

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

AAPM Task Group 68 on Intracranial stereotactic positioning systems, 2005

ACR Practice Guidelines for the Performance of Stereotactic Radiosurgery, 2006

ACR Practice Guidelines for the Performance of Stereotactic Body Radiation Therapy, 2006