Cyberknife:

A Collaborative Research Opportunity for the University of Waterloo and Grand River Regional Cancer Centre

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cancer care ontario | action cancer ontario

University of Waterloo

GRAND RIVER HOSPITAL

GRRCC IGRT Perspective, June 2006

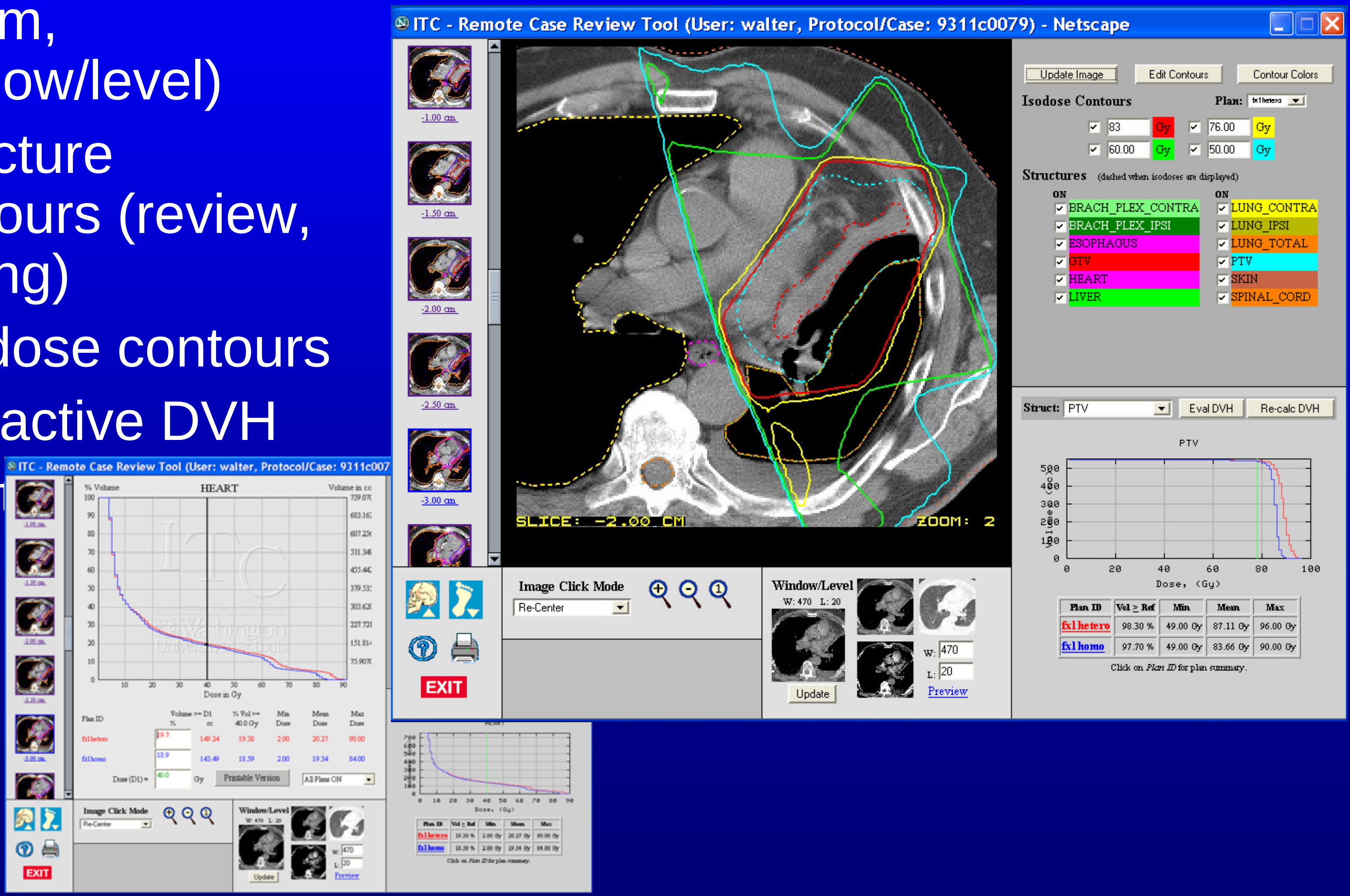
- *Implementation of IMRT, fall*
- *Installation of KV On-Board Imager (linac option), fall*
- *possibility for Cyberknife*
- *Informatics Development: CFI Hospital Reasearch Fund opportunity*

Required Infrastructure for Image Guided Radiation Therapy

- Diagnostic Imaging: multiple modality (4D CT, PET, MR)
- Volumetric contouring; target and OAR with margins
- IMRT planning; inverse optimization via dose objective function
- IMRT delivery; dynamic MLC with gated beam control
- Verification imaging; CR, EPID, KV imaging (cone beam CT, pulsed fluoro)
- Informatics and assessment of clinical outcomes (Dicom-RT and beyond)

Remote Review Tool

- CT Images (zoom, window/level)
- Structure contours (review, editing)
- Iso-dose contours
- Interactive DVH
- Poin displ



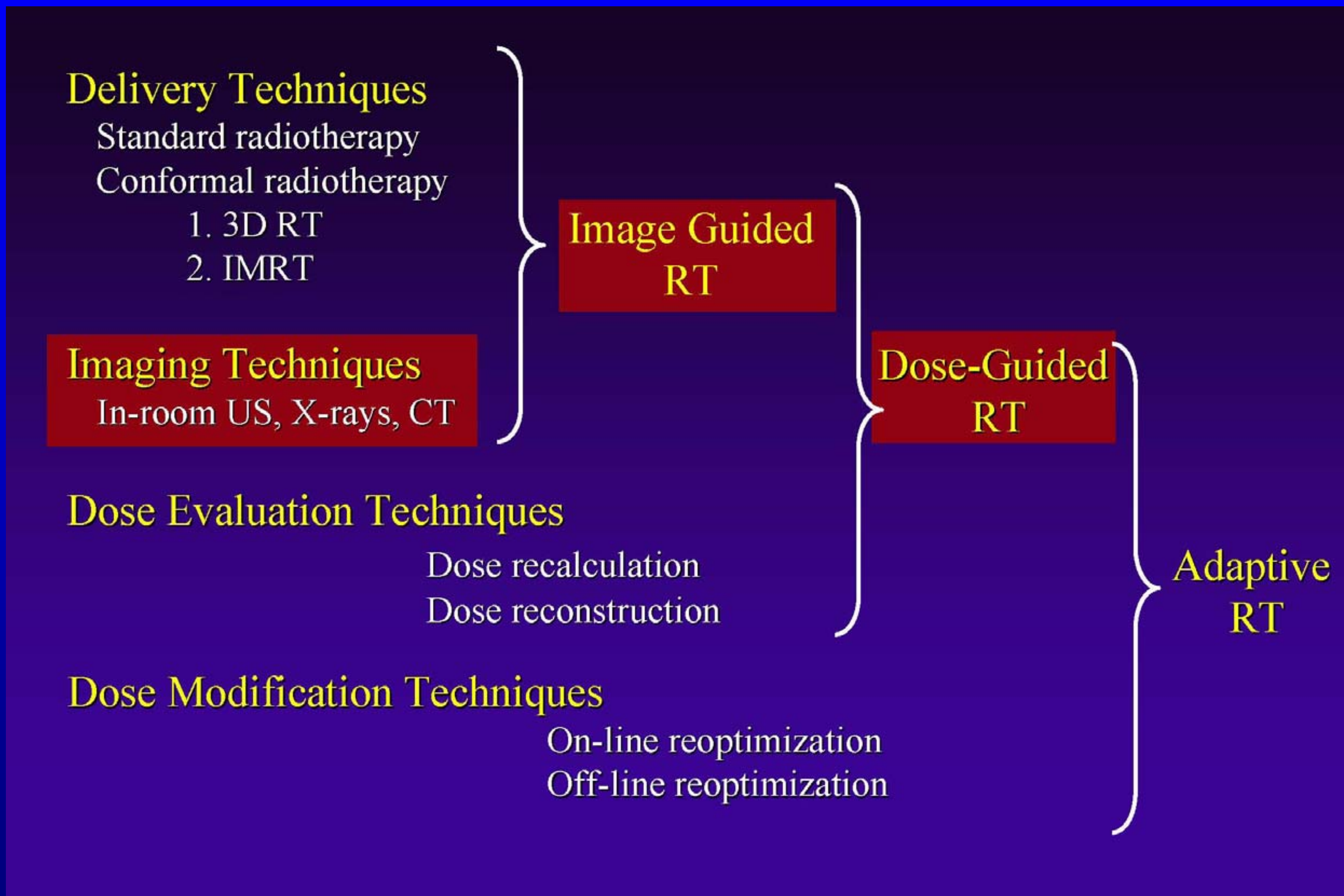
What is Image Guided Radiation Therapy?

- *technological improvements in therapeutic radiology providing precision, highly conformal dose coverage to a prescribed target volume and precision avoidance of surrounding healthy tissue*
- *3 and 4D diagnostic imaging technologies providing better definition of disease (PTV)*
- *Improved linear accelerator technology with precision servo-controlled dosimetry and dynamic multileaf collimator (beam shaping)*
- *MV and KV verification imaging integrated with linear accelerator; pulsed digital fluoroscopy and CBCT*
- *Dose-objective-based inverse treatment planning for static and dynamic IMRT beam delivery*
- *IGRT patient management software; data archival and retrieval systems, extensive image analysis tools, patient work list, tasking, electronic review and approval*

Whats is Adaptive Radiation Therapy?

- *IGRT combined with a "dynamic feedback loop" to perform re-planning and re-optimization as required*
- *Tumor regression and anatomical changes assessed dynamically*
- *Deformable dose registration on changing anatomy*

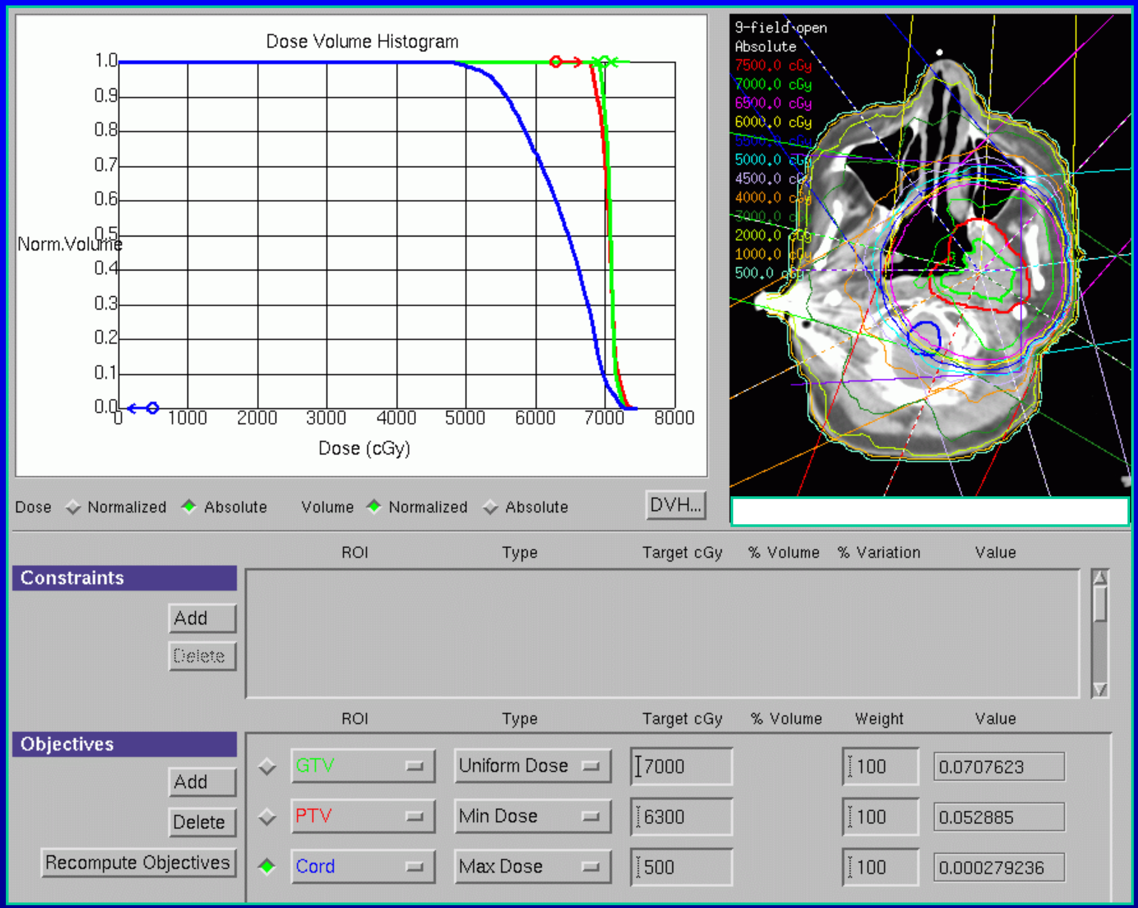
Adaptive Radiation Therapy, P. Kupelian ASTRO '06



Inverse Planning with P^3IMRT

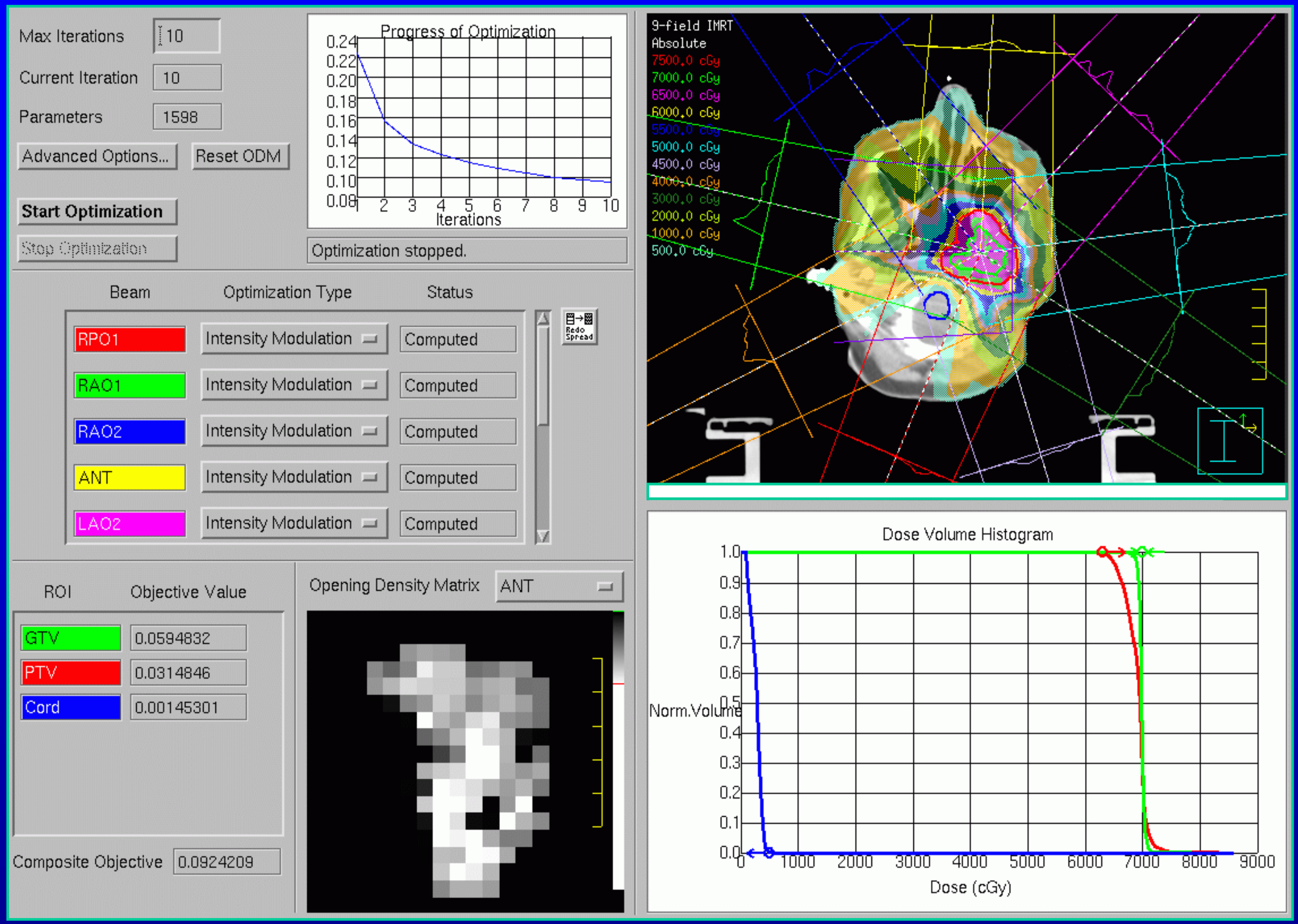
9-Beam Head & Neck Plan #1

Step 1: Define treatment objectives



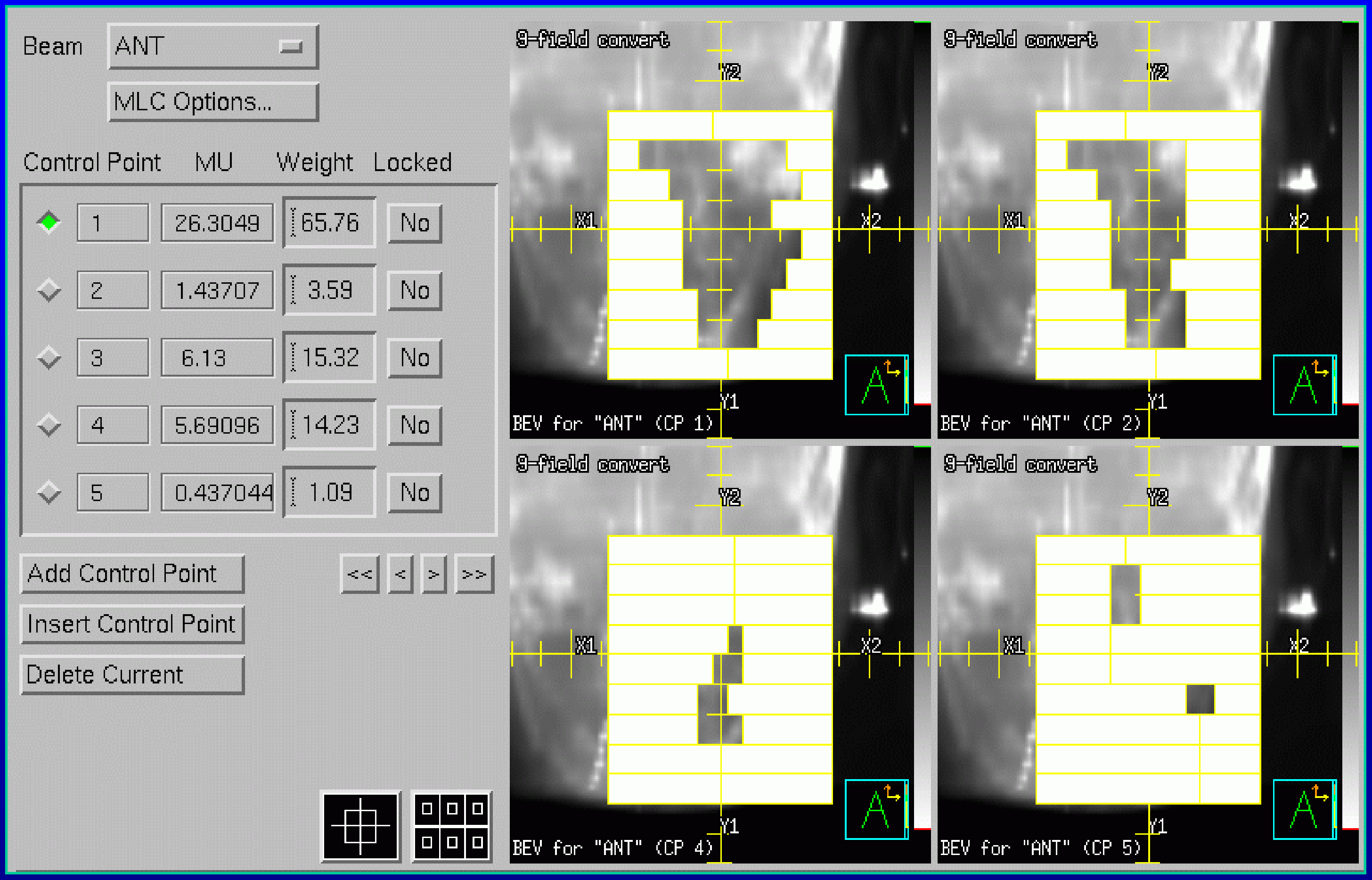
Images courtesy of John Gibbons, Ph.D., Palmetto-Richland Memorial Hospital, Columbia, SC

Step 2: Optimize intensity modulation



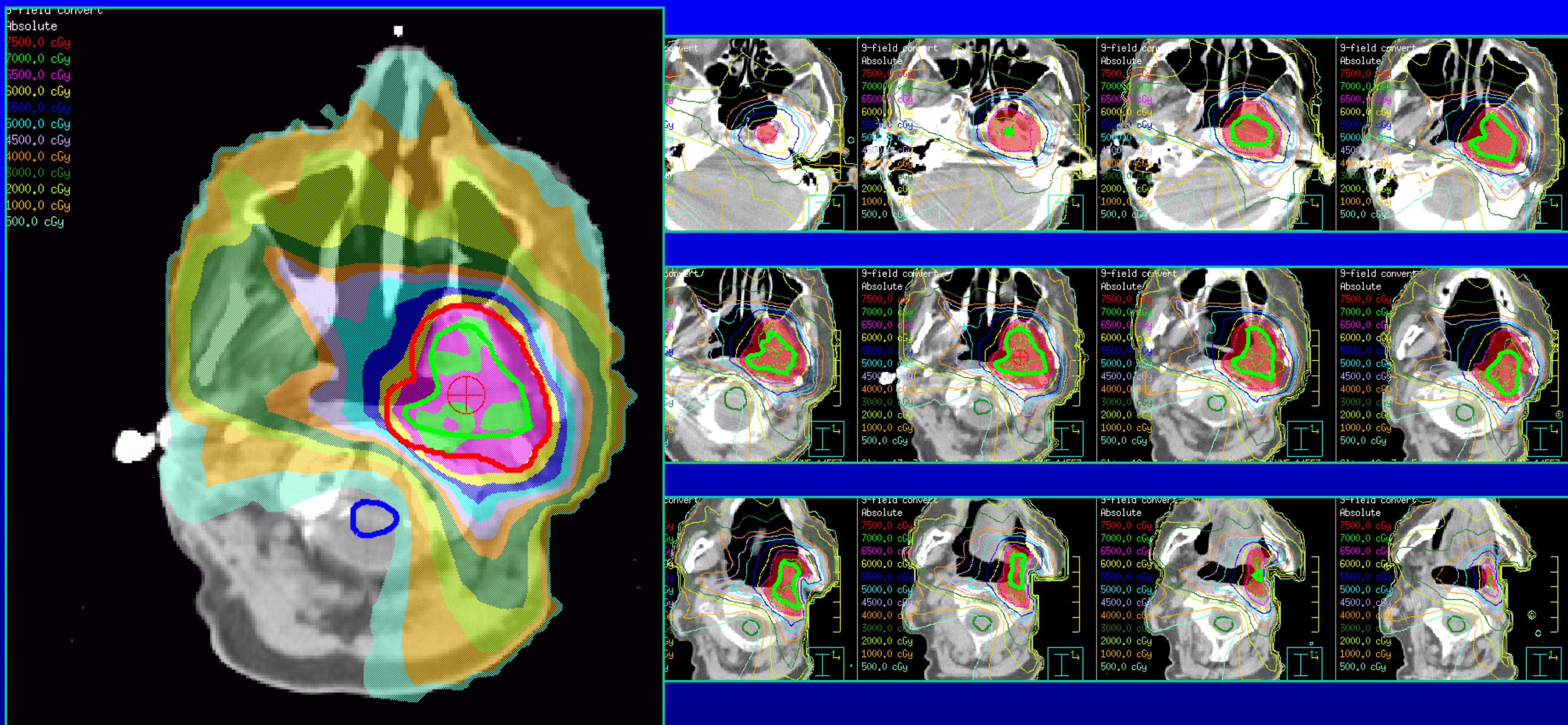
Images courtesy of John Gibbons, Ph.D., Palmetto-Richland Memorial Hospital, Columbia, SC

Step 3: Convert ODM to MLC segments



Images courtesy of John Gibbons, Ph.D., Palmetto-Richland Memorial Hospital, Columbia, SC

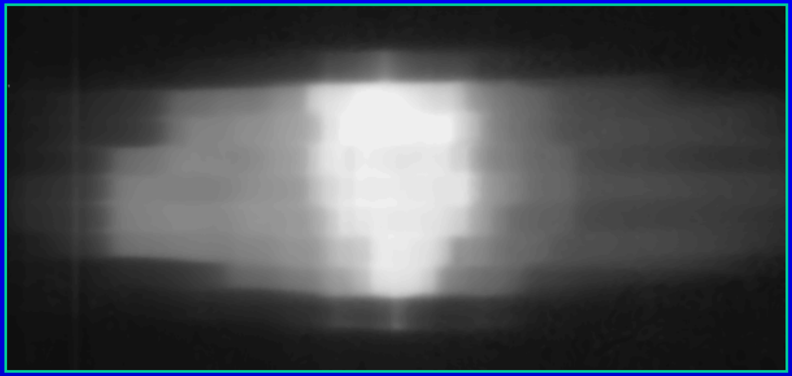
Step 4: Compute final CC Convolution dose distribution



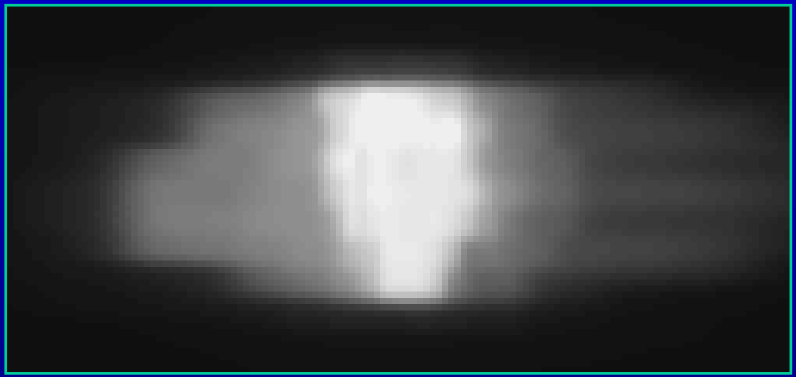
Images courtesy of John Gibbons, Ph.D., Palmetto-Richland Memorial Hospital, Columbia, SC

Step 5: Perform QA

Film dosimetry for 9-beam plan in solid phantom



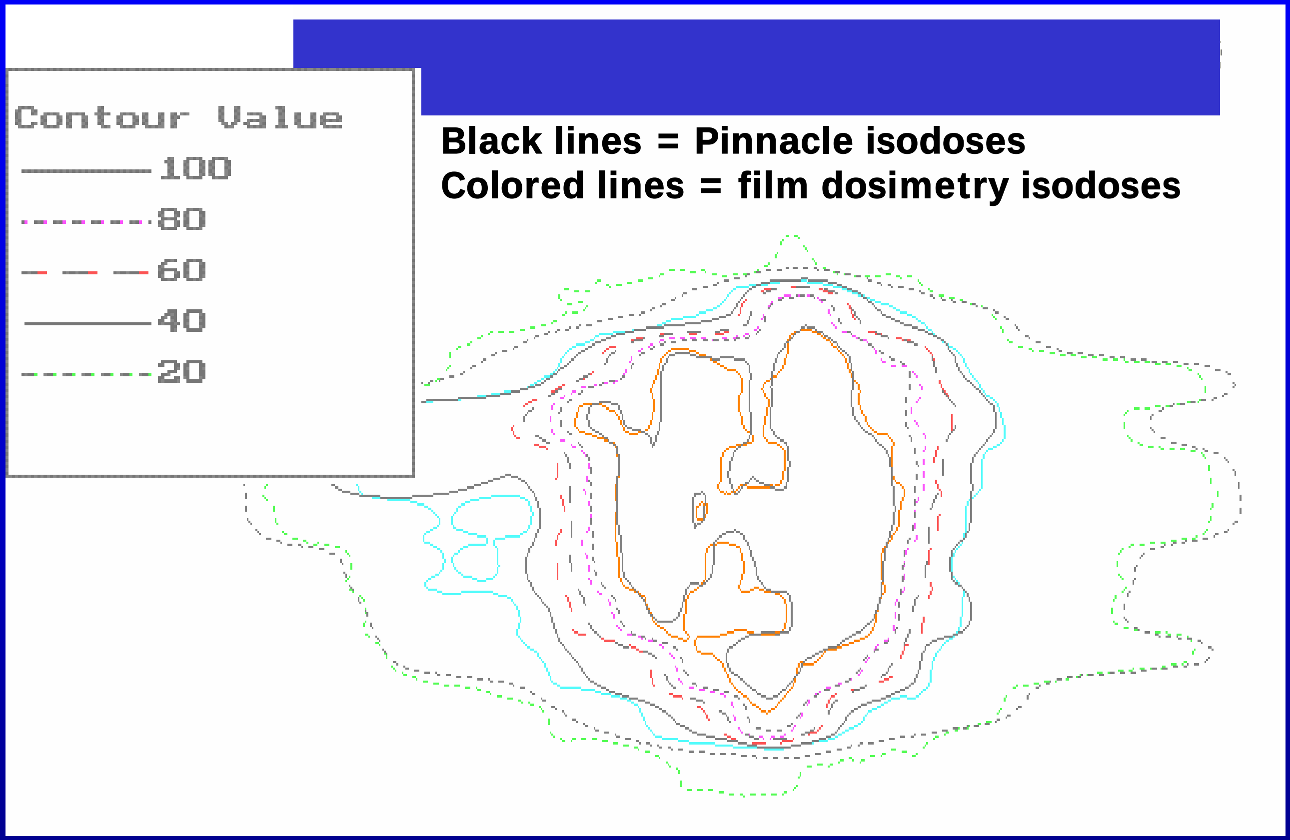
Pinnacle planar dose map for 9-beam plan in solid phantom



Images courtesy of John Gibbons, Ph.D., Palmetto-Richland Memorial Hospital, Columbia, SC

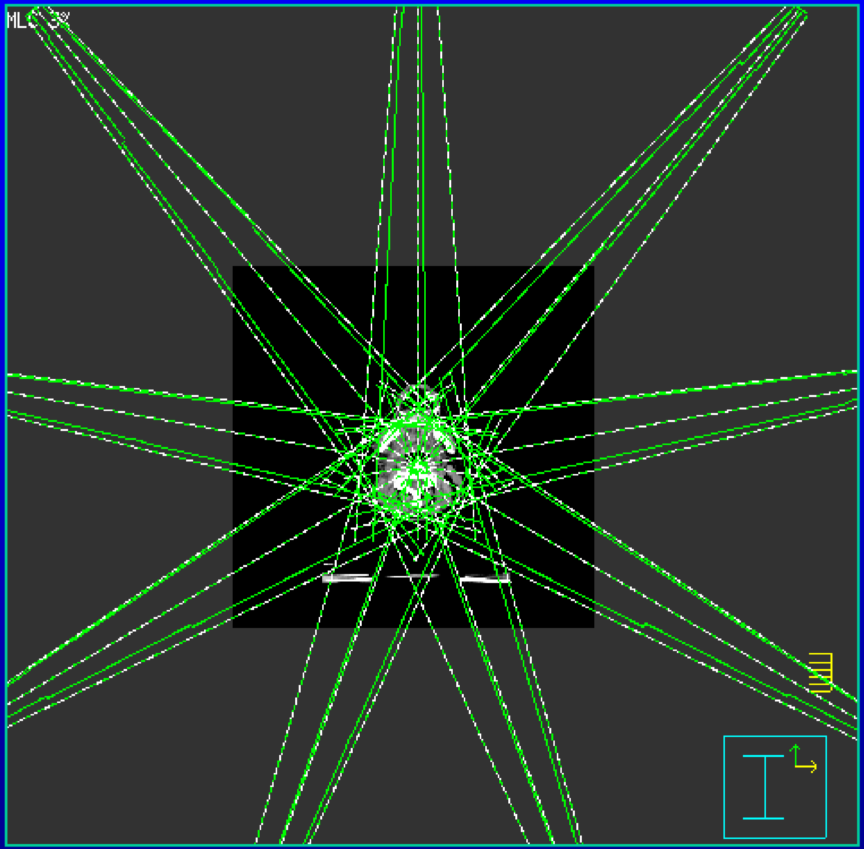
Step 5: Perform QA

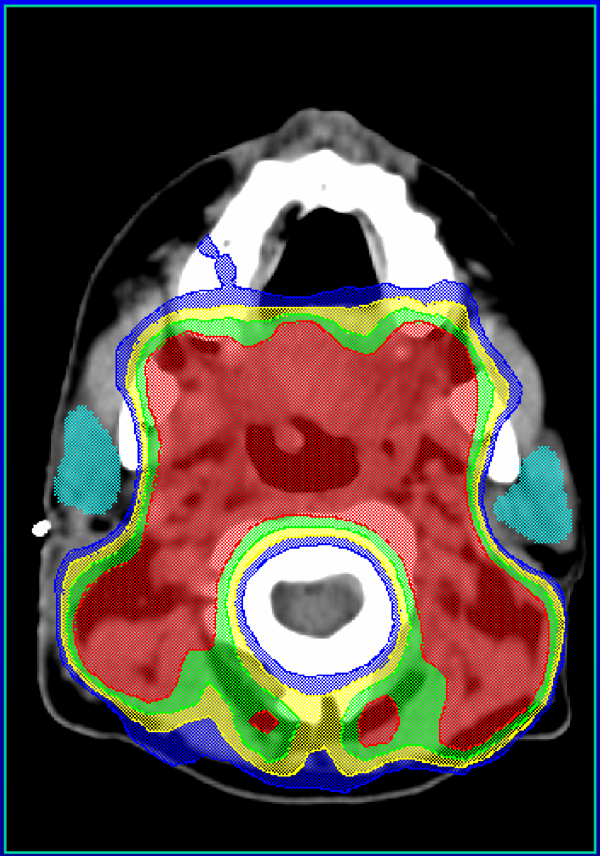
Planned vs measured isodoses using film dosimetry



Images courtesy of John Gibbons, Ph.D., Palmetto-Richland Memorial Hospital, Columbia, SC

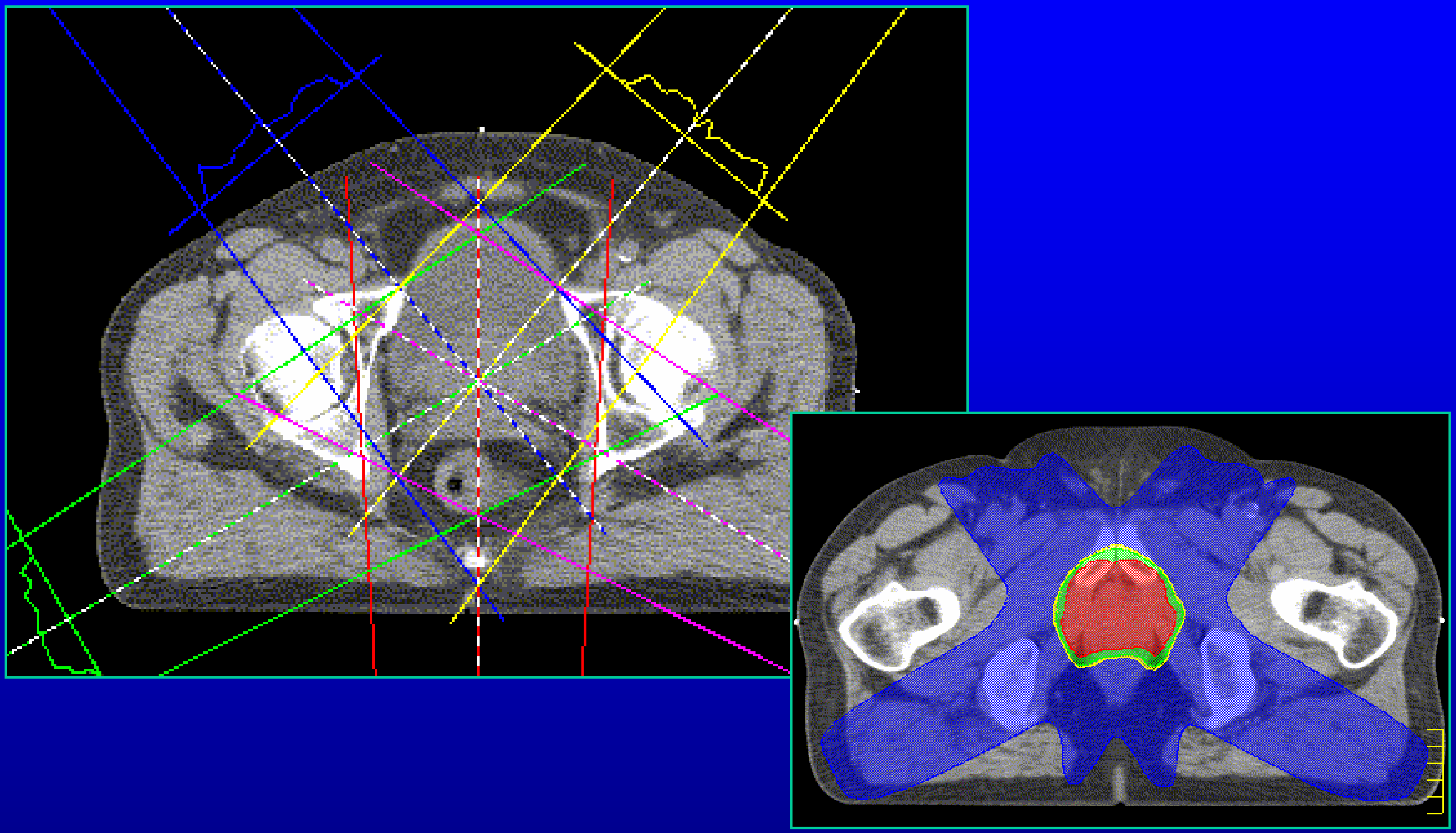
Parotid-sparing 9-beam head & neck IMRT





Images courtesy of Chester Ramsey, MS, Thompson Cancer Survival Center, Knoxville, TN

Prostate 5-beam step-and-shoot IMRT



Images courtesy of Chester Ramsey, MS, Thompson Cancer Survival Center, Knoxville, TN

Step&Shoot Dosimetry Anomaly, Grigorov et al, 2006

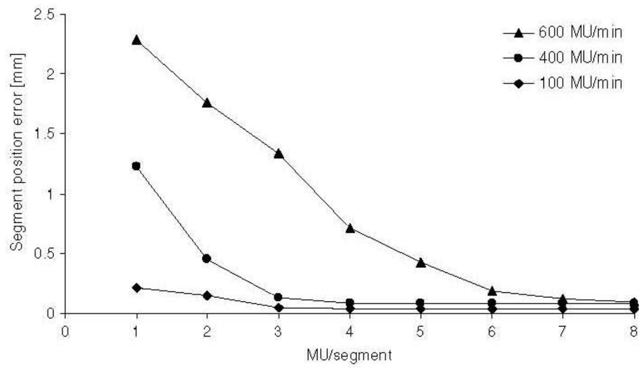


Figure 3. Segment positional error measured by RK ionization chamber of the segment with an off-axis distance of 9.5 cm measured for 1 to 8 MU/seg at SAD = 100 cm and depth = 5 cm in Solid Water phantom. The dose rate is a parameter.

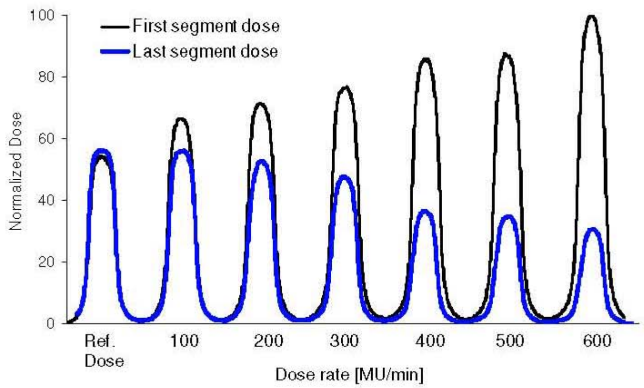


Figure 4. Segment dose errors caused by the 'overshoot' effect for 1 MU irradiated by dose rates in the range from 100 to 600 MU min^{-1} compared with a reference dose of 1 MU. All beam profiles are measured at the central axis of the beam for the segment size of $1 \times 1\ cm^2$ at 100 cm SAD and 5 cm depth. The dose is normalized to the maximum dose of the first segment irradiated with 600 MU min^{-1}.

Clinical Relevance of Dosimetry Problem

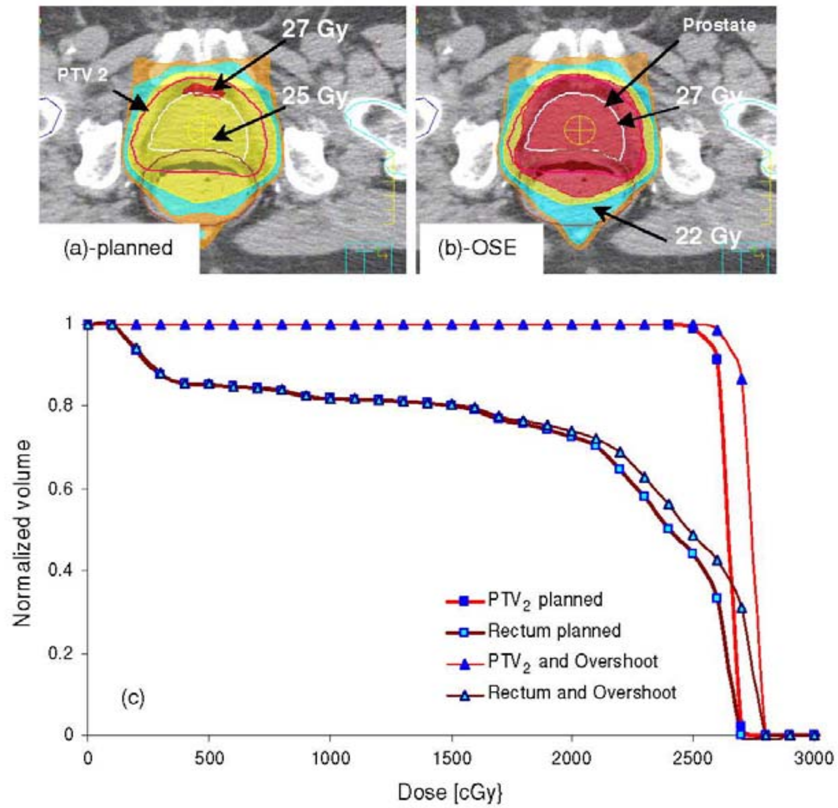


Figure 5. (a) Top left: planned dose distributions. (b) Top right: dose distributions with simulation of the 'overshoot' effect. (c) Bottom: DVHs for the rectum and PTV_2. Square dots represent the original plan. The curves with the triangular dots represent the simulated 'overshoot' effect (OSE). The simulation represents the dose distribution and DVHs achieved only by the first beam segments for a 5-beam IMRT prostate plan delivered in 41 fractions, for planned treatment dose of 82 Gy.

Correction for Step&Shoot Dosimetry Anomaly

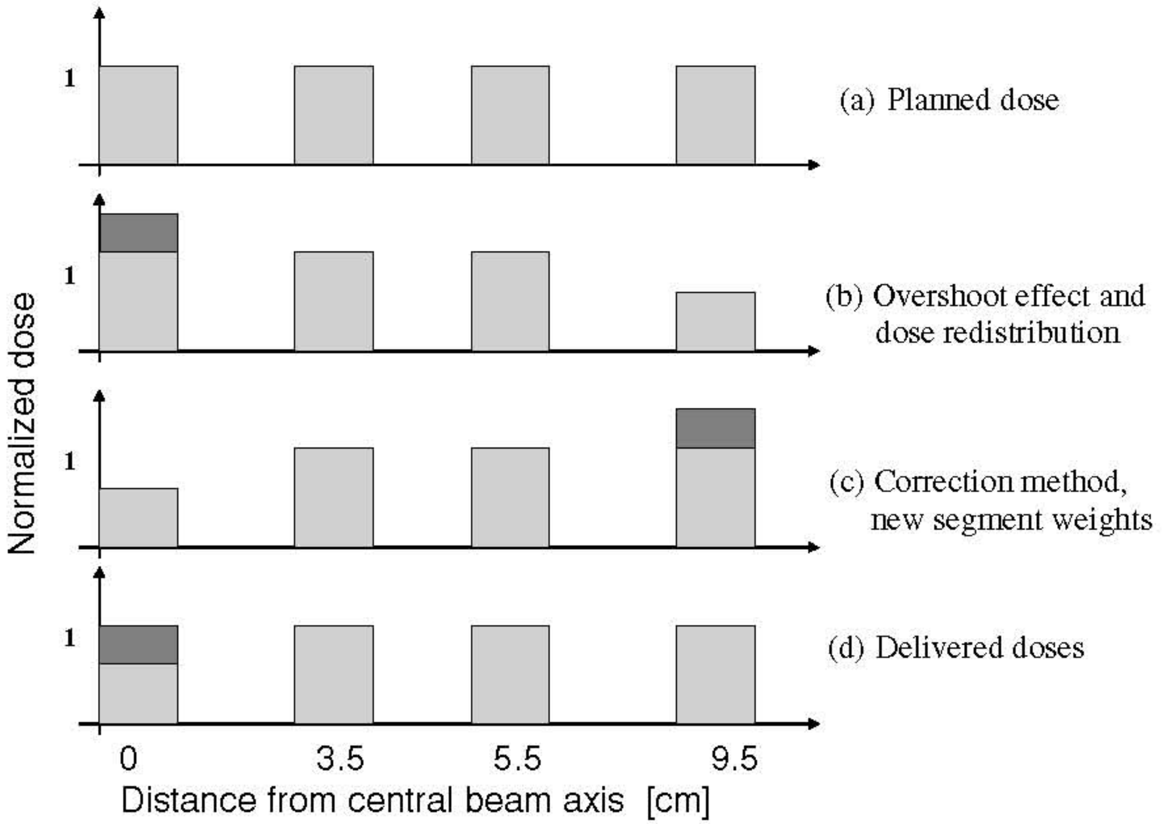
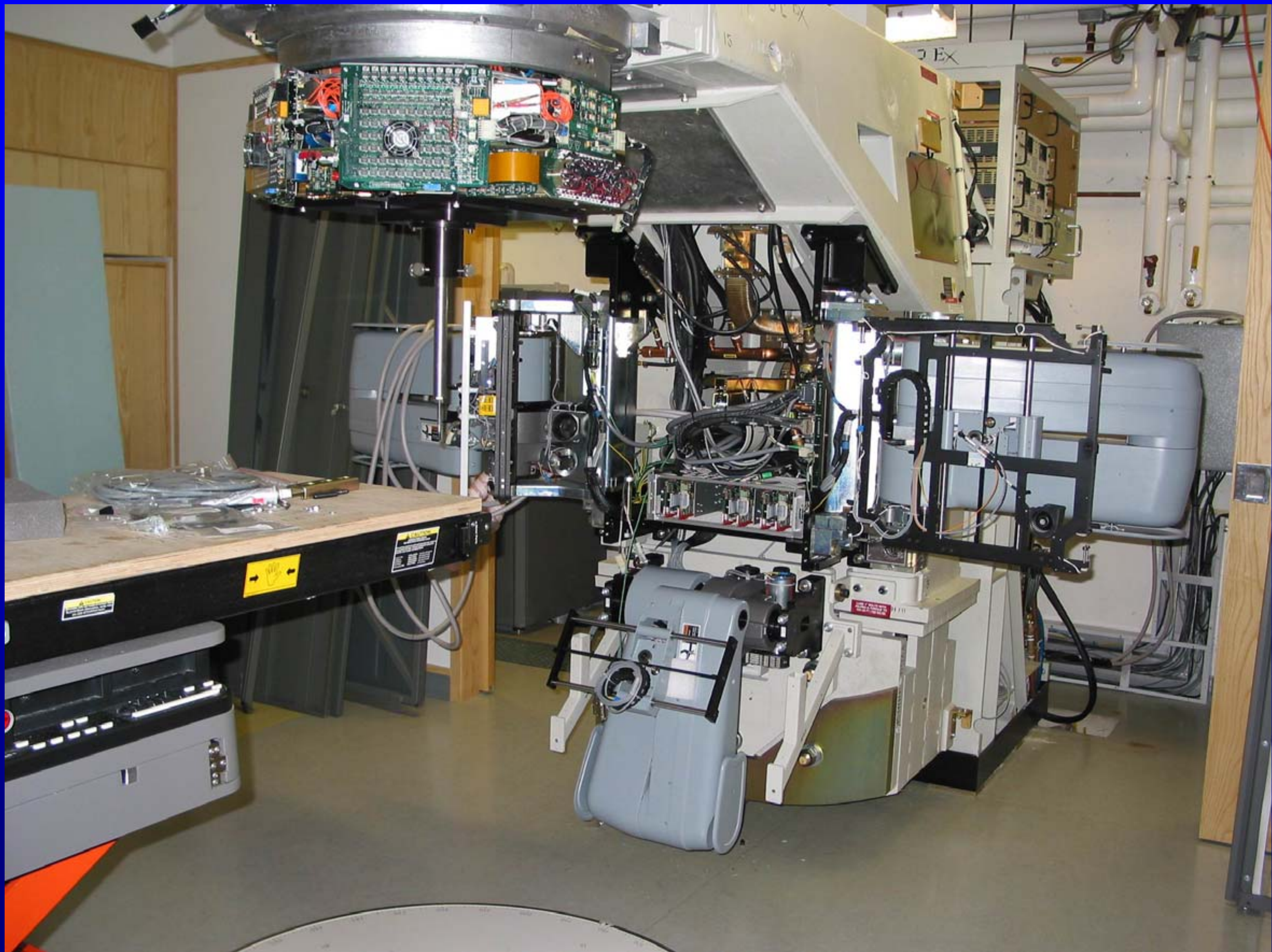


Figure 7. Graphical depiction of the method for correction of the 'overshoot' effect. The light shaded pattern and the dark shaded pattern represent the segment MU and the ΔMU inaccuracy caused by the 'overshoot' effect, respectively. (a) View of the initially planned MU; (b) affected beam with redistribution of the MU between the segments; (c) corrected segment MU and (d) final irradiated segment MUs.

Varian OBI Installation at GRRCC, January 2006

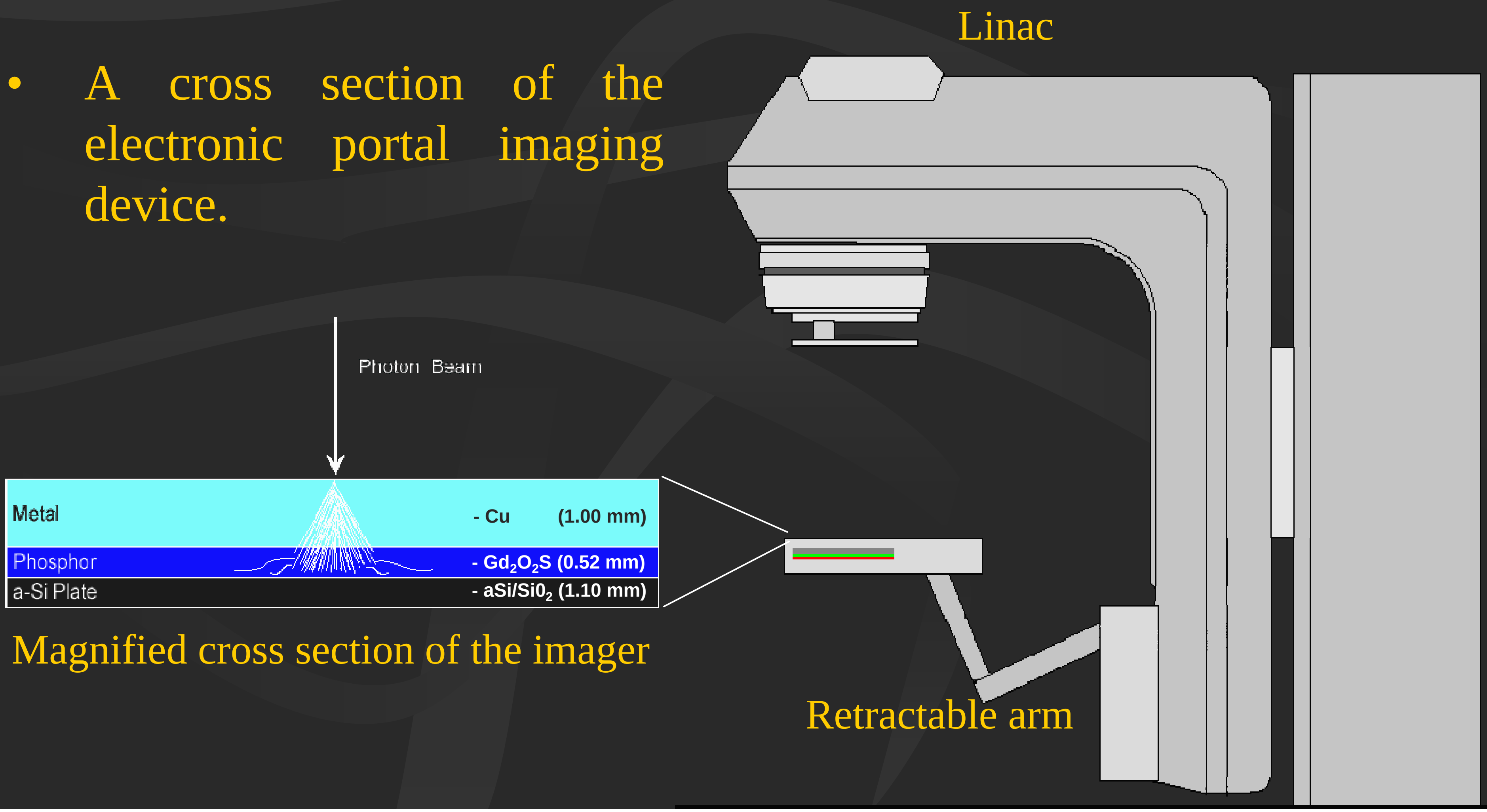


Robotic arm controller and high frequency generator for Varian OBI

Varian OBI Installation at GRRCC, January 2006

The Electronic Portal Imaging Device

- A cross section of the electronic portal imaging device.

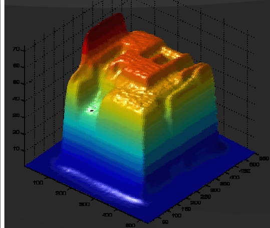


Magnified cross section of the imager

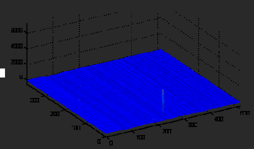
IMRT Image Acquisition Process
A. Fleck

Raw EPID Image (IMRT field)

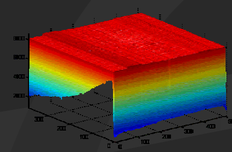
IMRT Field



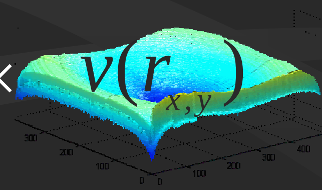
Dark Field



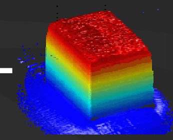
Flood Field



Diagonal Beam Profile



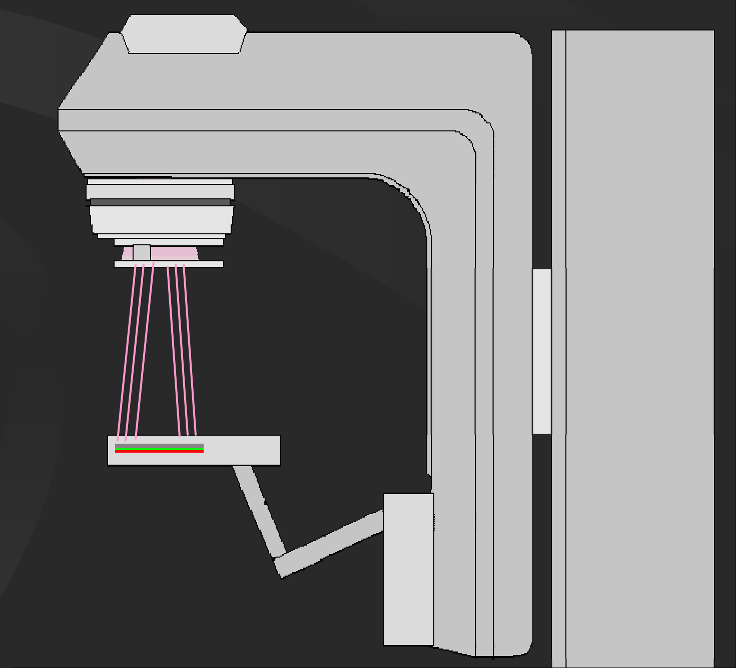
Normalize (10 x 10)



ISL

$$\left[\text{IMRT Field} - \text{Dark Field}\right] \div \text{Flood Field} \times \bar{k}_{FF} \times v\left(r_{x,y}\right) \div \text{Normalize} \times \left(\frac{SAD}{SDD}\right)^{2}$$

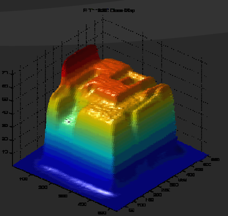
Comparison (in Matlab)
and/or
Clinical Vision Review Environment



Pinnacle - Planar Dose Map

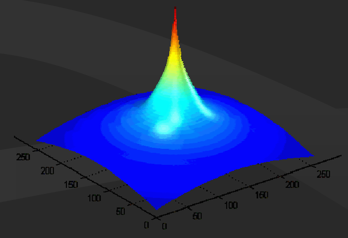
Pinnacle TPS planar dose map (IMRT field)

IMRT field

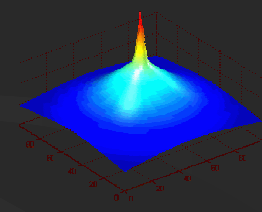


$$\left[\text{IMRT field} \times MU \times \frac{OF(x,y)}{PSF(x,y)} \right] \otimes^{-1} \text{Phantom kernel} \otimes \text{Dose-glare kernel}$$

Phantom kernel



Dose-glare kernel



Comparison (in Matlab)
and/or
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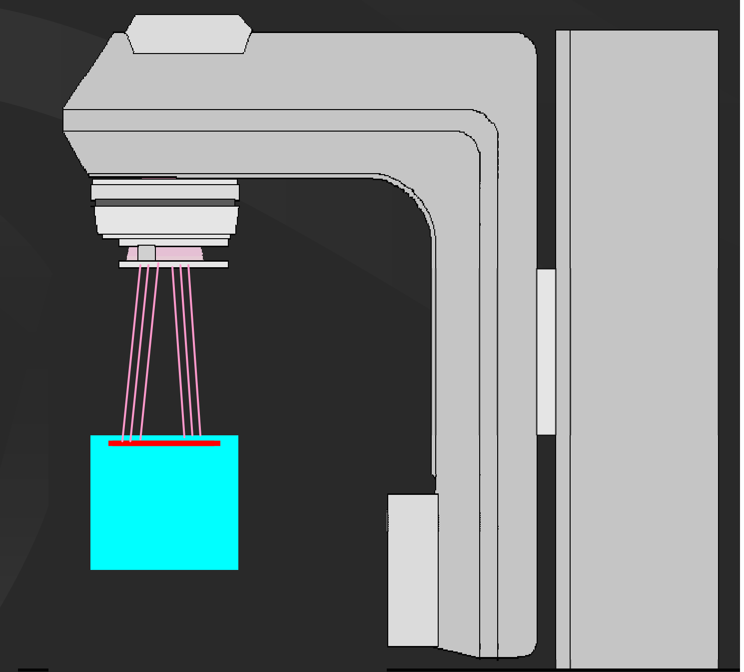
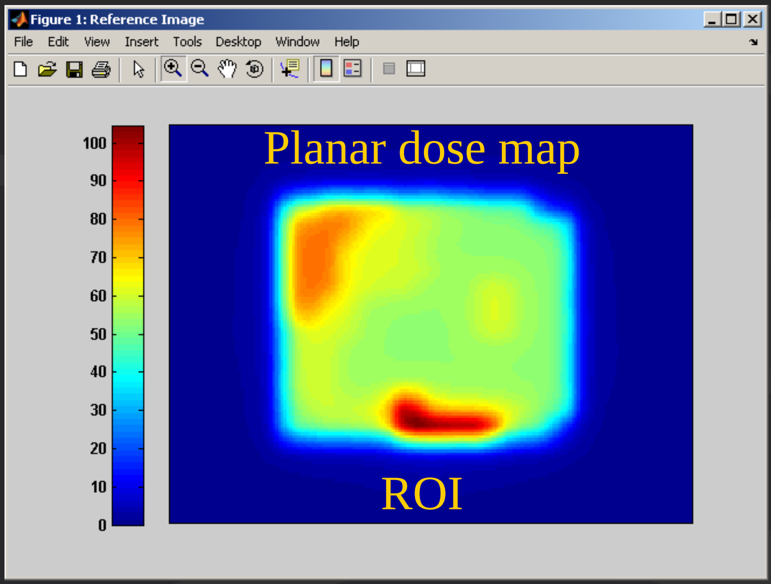
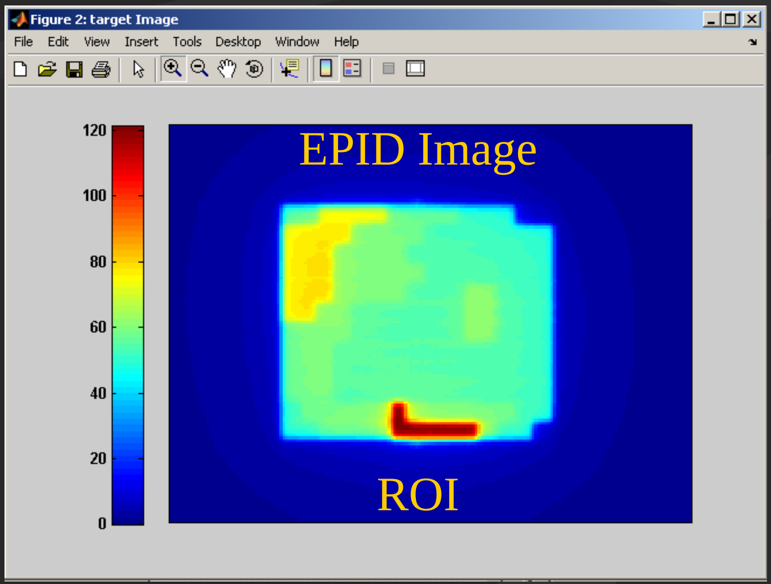
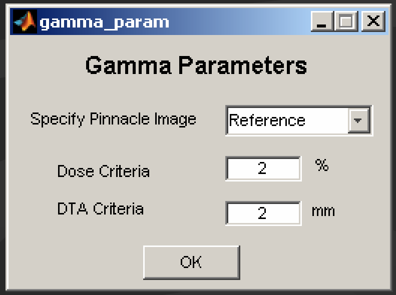


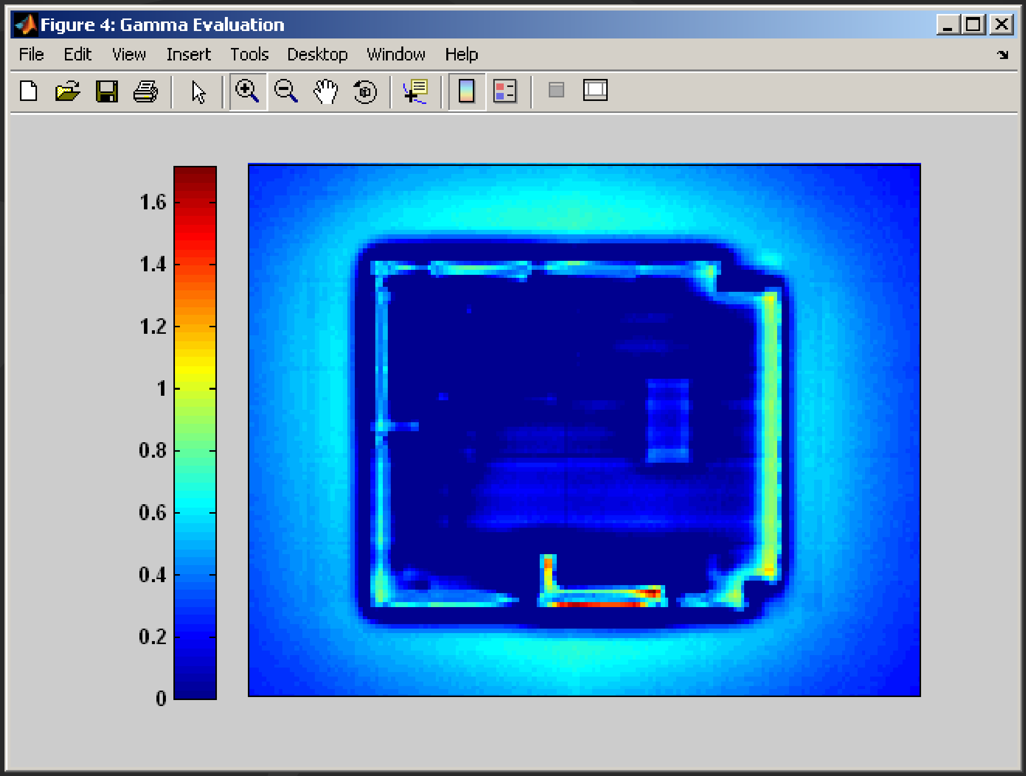
Results - Pinnacle Planar Dose vs EPID measurement



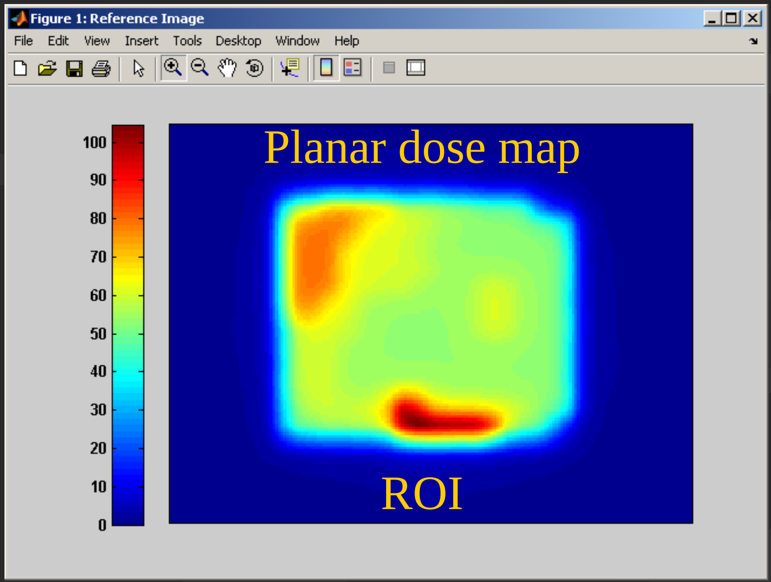


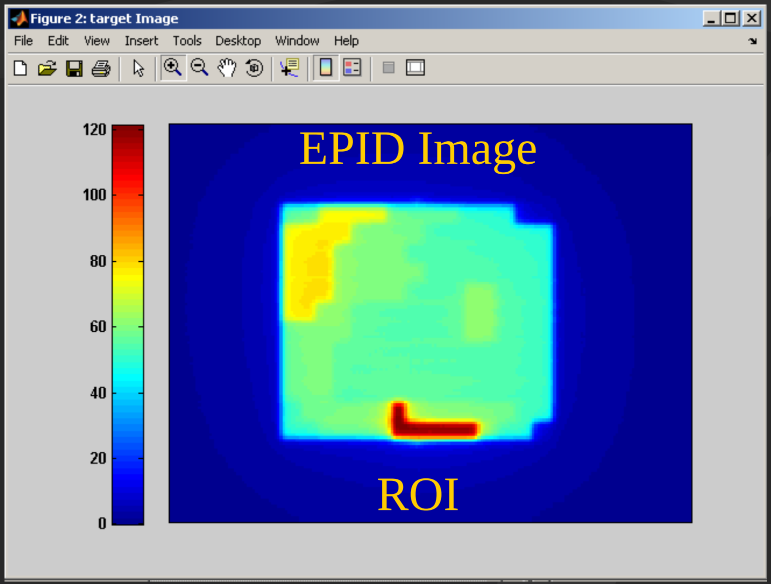


$$\gamma = \min\left\langle \sqrt{\left(\frac{\Delta D}{\Delta D_{max}}\right)^2 + \left(\frac{\Delta r}{DTA}\right)^2} \right\rangle$$

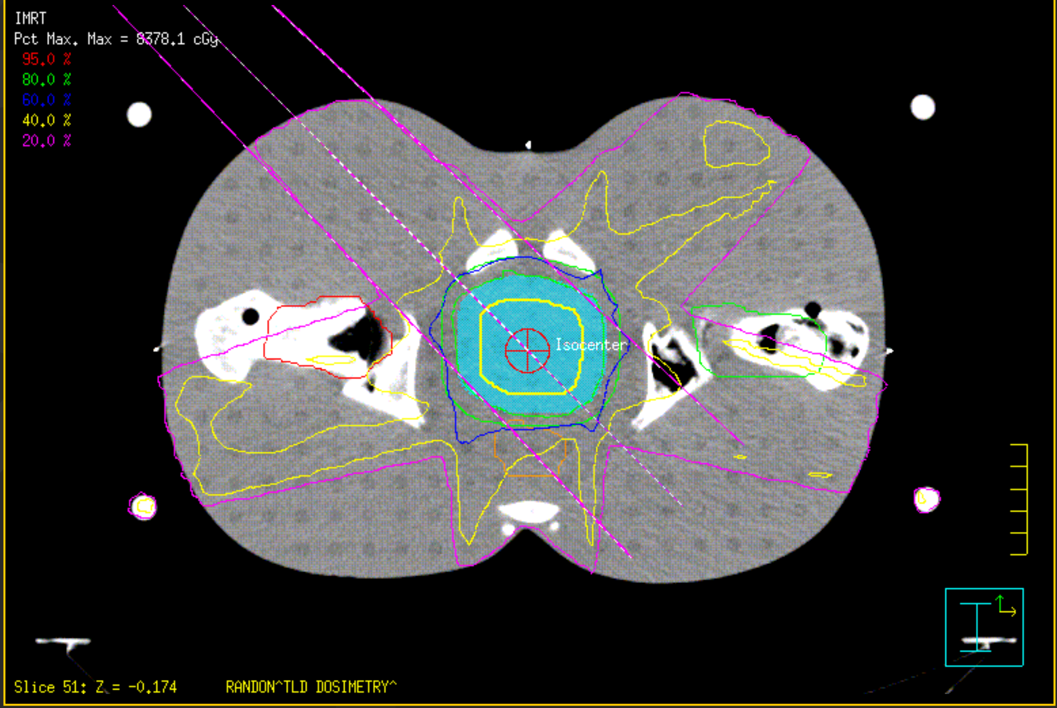


Results - Pinnacle Planar Dose vs EPID measurement

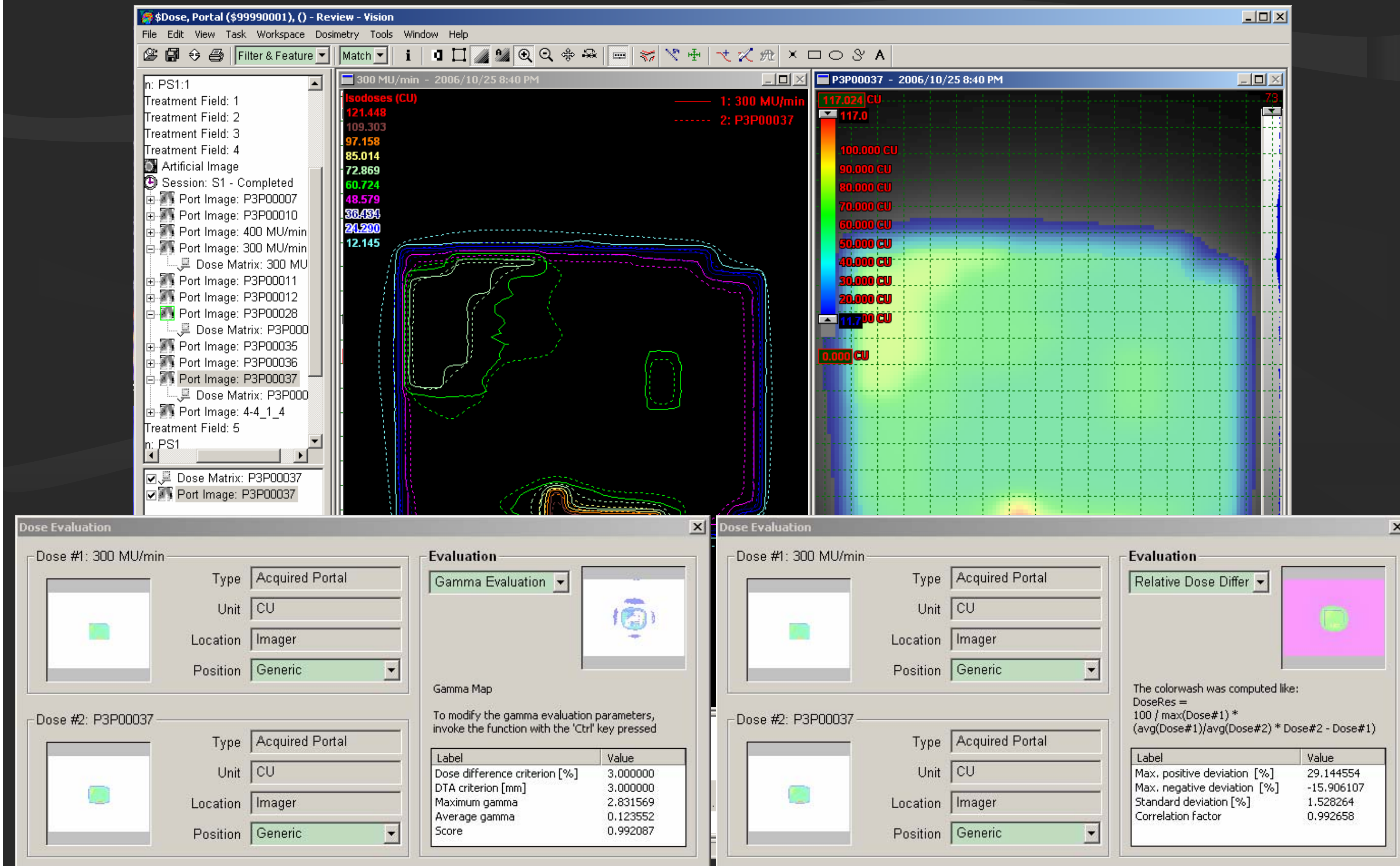


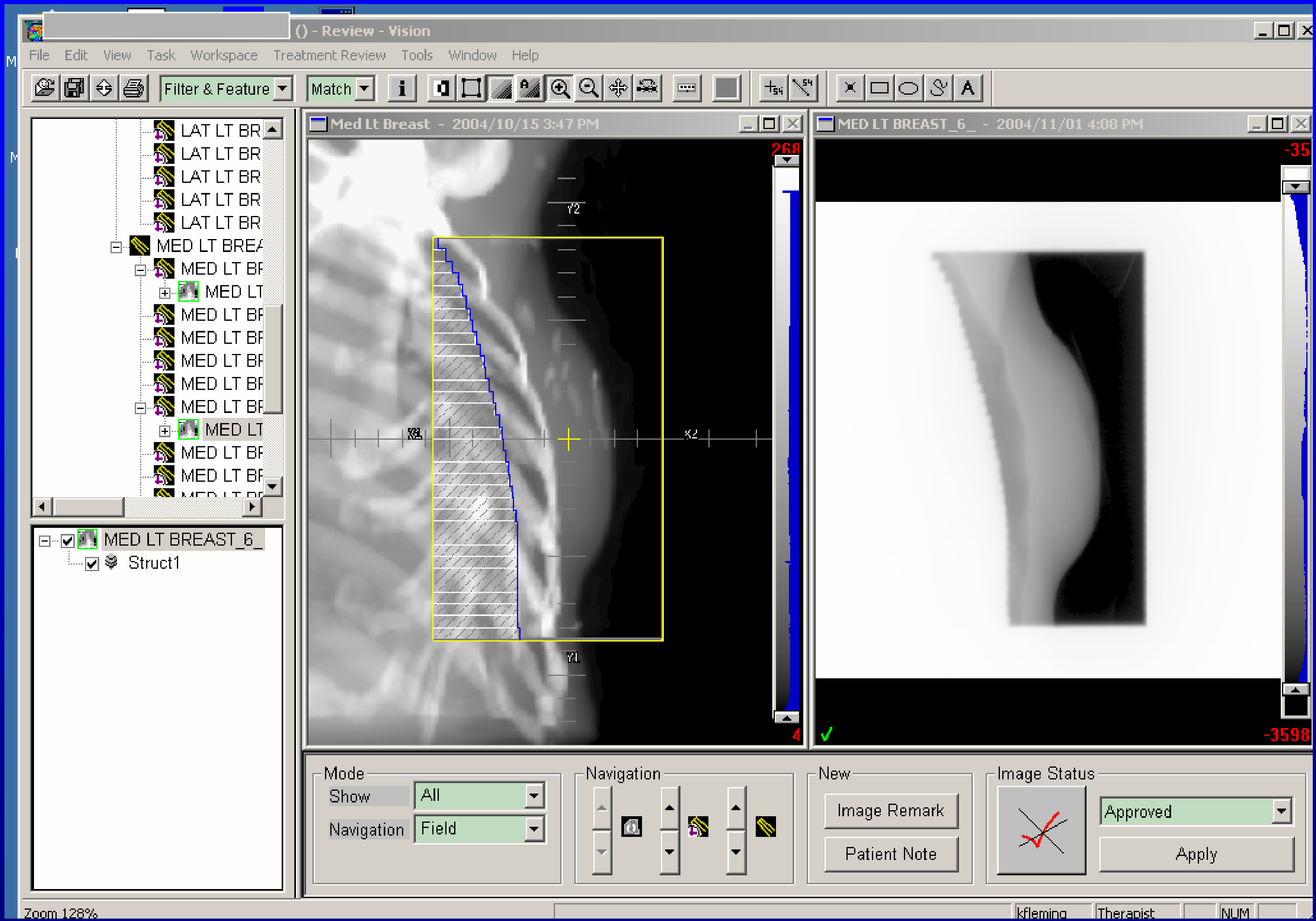


- Beam 4 of an IMRT prostate plan



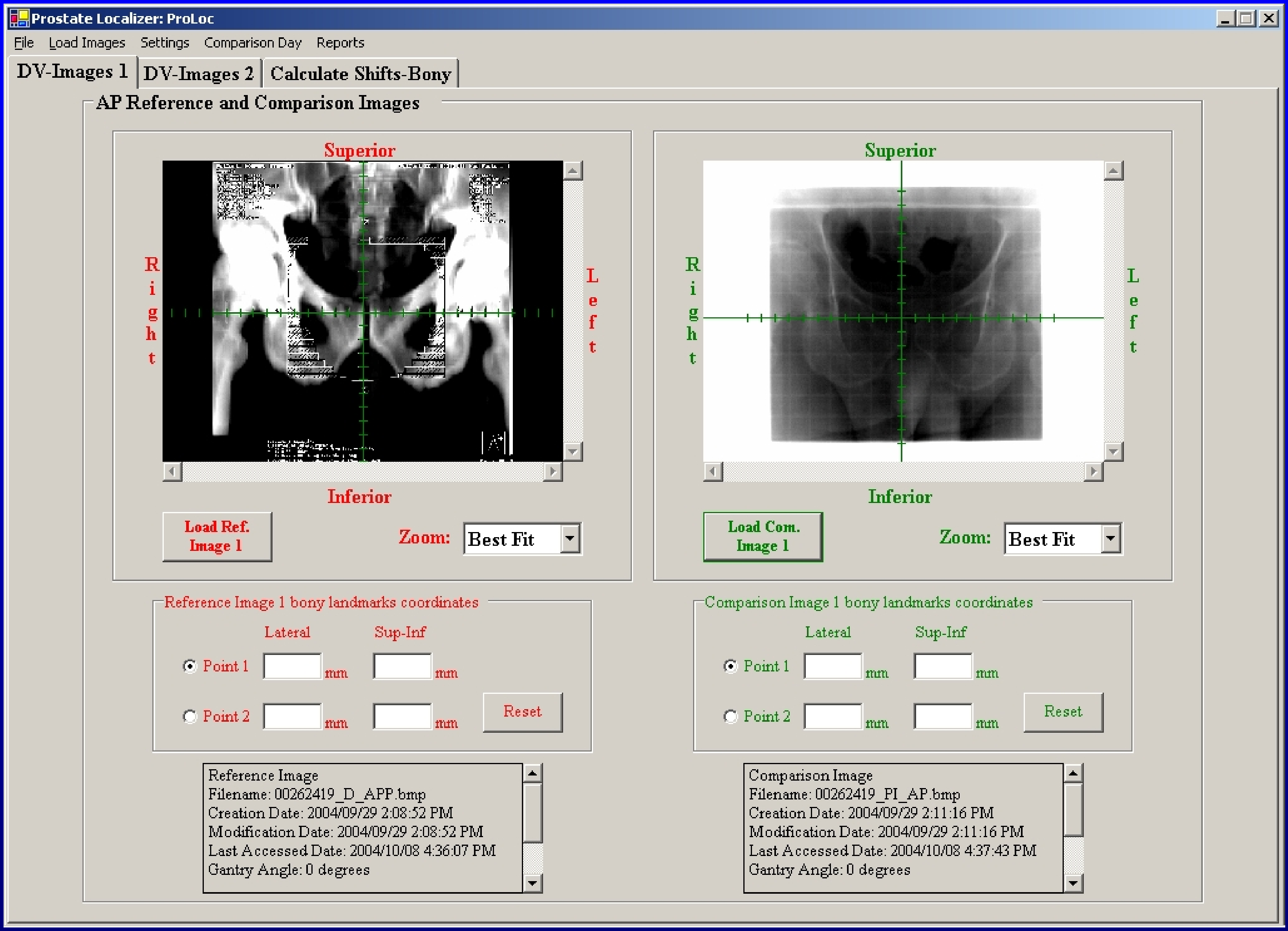
Results - Pinnacle Planar Dose vs EPID measurement





Reference DRR and Portal Image of breast

Image guided localization system at GRRCC developed by E. Osei



Evaluation of internal organ motion for prostate IMRT treatment planning using of dose gradient and probability density function

Runqing Jiang

Supervisors

Dr. Rob Barnett   Prof. Jeff Chen

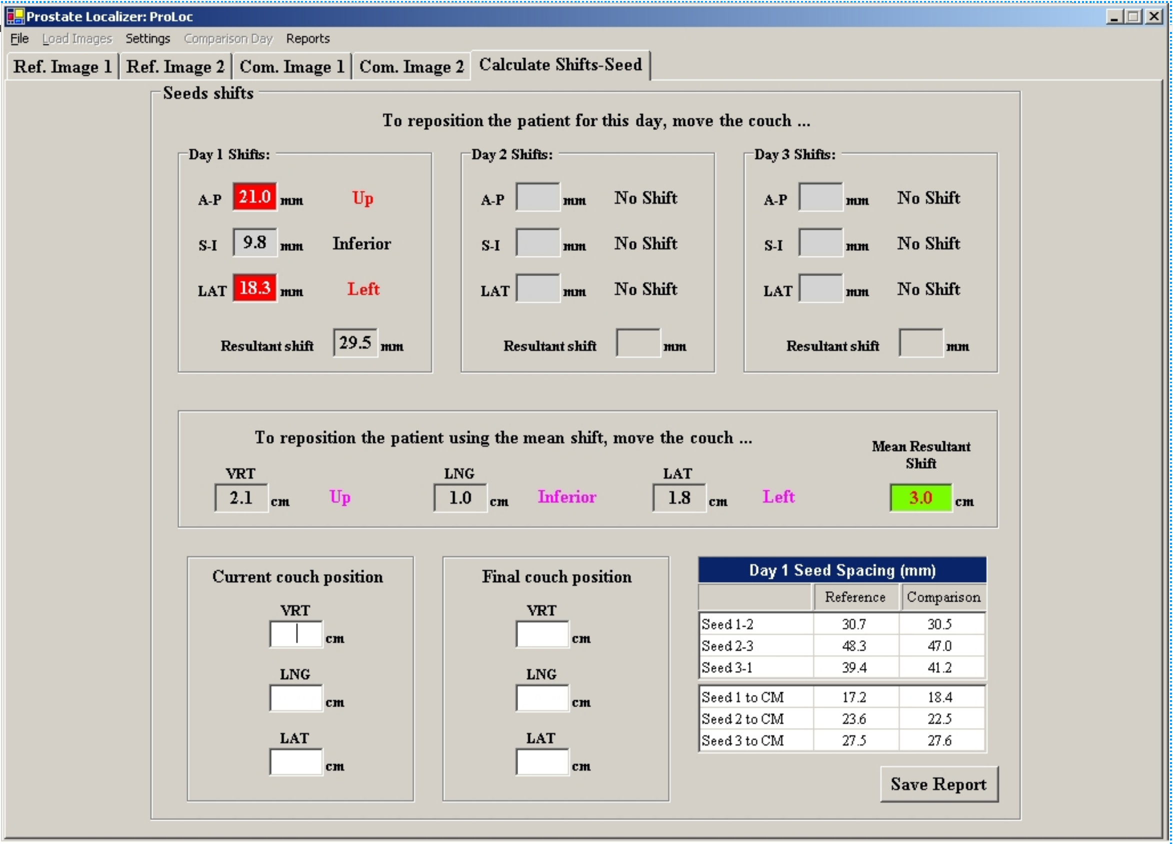
GRAND RIVER Regional Cancer Centre

University of Waterloo

Organ Motion

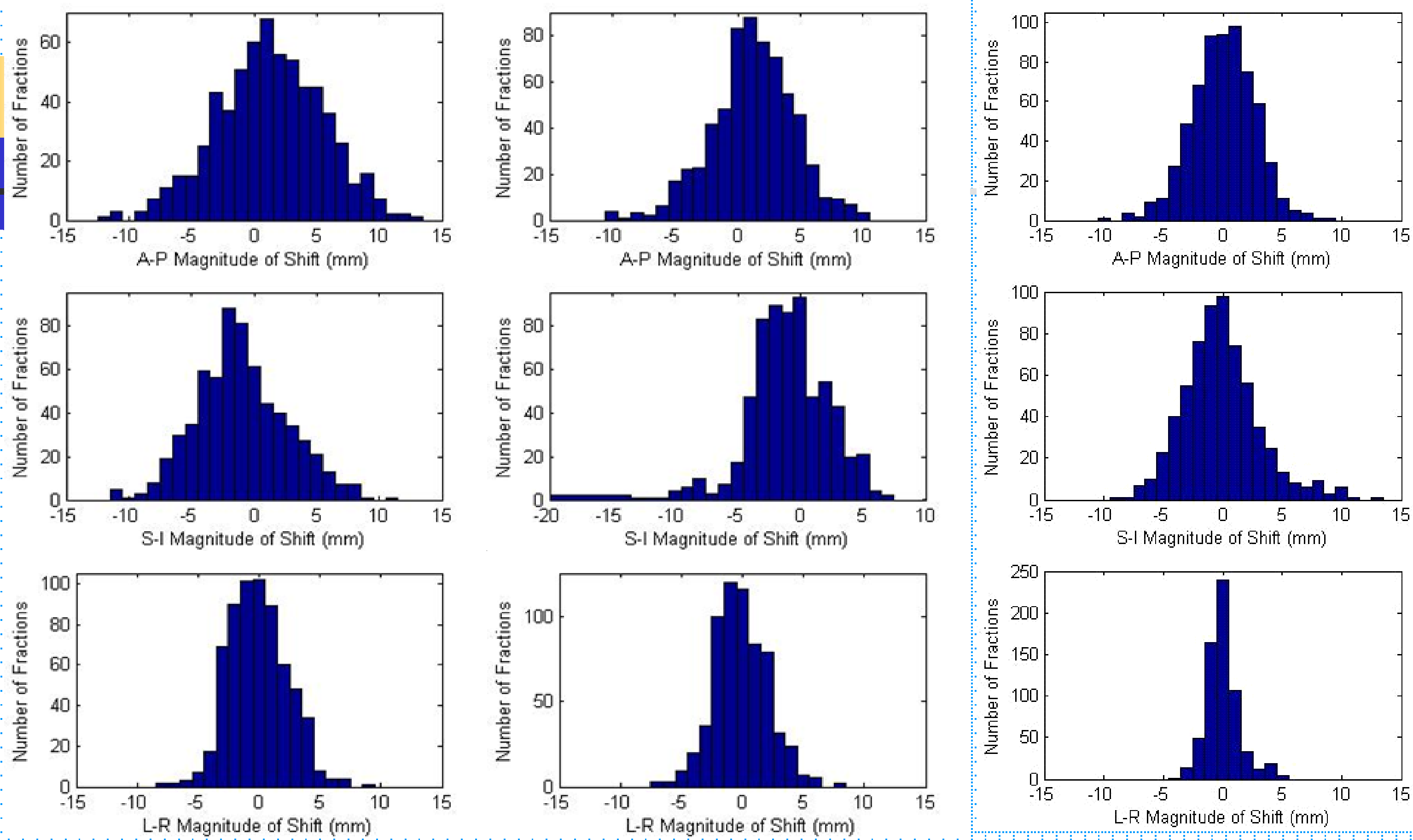
- Organ motion: uncertainty in the position of an organ relative to the bony anatomy
- Motion of internal organs (e.g. prostate, bladder, and rectum) significantly impair the intended precision
- Organ motion $\Rightarrow$ Tumor may move out of the high dose region, normal tissue may move in the high dose region $\Rightarrow$ TCP $\Downarrow$ and NTCP $\Uparrow$

IGRT data from GRRCC



Organ motions and setup errors were calculated by comparing portal images with DRR

Seeds Bone Prostate motion



A: "-"
P: "+"
L: "-"
R: "+"
S: "-"
I: "+"

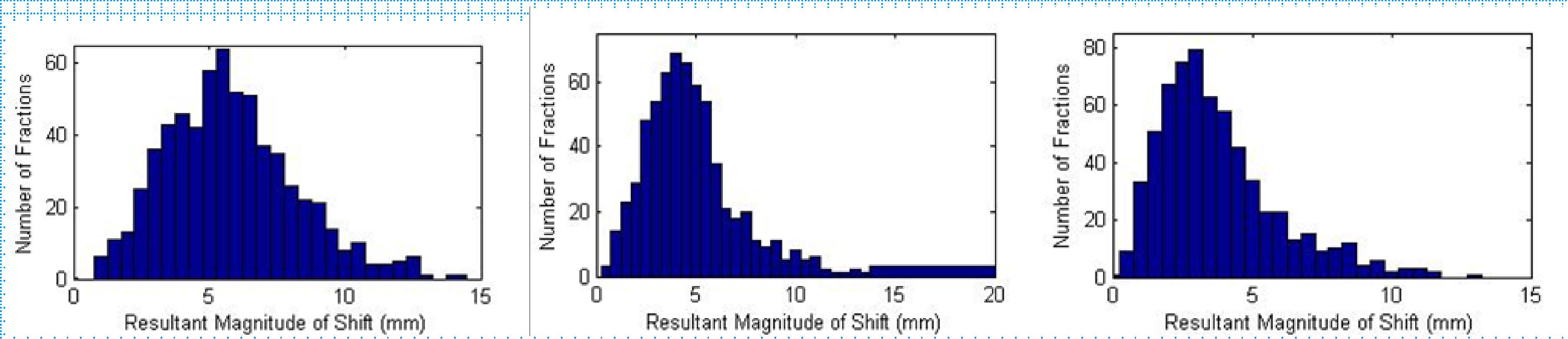
AP: 1.25±4.18mm
LR: -0.10±2.40mm
SI: -1.03±3.64mm

AP: 1.24±3.33mm
LR: -0.09±2.20mm
SI: -0.91±3.22mm

AP: 0.01±2.64mm
LR: -0.01±1.37mm
SI: -0.12±3.18mm

Resultant result

$$R = \sqrt{AP^2 + LR^2 + SI^2}$$

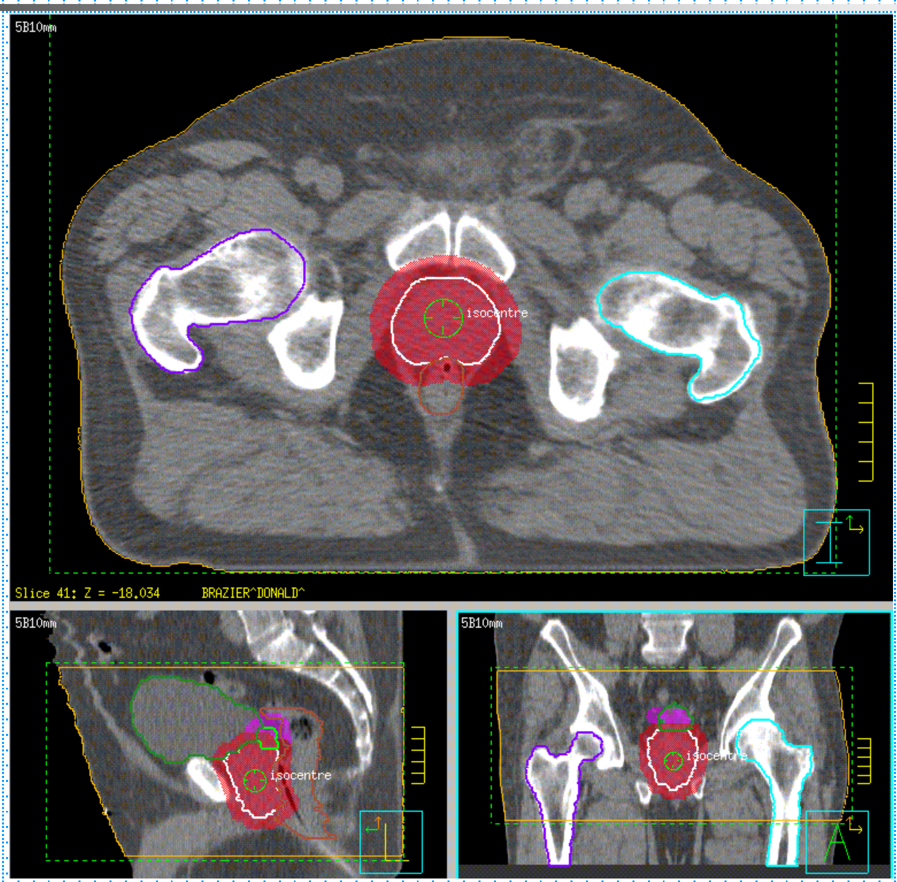


Seeds
R>5mm 61%

Bone
R>5mm 37%

Prostate motion
R>5mm 23%

Margin --- Prostate PTV



ICRU-62 report: an overall standard deviation was determine by adding SD of systematic errors and SD of organ motion in quadrature

Dose Gradient and Convolution with PDF

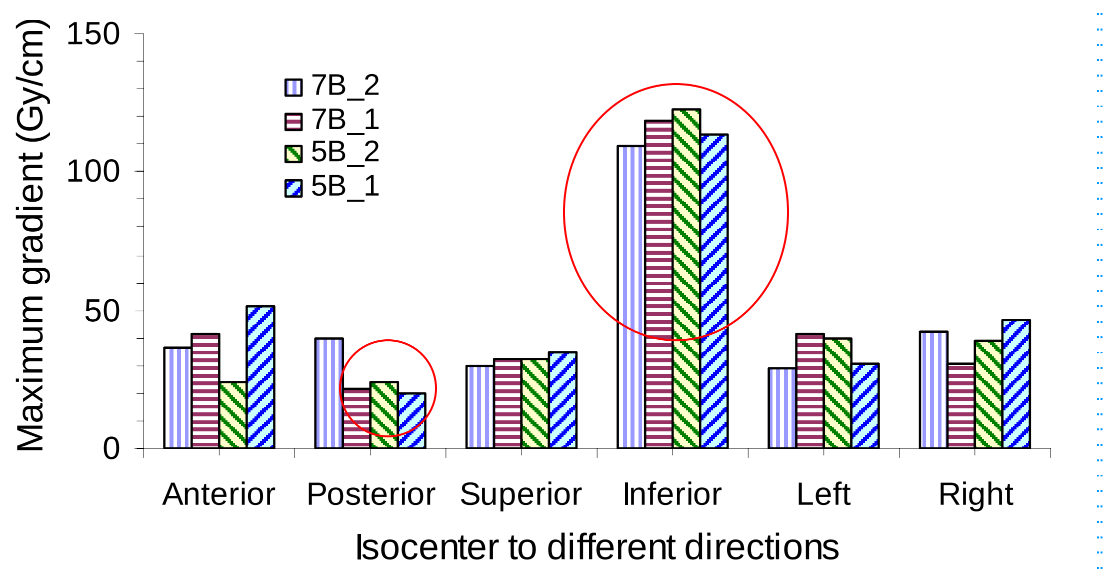
$$\overline{D}(x,y,z)=\iiint D_0(x',y',z')P(x-x',y-y',z-z')dx'dy'dz'$$

$$\overline{D}=D_0\otimes P$$

$$\frac{\partial \overline{D}}{\partial \vec{r}}=\frac{\partial D_0}{\partial \vec{r}}\otimes P=D_0\otimes\frac{\partial P}{\partial \vec{r}}$$

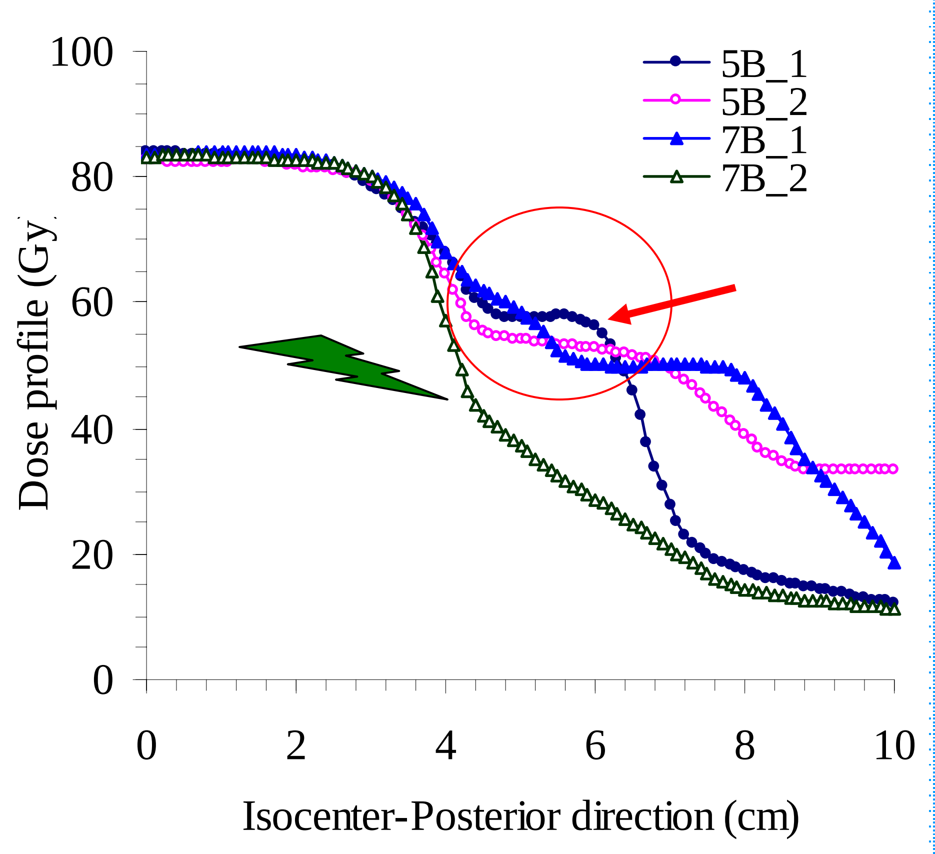
$$\overline{D}=\int[\frac{\partial D_0}{\partial \vec{r}}\otimes P]d\vec{r}=\int[D_0\otimes\frac{\partial P}{\partial \vec{r}}]d\vec{r}$$

Maximum dose gradient

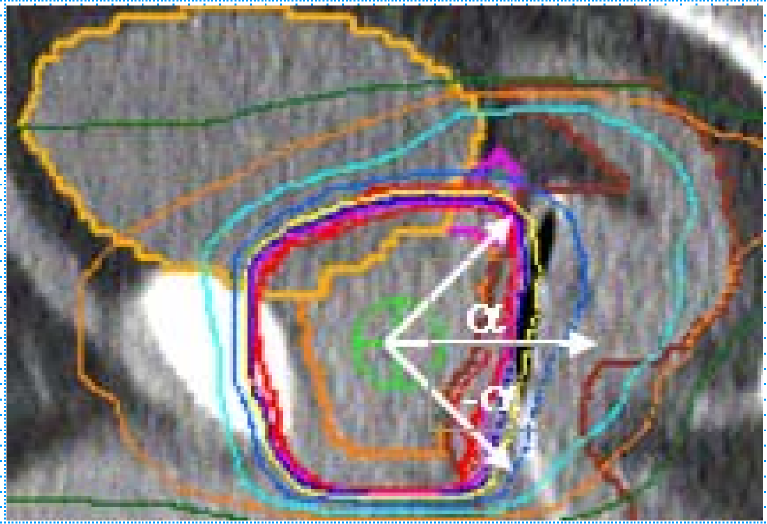


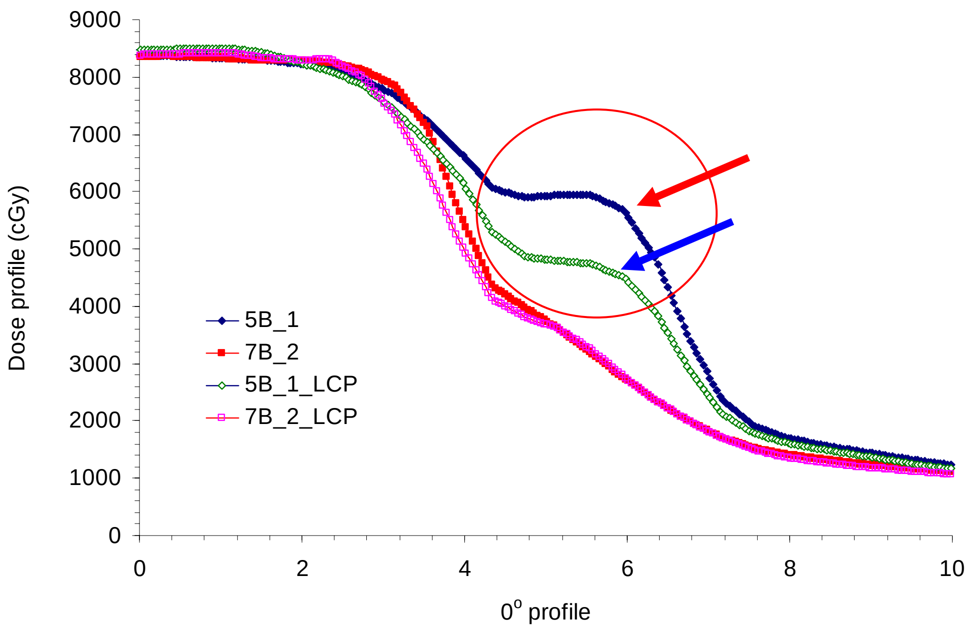
Maximum Dose gradient for different IMRT techniques

Effects of dose profile on rectum



Dose Profile in sagittal plane





Consideration of Directional Dose Gradient and Contour Probability Density Function

- *Strong framework for assessing impact of internal organ motion on dose distribution*
- *Provides a focus on dose gradient as a metric for IMRT quality*

Fractionation
LQ Model

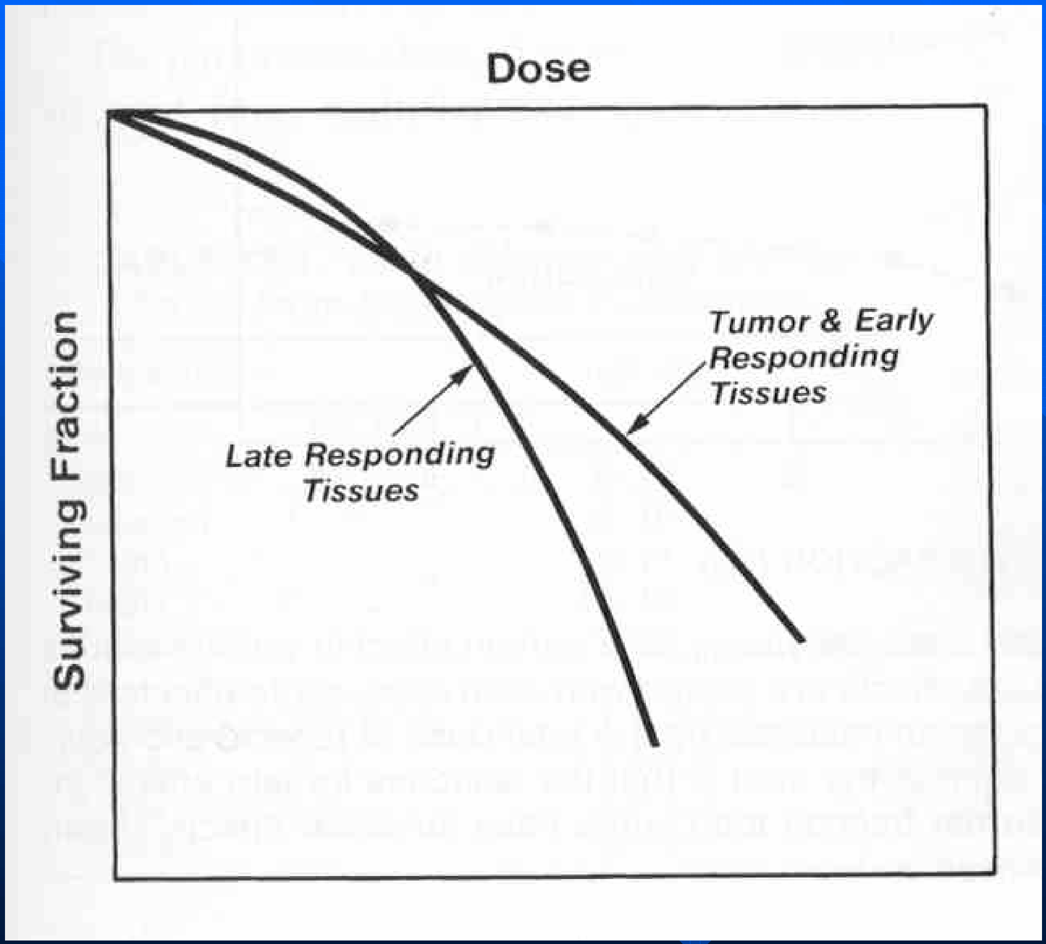
- Fractionated survival

$$S = [e^{-(\alpha d + \beta d^2)}]^n$$

$$S = e^{-nd(\alpha + \beta d)}$$

- Where d = dose/fraction; n = number of fractions

Early Reacting and Late Reacting Tissue



Early Reacting and Late Reacting Tissue

TABLE 22.1. *Ratio of Linear to Quadratic Terms From Multifraction Experiments*

Reactions	α/β, Gy
Early	
Skin	9–12
Jejunum	6–10
Colon	10–11
Testis	12–13
Callus	9–10
Late	
Spinal cord	1.7–4.9
Kidney	1.0–2.4
Lung	2.0–6.3
Bladder	3.1–7

Fractionation
LQ Model

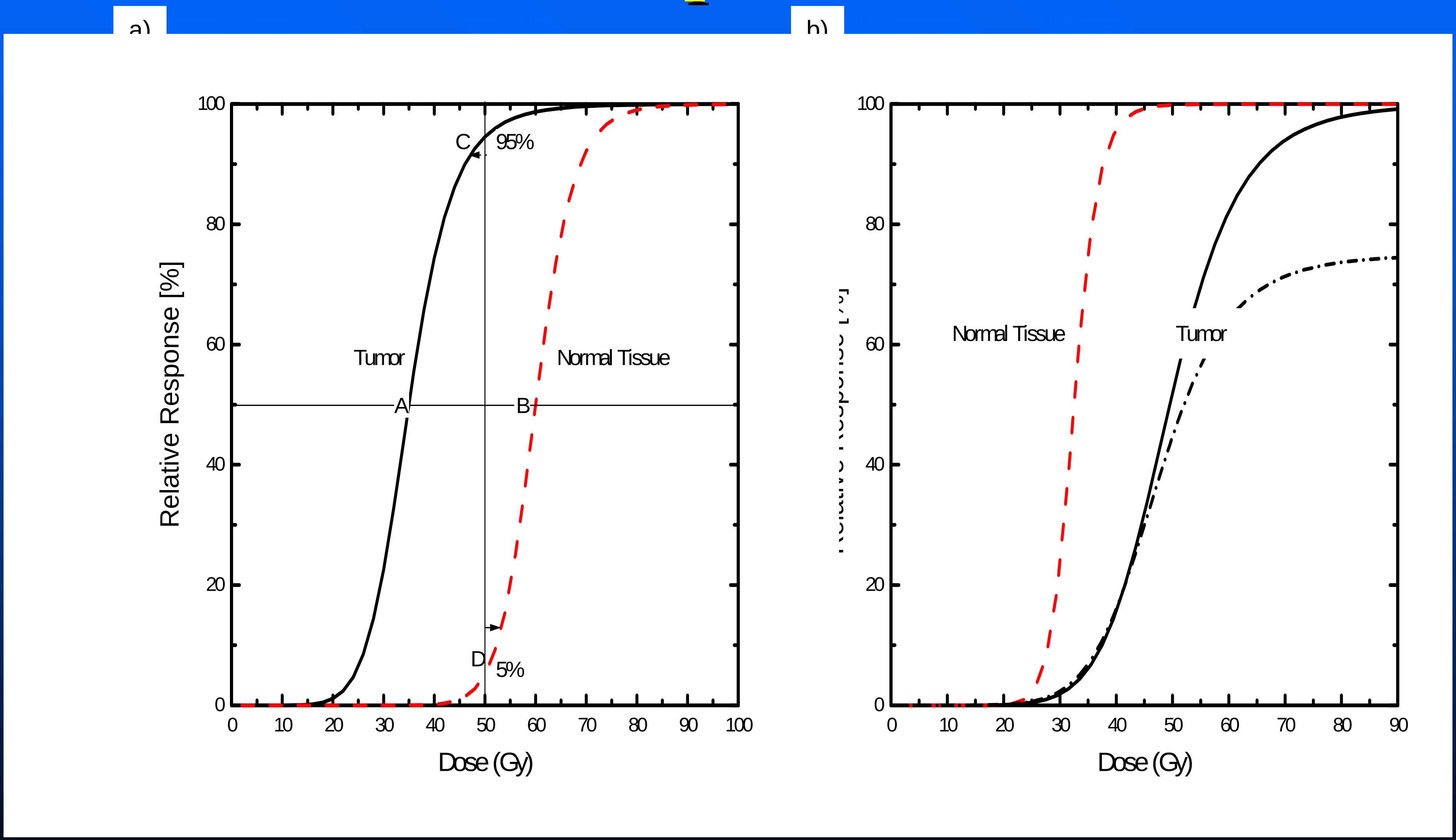
- Effect (response level) is given by:

$$E = -\ln S = n\,d\,(\alpha + \beta\,d)$$

Early Reacting and Late Reacting Tissue Summary

- Dose-response is more curvy for late effects than early effects.
- Early responding tissues (including tumour) $\alpha/\beta \sim 10$ Gy.
- Late responding tissues $\alpha/\beta \sim 2\text{-}3$ Gy.
- Late responding tissues more sensitive to change in fractionation.
- Fraction size is dominant factor determining late effects.

Normal and Tumour Cell Response

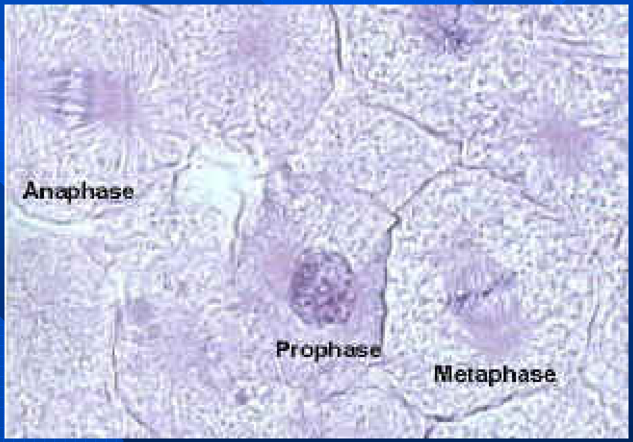


Normal and Tumour Cell Response

- Therapeutic ratio = D_B / D_A.
- We want to max the ratio, ie ↑ D_B and ↓ D_A.
- In reality, it is very difficult to do.
- Maximize the tumour control, minimize normal tissue complications → new radiotherapy techniques.

Four R's Radiobiology

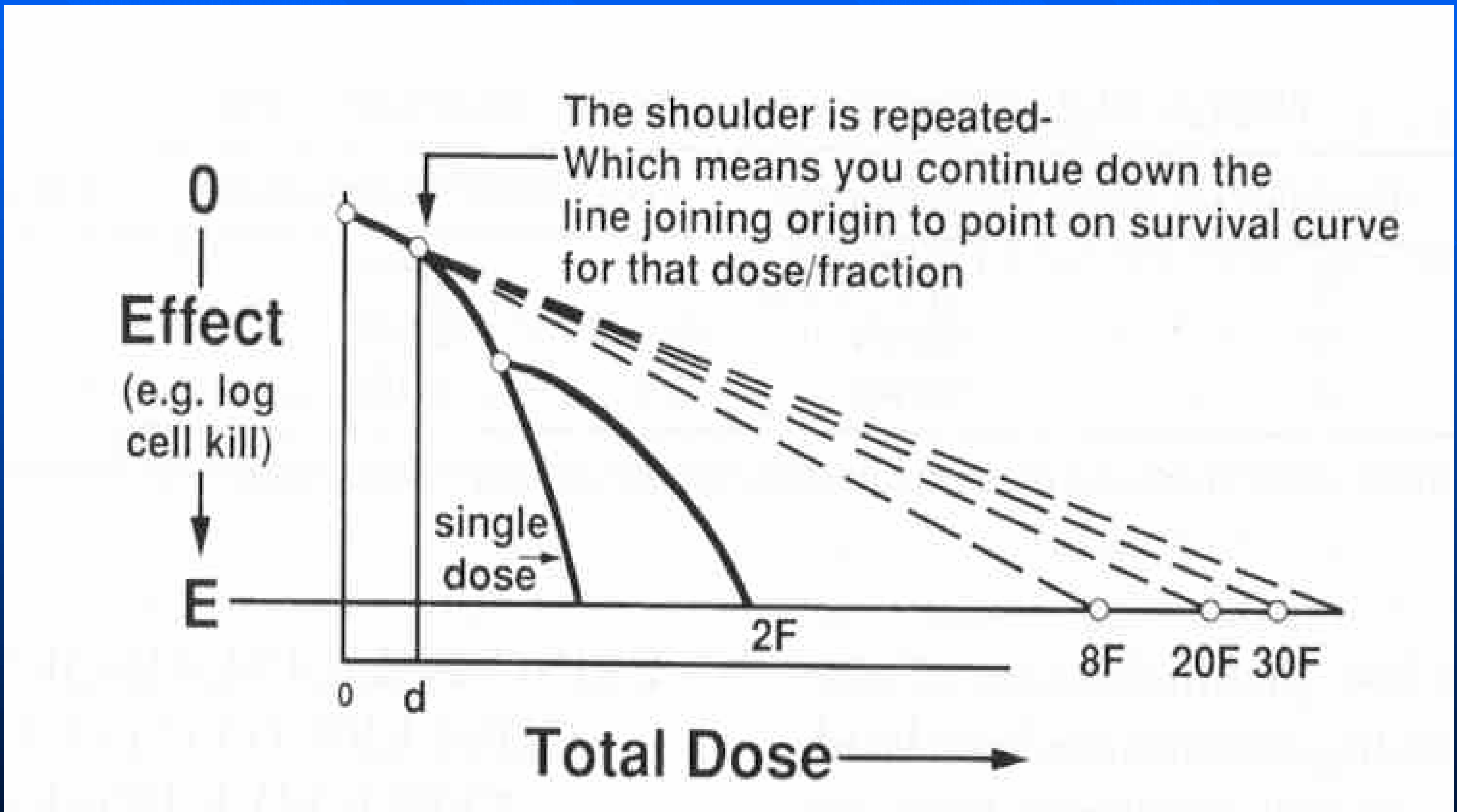
- Repair
  - DSB is repaired by enzymes ~ hours
- Redistribution (Reassortment)
  - Cell cycle effect ~ day
- Repopulation
  - Cell "growth" ~ week
- Reoxygenation
  - Oxygen effect ~ 0.25 – 1 day



Fractionation

- Dividing dose in number of fractions spares normal tissues.
  - Repair normal tissue
  - Repopulation of normal tissue
- Dividing dose in number of fractions increases damage to tumour.
  - Reoxygenation
  - Redistribution into radiosensitive phases

Fractionation



Fractionation
LQ Model

- Assuming tissue response related to cell survival.
- Introducing Extrapolated Response Dose (ERD) or Biologically Effective Dose (BED)

$$E = nd\,(\alpha + \beta d)$$

$$ERD\ or\ BED = \frac{E}{\alpha} = nd\,[1 + \frac{d}{(\frac{\alpha}{\beta})}]$$

Fractionation
LQ Model – Time Factor

$$E = nd(\alpha + \beta d) - \lambda(T - T_k)$$

$$\lambda = \frac{\ln 2}{T_d}$$

- T = overall treatment time.
- T_k = time at which rapid proliferation sets in.
- T_d = tumour doubling time.

Radiobiology of IMRT/IGRT

- *Conformal delivery to PTV and conformal avoidance of OARs are redefining conventional radiobiology*
- *Escalated dose and hypofractionation where advantageous*

CyberKnife® Robotic Radiosurgery

ACCURAY

The Evolution of Radiosurgery

Radiosurgery: Introduced Promising Hope

- Radiosurgery introduced in 1960’s
- Initial success (intracranial)
- Single fraction
- Less invasive than surgery
- Proven clinical benefits (intracranial)
- Historically limited:
  - Limited accuracy (manually adjusted)
  - No correction for patient/tumor movement
  - Frame based

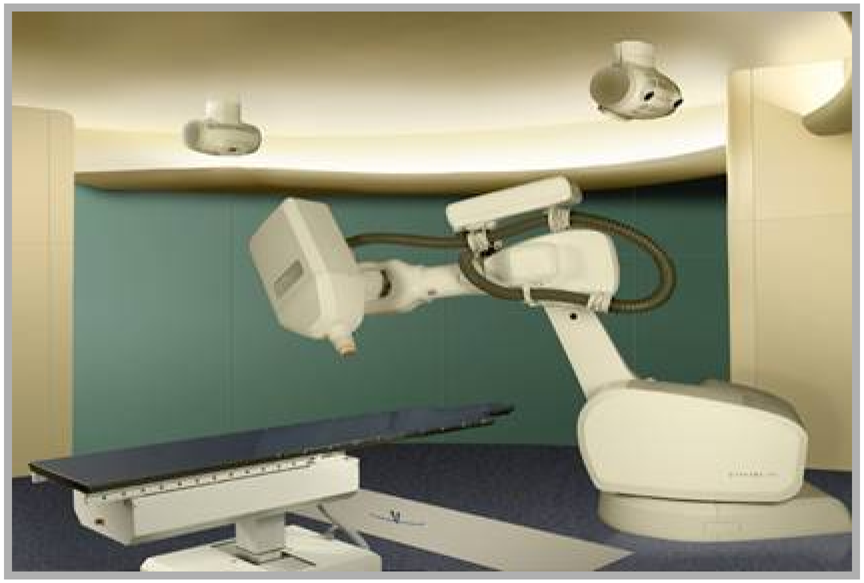
Advancing the Power of Radiosurgery: CyberKnife® Robotic Radiosurgery

- Intelligent robotic technology
  - Enables radiosurgery anywhere in the body
  - Extreme accuracy (sub-millimeter)
  - Repeatable precision (automated)
- Advanced image guidance
  - Track patient/tumor, detect movement & changes, and automatically make corrections throughout the entire treatment
  - Provides increased patient comfort (no need for head or body frame)

CyberKnife® Treatment

CyberKnife® Robotic Radiosurgery System

- Broad clinical application
  - Intracranial radiosurgery
  - Extracranial radiosurgery
    - Spine
    - Lung
    - Prostate
    - Liver
    - Pancreas
    - Other

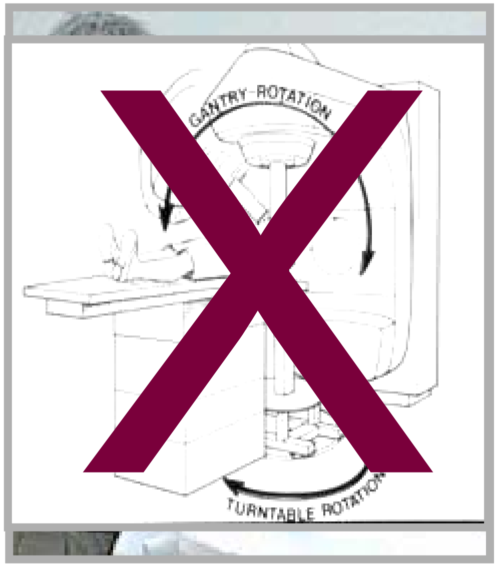


- Proven clinical experience
  - Over 20,000 patients treated worldwide
  - Over 160 clinical and technical papers
  - Over 160 medical centers worldwide have chosen the CyberKnife system

CyberKnife® Robotic Radiosurgery System:

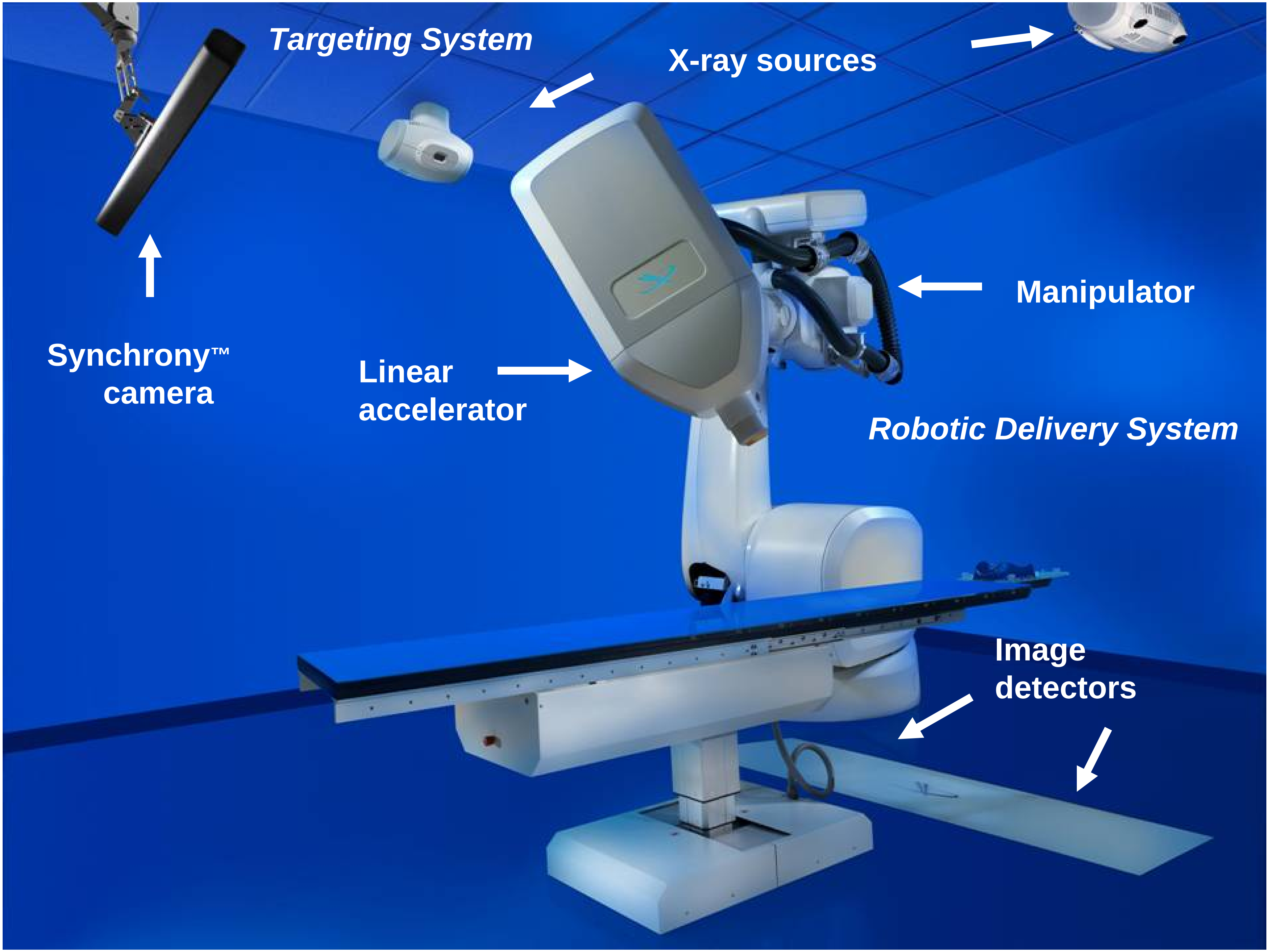
CyberKnife® Radiosurgery is Different from Traditional Radiosurgery

- Patient Setup
  - ***No head or body frames*** required
- Treatment Delivery
  - ***Non-isocentric*** delivery using intelligent robotic guidance and tracking technology delivers sub-millimeter accuracy



CyberKnife® System Overview

CyberKnife® System
The Next Generation in Robotic Radiosurgery


Targeting System
X-ray sources
Manipulator
Synchrony™
camera
Linear
accelerator
Robotic Delivery System
Image
detectors

CyberKnife® Robotic Radiosurgery System

- Intelligent Robotic Technology
  - Continuous feedback
  - Automated system
  - Tracks and detects any movement in tumor or patient location
  - Corrects to ensure sub-millimeter accuracy

World's Most Accurate Radiosurgery System

CyberKnife® G4: Image Guidance System

CyberKnife® G4: Image Guidance System

- Flush-mounted, In-floor X-ray Image Detectors
  - Significant increase in treatment workspace volume
  - Increased Field of View (FOV) of patient
  - Increased image resolution
  - Expands potential for extracranial applications

Linac

CyberKnife® G4: Linear Accelerator

CyberKnife® G4: Linear Accelerator

- Powerful 600 MU/min X-band Linear Accelerator
  - Delivers a 50% higher dose rate*
  - Significantly reducing treatment times

	CYBERKNIFE 4th GENERATION CAPABILITIES
LINAC DOSE RATE	600 MU/min.
AVERAGE TREATMENT TIME (CRANIAL)	20-30* min.
AVERAGE TREATMENT TIME (EXTRACRANIAL)	30-55* min

*based on simulations

** Higher dose rate compared to previous generations of CyberKnife*

CyberKnife® G4: Contact Detection

- Contact Detection Sensor
  - CyberKnife system stops if end of Linac contacts an obstacle
  - Backup safety system

Patient / Tumor Motion Tracking

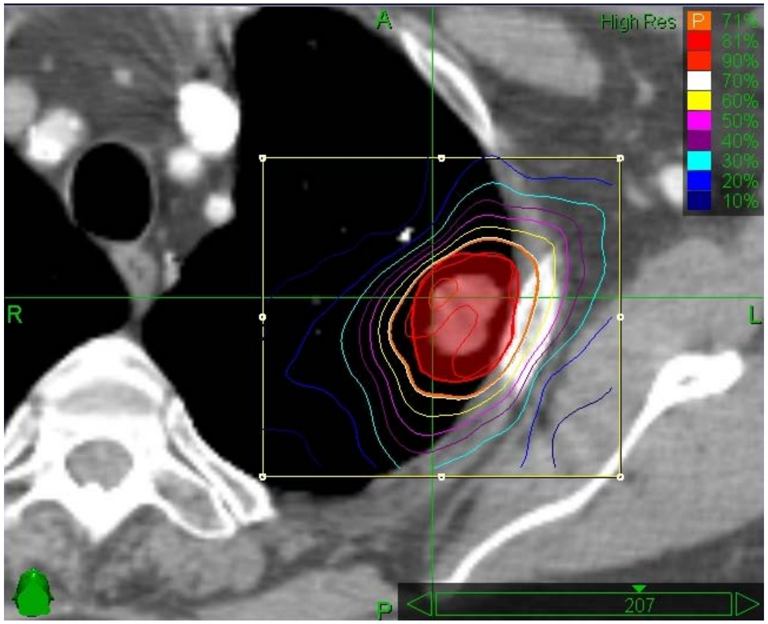
Synchrony™ Respiratory Tracking System

- Synchrony camera
- Synchrony tracking markers
- Fiber optic sensing technology
- Tracks patient's respiratory motion

CyberKnife® Treatment with Synchrony™

CyberKnife® Treatment with Synchrony™

- Synchrony's Benefits:
  - – Patient breathes normally (no breath holding or gating techniques required)
  - – Designed to track, detect, and correct for tumor and patient movement throughout the treatment
  - – Sub-millimeter tracking accuracy*
  - – Minimal damage to healthy tissue



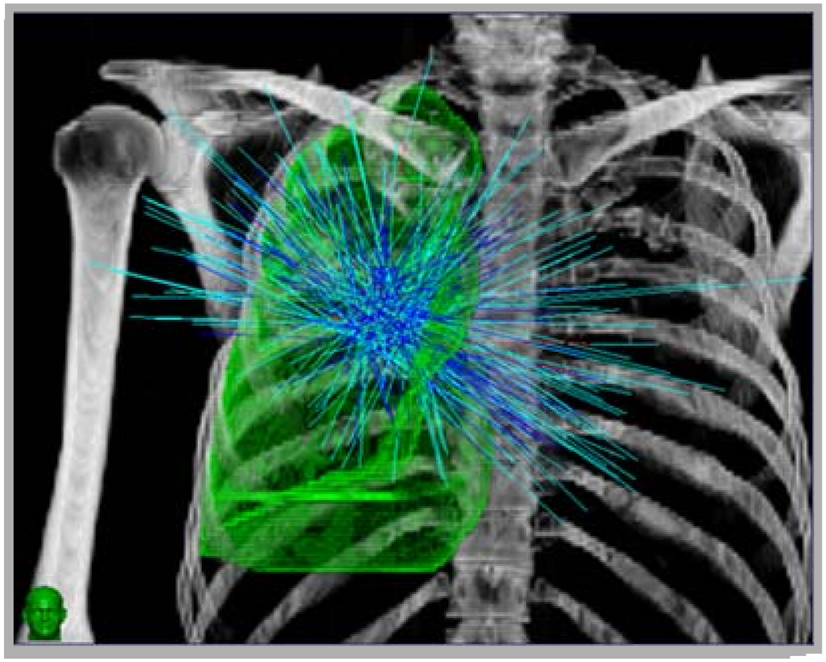
*Reference: Dieterich S, Taylor D, Chuang C, Wong K, Tang J, Kilby W, Main W. The CyberKnife Synchrony Respiratory Tracking System: Evaluation of Systematic Targeting Uncertainty

Advantages of Synchrony™

- Unprecedented accuracy
  - Mean systematic error of 0.70 ± 0.33mm
  - Accuracy specification of 1.5 mm for moving targets
- Intelligent respiratory compensation
  - Automatically adapts to changes in breathing patterns
- Fast treatment times
  - No need to gate beam
  - No need for breath holding
- Radiosurgery precision for small or large targets
  - Completes treatment in 1-5 fractions

Synchrony™ Experience

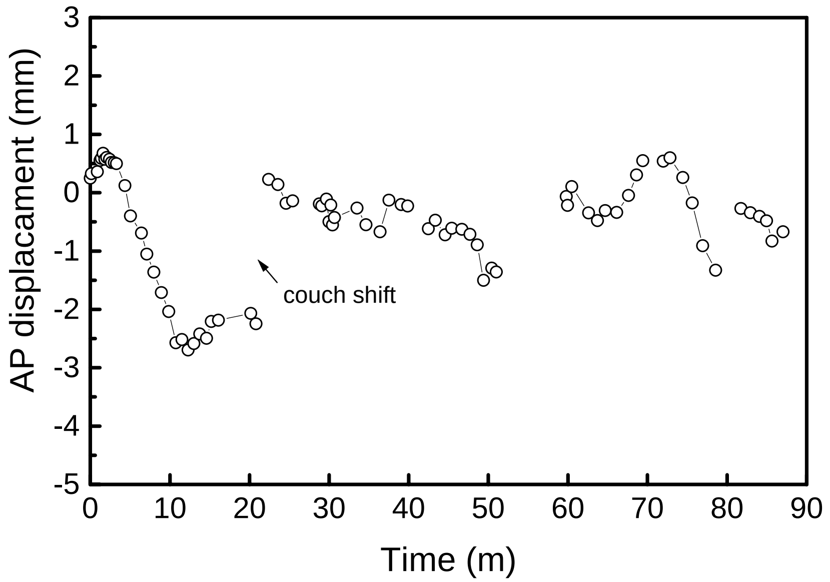
- Over 1200 patients treated
- Over 30 sites actively treating with most sites installed
- Lung, fastest growing CyberKnife treatment with over 85% reported local control
- 5 peer reviewed journal papers in the last 8 months



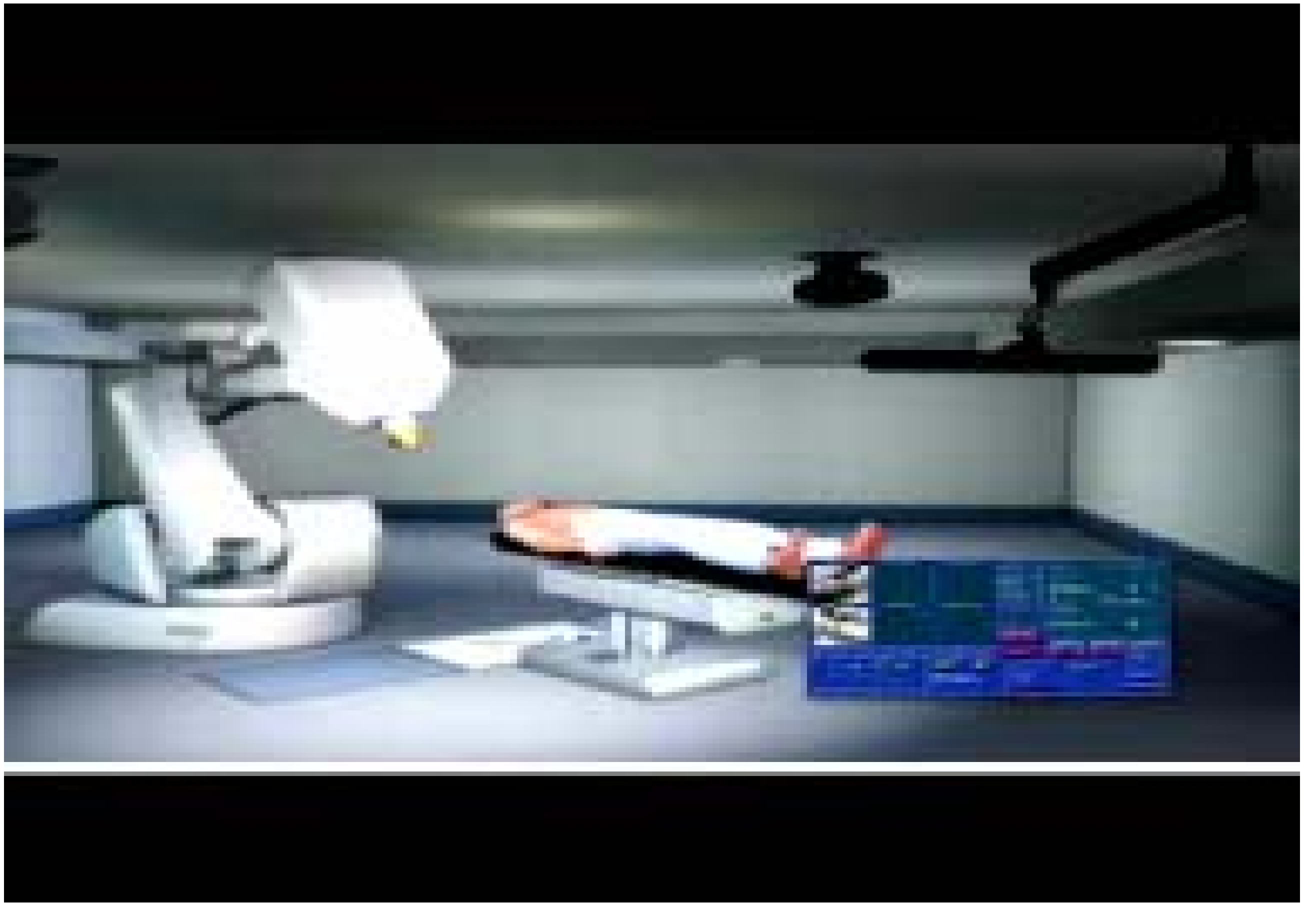
Spine Tracking

Image guided set-up is not enough…

Spines move during treatment



Xsight™ Spine Tracking System

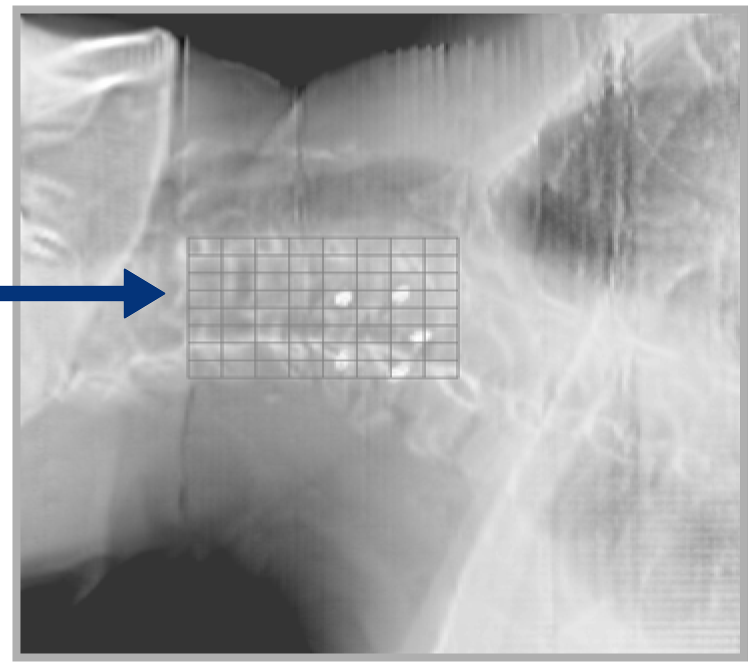


Xsight™ Key Features

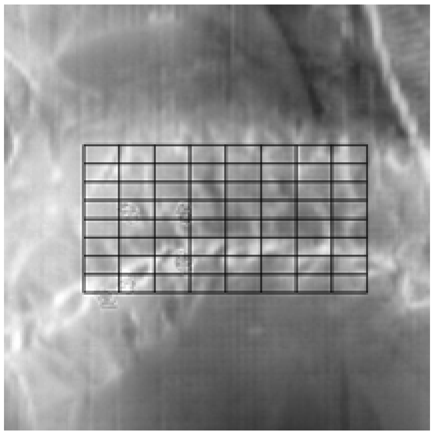
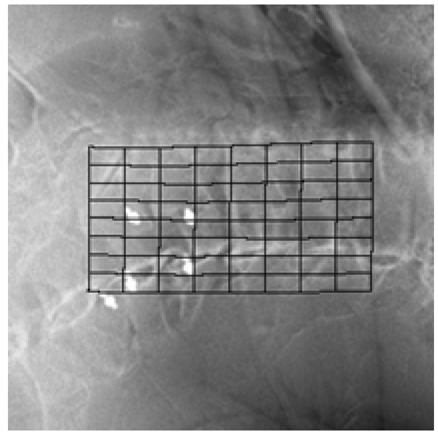
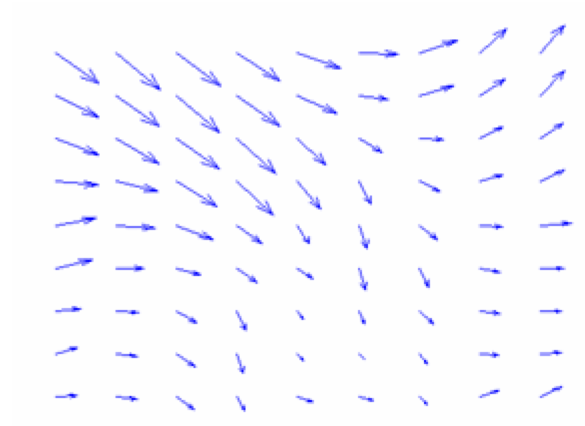
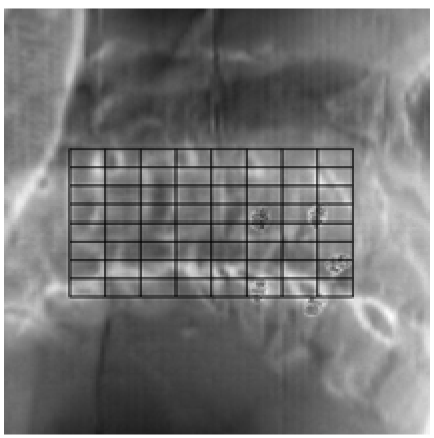
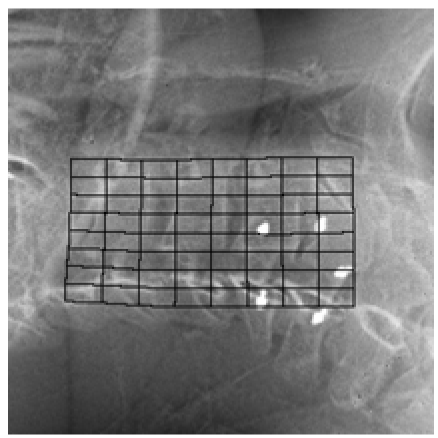
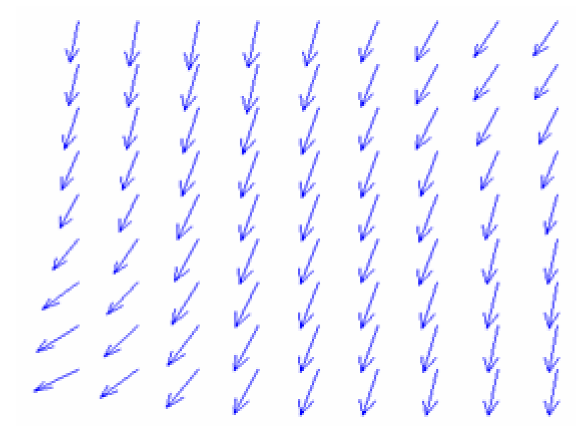
- Automatically locates and tracks tumors along the spine
- Eliminates the need for surgical implantation of radiographic markers
- Facilitates faster, less complex treatments

Hierarchical Mesh Tracking
- – Enables registration of non-rigid skeletal anatomy
- – Estimates local displacements in bony features
- – Important aspect because vertebrae move relative to each other (spine is not a rigid structure)

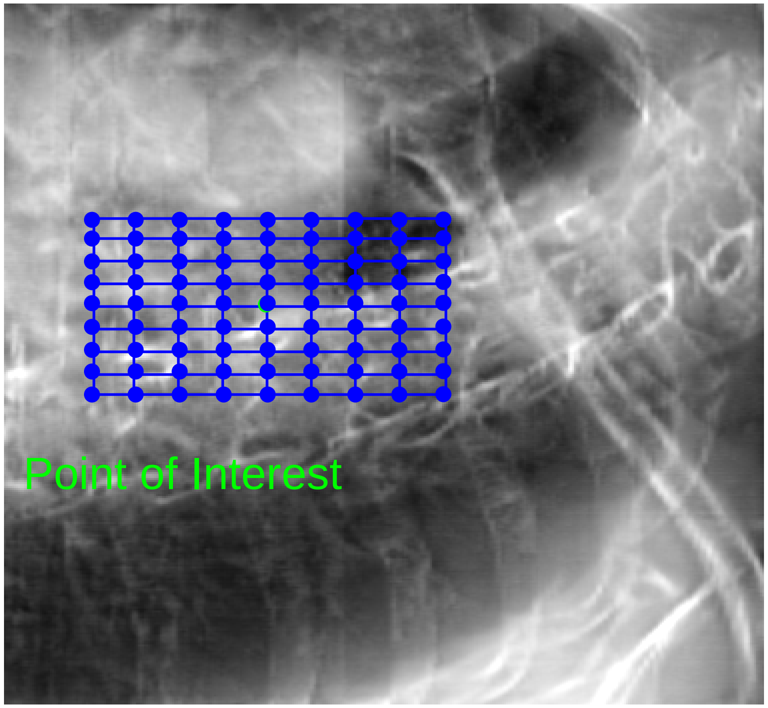
Step 1



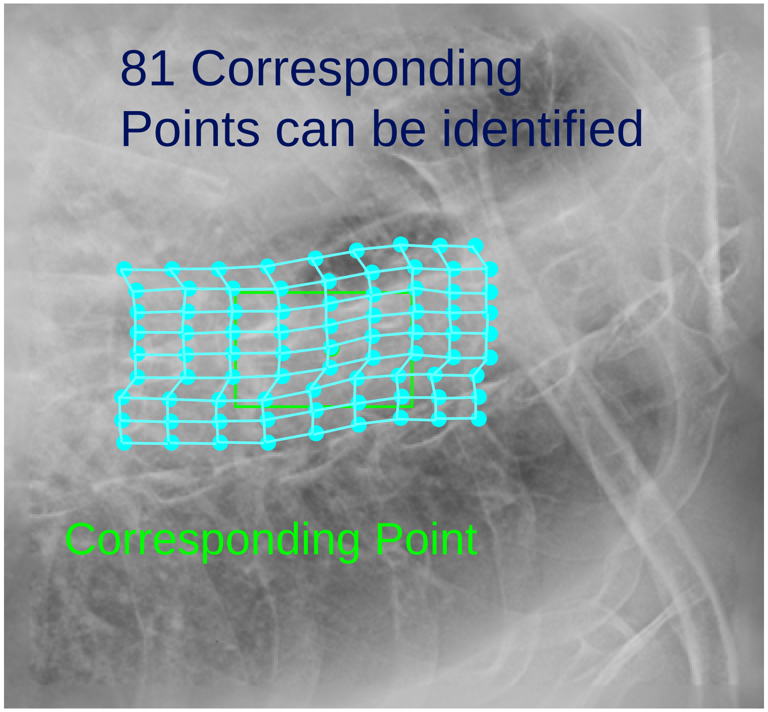
How it Works…

	DRR (from CT)	Live kV image	Displacement Field
Image A			
Image B			

Skeletal Structure Tracking



DRR Image



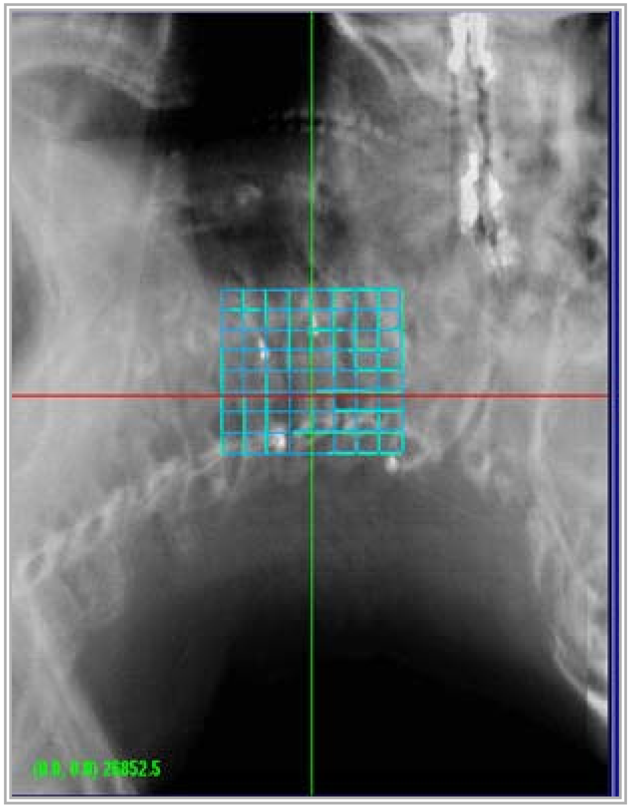
Live Image

Advantages of Xsight™

- Sub-millimeter accuracy
  - Accounts for non-rigid spine
- Non-invasive spine tracking
  - No implanted fiducials
- Ultra fast registration
  - 6D registration, around 2 seconds
- Extremely robust (cervical thru sacrum)
  - Nearly 100% of spine cases eligible

Xsight™ Experience

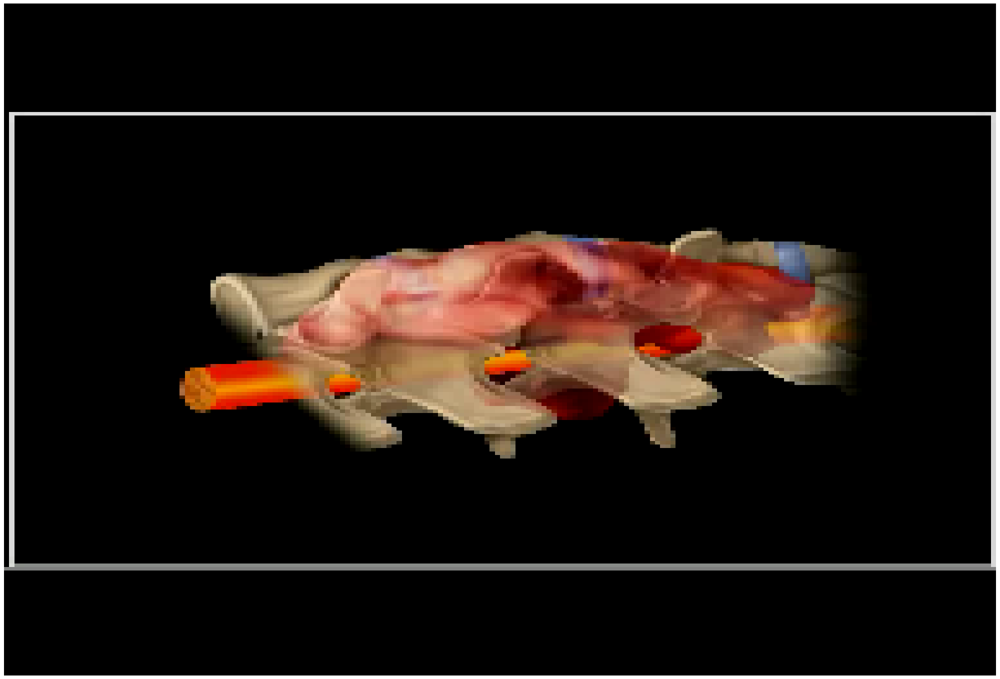
- Over 400 patients treated
- Almost 100% spine cases eligible
- 75% increase in spine treatments since introduction
- 25 sites using Xsight™
- 8 additional sites installed



Treatment Delivery

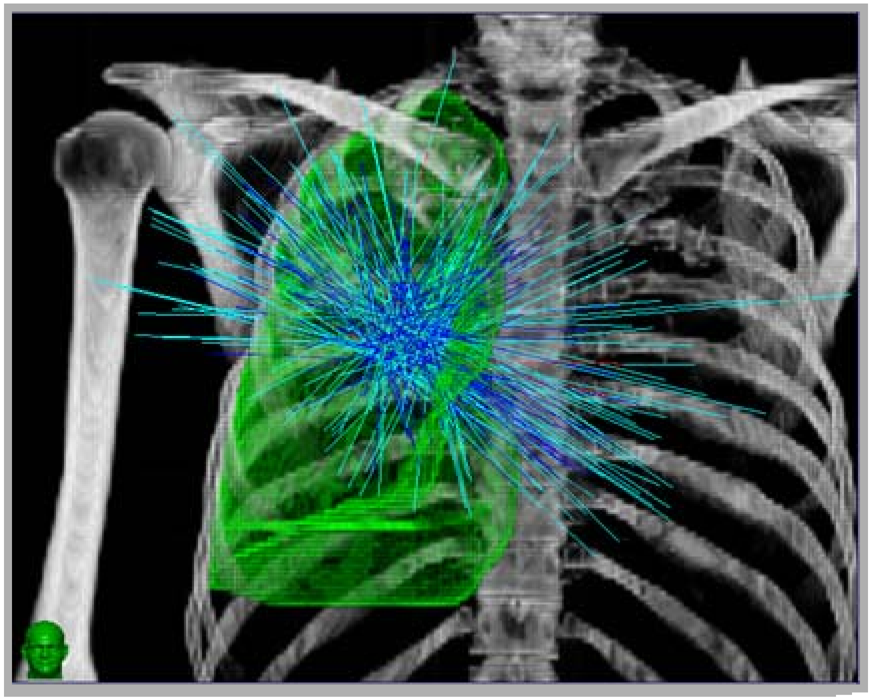
CyberKnife® Conformality

- Non-Isocentric Beam Delivery
  - Highly collimated beams
  - Non-convergent beams
  - Superior conformality while maximizing homogeneity



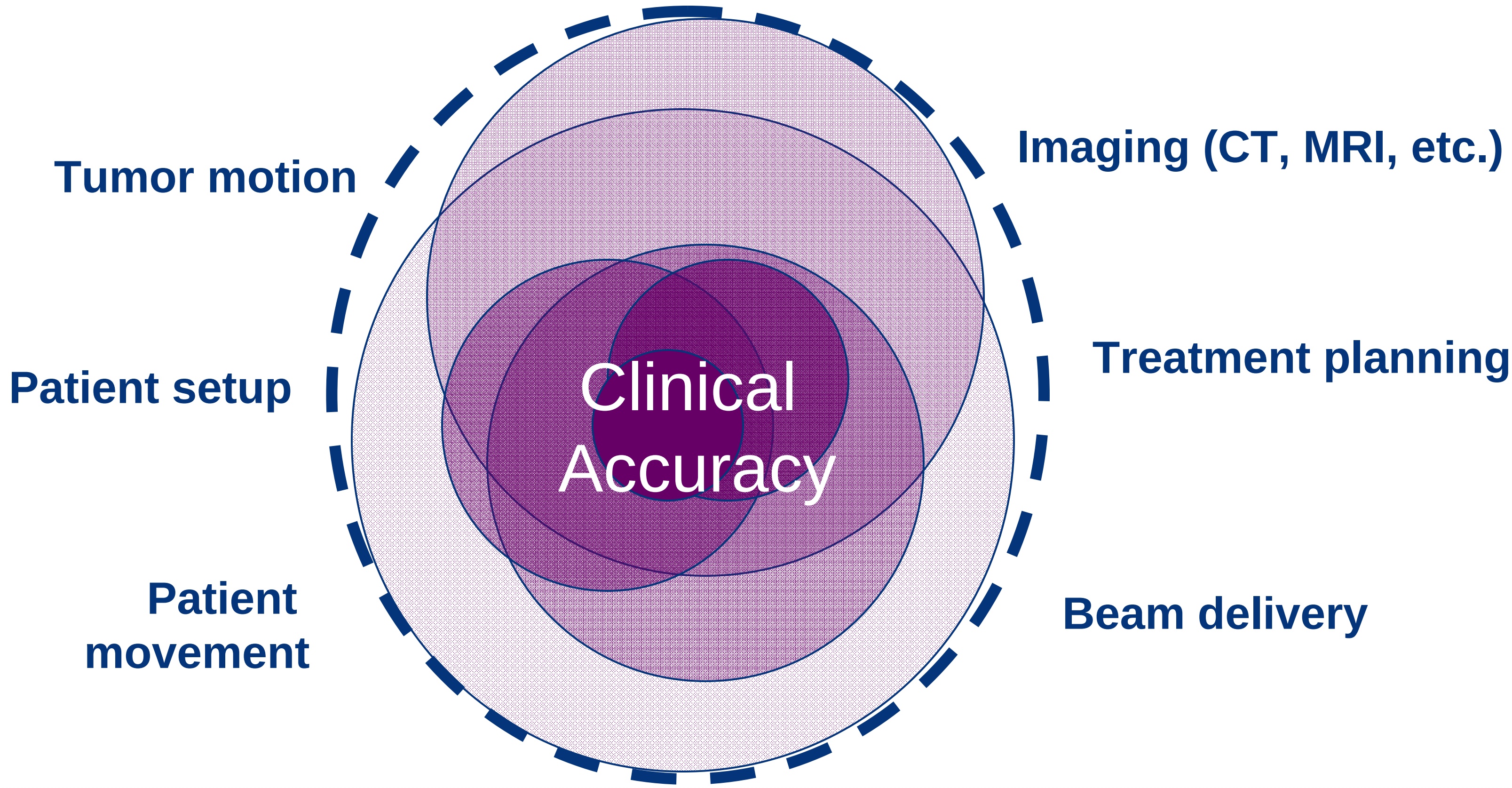
CyberKnife® Conformality

- Non-Coplanar Beam Delivery
  - Automatically minimizes entrance/exit beam interactions
  - No patient or linac re-positioning required



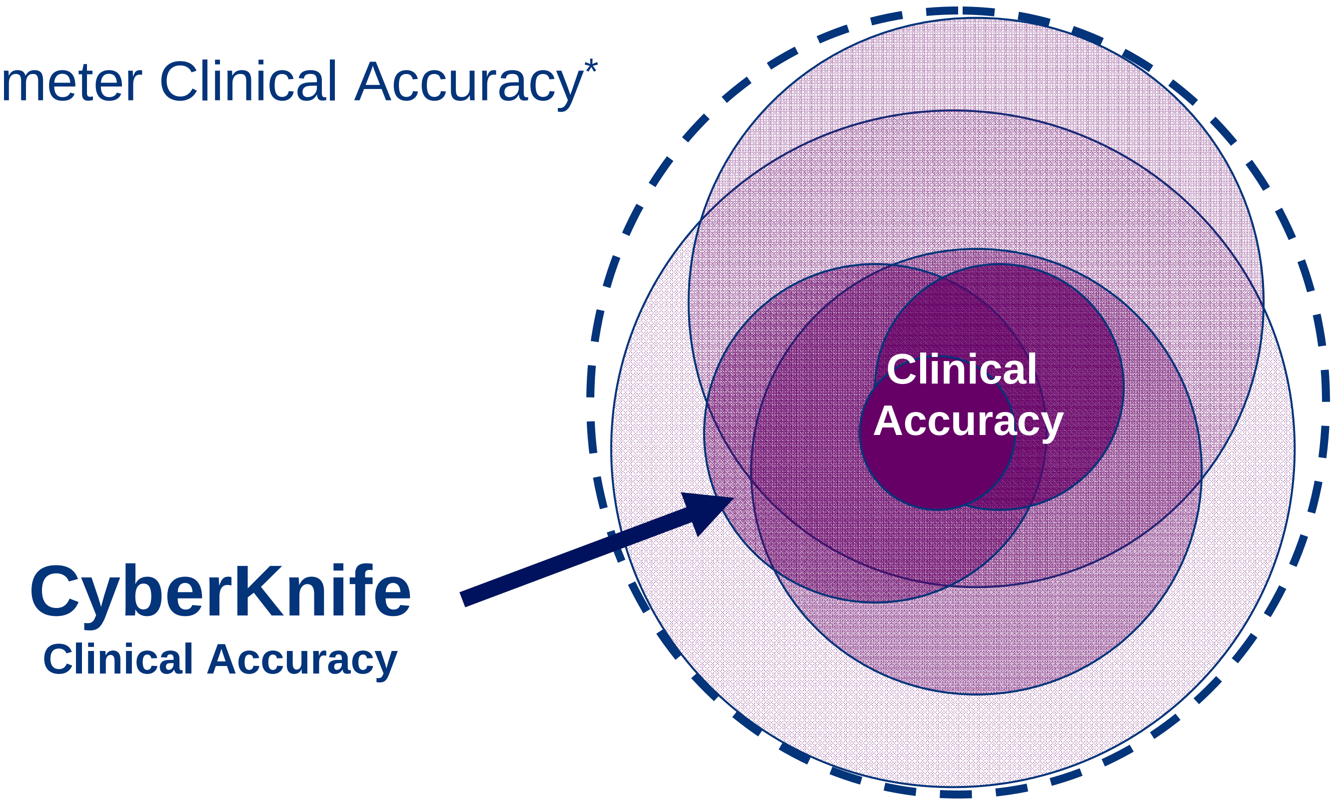
Defining Accuracy

- Traditional Definition: Mechanical Accuracy
- New Definition: Clinical Accuracy



CyberKnife® Robotic System Accuracy

- Mechanical Accuracy = 0.2 mm
- Sub-Millimeter Clinical Accuracy*



References:

- Yu C, Main W, Taylor D, Kuduvalli G, Wang M, Apuzzo M, Adler J. An Anthropomorphic Phantom Study of the Accuracy of CyberKnife Spinal Radiosurgery. *Neurosurgery*, November 2004.
- Dieterich S, Taylor D, Chuang C, Wong K, Tang J, Kilby W, Main W. The CyberKnife Synchrony Respiratory Tracking System: Evaluation of systematic targeting uncertainty

CyberKnife® System Accuracy

Stationary Tumors

- CyberKnife delivers treatments with sub-mm accuracy*

Site	anterior	left	superior	radial
1	-0.32	0.26	0.21	0.46
2	-0.24	-0.26	-0.17	0.39
3	0.00	0.04	0.08	0.09
4	-0.46	-0.33	-0.38	0.68
5	0.35	0.32	0.60	0.76
6	-0.04	-0.14	-0.14	0.20
7	-0.55	-0.72	-0.01	0.91
8	-0.18	-0.86	-0.24	0.91
9	-0.15	0.31	0.1	
Mean				
SD				

0.53 mm
±0.3 mm

CyberKnife Total Targeting Error in mm for systems tested 2003-2004.

*References: Yu C, Main W, Taylor D, Kuduvalli G, Wang M, Apuzzo M, Adler J. An Anthropomorphic Phantom Study of the Accuracy of CyberKnife Spinal Radiosurgery. *Neurosurgery*, November 2004.

CyberKnife® System Accuracy

Moving Tumors

- Dieterich, S, et al. The CyberKnife Synchrony™ Respiratory Tracking System: Evaluation of Systematic Targeting Uncertainty
  - Objective: Quantify systematic geometric uncertainties in treatment delivery using Synchrony for range of simulated respiratory motions
  - Methodology: Accuracy measured at Georgetown University Hospital, Boulder Community Hospital, UCSF

	Site 1	***Site 2***	***Site 3***	***Mean***	***SD***
0 deg	1.05	0.62	0.46	0.71	0.31
15 deg	1.05	0.74	0.11	0.63	0.48
30 deg	1.08	0.55	0.64	0.76	0.28

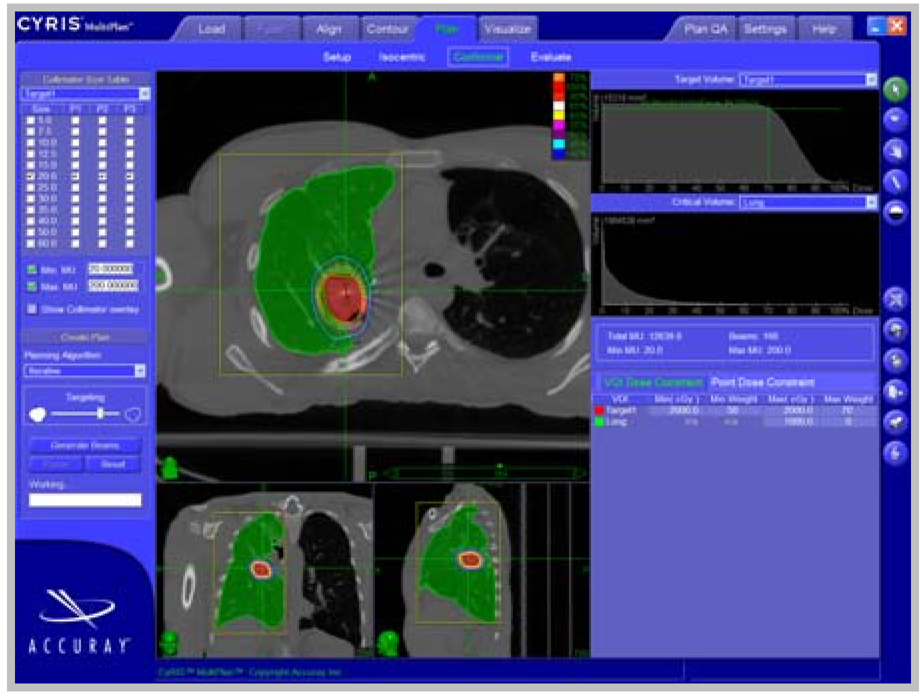
  - **Results: Mean systematic error of 0.70 ± 0.33 mm**
  - Synchrony accuracy specification: 1.5 mm

Reference: Dieterich S, Taylor D, Chuang C, Wong K, Tang J, Kilby W, Main W. The CyberKnife Synchrony Respiratory Tracking System: Evaluation of Systematic Targeting Uncertainty

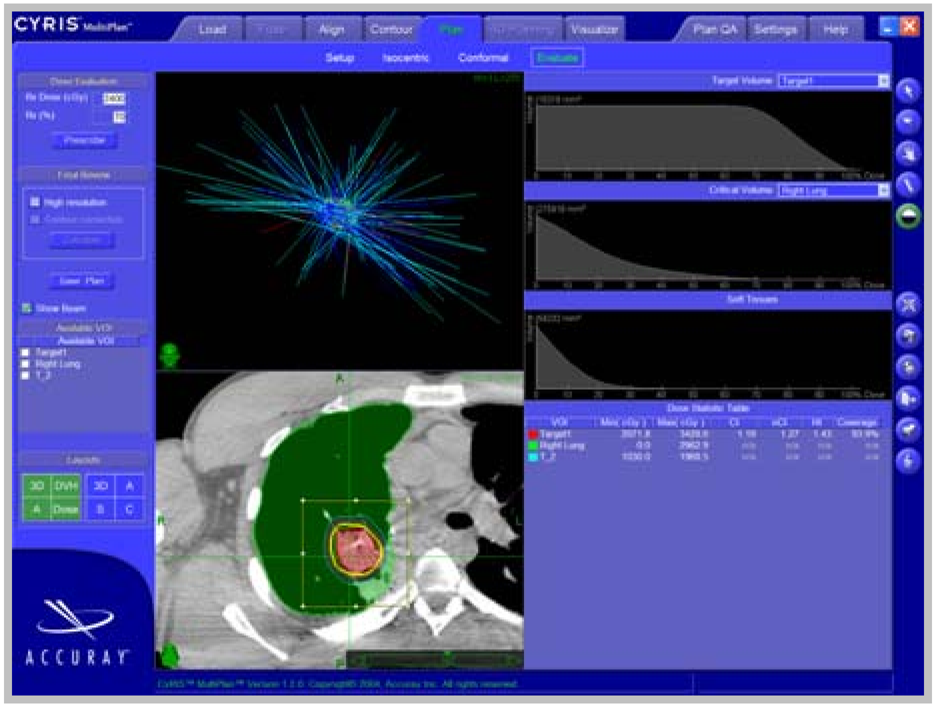
Treatment Planning

CyRIS™ MultiPlan™ Treatment Planning

- Optimized for intracranial and extracranial radiosurgery
- Work flow management
- Advanced, automated and manual image fusion
- Automated planning and contouring tools



CyRIS™ MultiPlan™ Treatment Planning

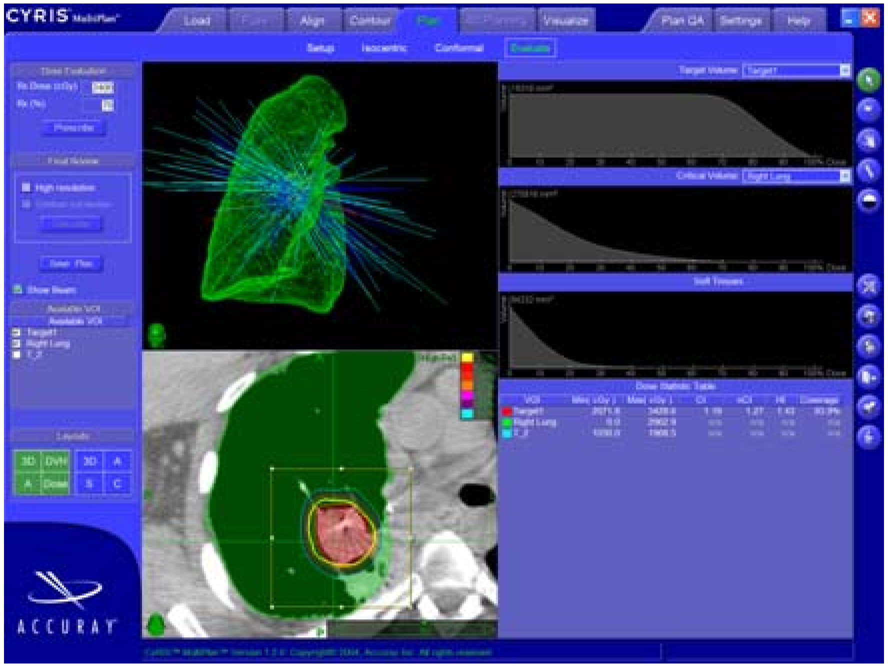


- Multiple optimization approaches including real-time visualization and interaction
- Powerful plan review tools
- Easily, efficiently generate highly conformal plans
- Windows XP/PC product platform

CyRIS™ MultiPlan™ Treatment Planning

Benefits

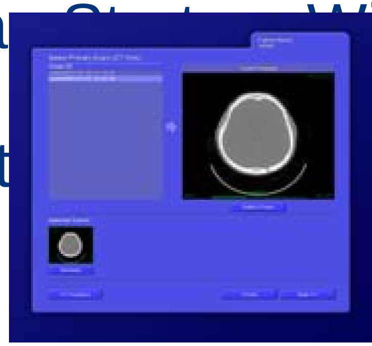
- Fast, multi-modality image fusion
- Simplified contouring
- Supports forward and inverse planning methods
- Achieves desired plan results quickly and efficiently
- Streamlines overall planning process
- Maximize the capabilities of CyberKnife System



CyberKnife® G4: Treatment Planning Wizard

Load Patient

Select Study



Select Exams

Anatomical Planning Template

- Designed to streamline the treatment planning process
- Simplified, intuitive user interface
- Automatic workflow navigation
- Predefined treatment planning parameters organized by anatomical region
- Emphasis on treating tumors anywhere in the body

CyberKnife® Treatment Workflow

ACCURAY

Patient Setup

- No head or body frame required
- Intracranial cases: Thermoplastic mask
- Extracranial cases
  - Spine: no fiducials or markers needed
  - Soft-tissue tumors: Gold seed markers
  - Moving tumors: Synchrony vest

Photo courtesy of Naples Community Hospital

CyberKnife® Treatment Procedure

1. Patient Consult
2. Patient Setup
3. Image Acquisition
4. Treatment Planning
5. Treatment Delivery

Photos courtesy of Stanford University Hospital, Naples Community Hospital, University of Southern California, St. Joseph's Hospital

Case Studies

Optic Apparatus Meningioma†

Barrow Neurological Institute

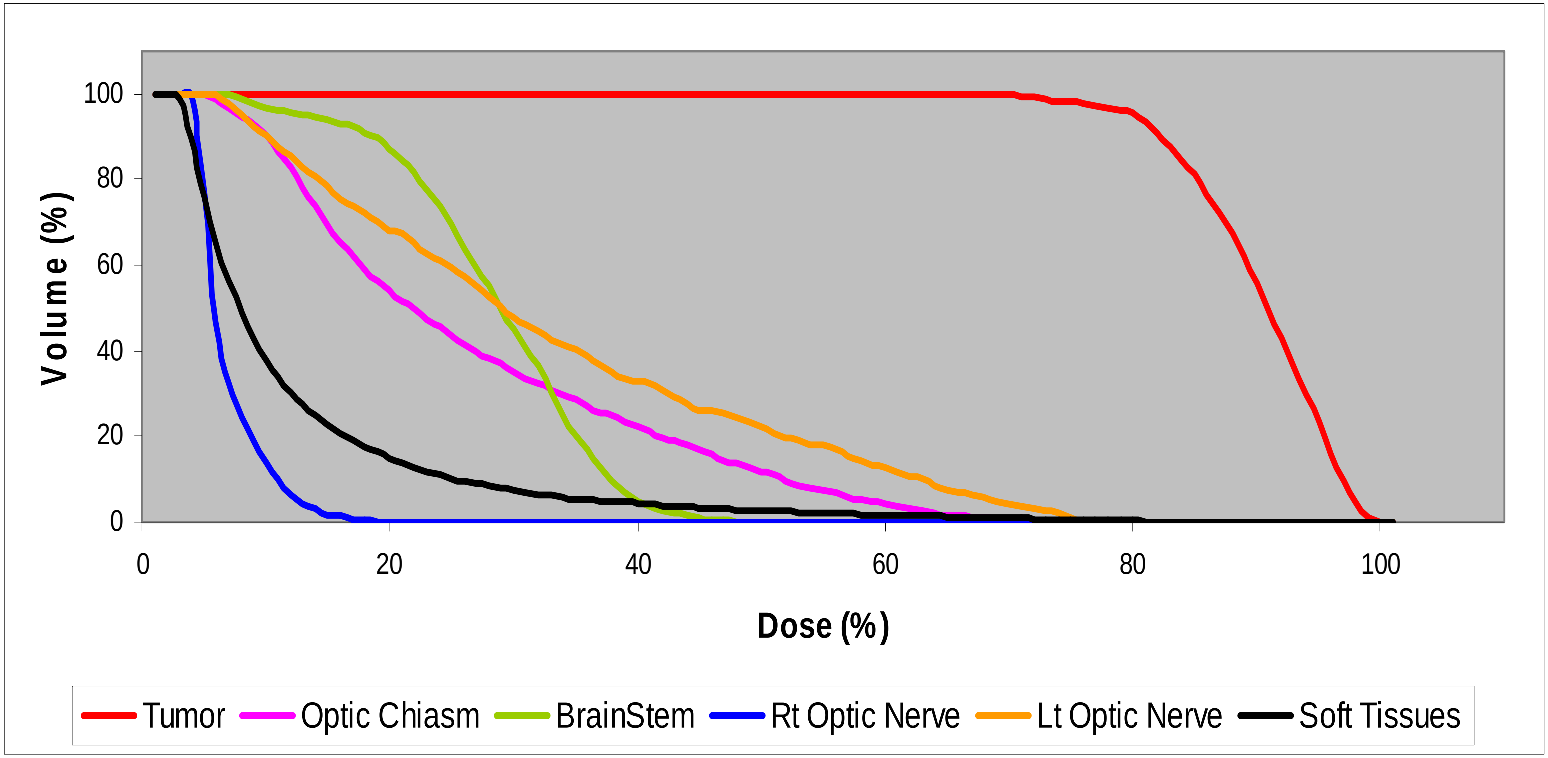
Optic Apparatus Meningioma†

- Rx 2500 cGy to 75% isodose in 5 fractions
  - Previously resected
- Tumor volume = 3.2 cc
- Treatment delivered in 208 beams
- Conformality Index (PIV/TIV) = 1.39
- Treatment time ~ 40 minutes per fraction
  - Includes setup and patient alignment
  - Beam on time ~ 15 minutes per fraction
- Vision spared in healthy eye, vision restored in affected eye

†Case provided courtesy of Barrow Neurological Institute

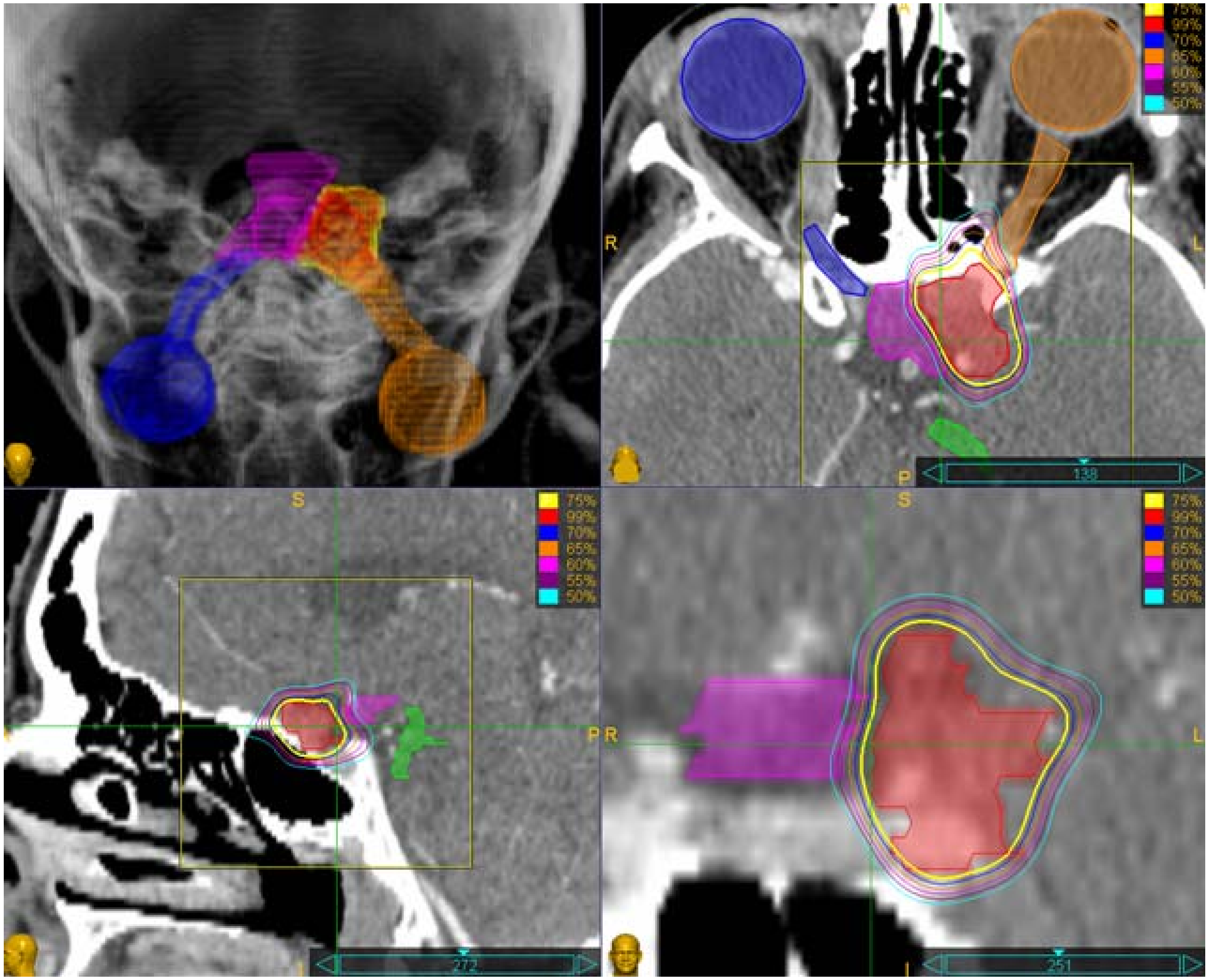
Optic Apparatus DVH†

- Rx 2500 cGy to 75% isodose in 5 fractions
  - Previously resected



†*Case provided courtesy of Barrow Neurological Institute*

Optic Apparatus Meningioma†

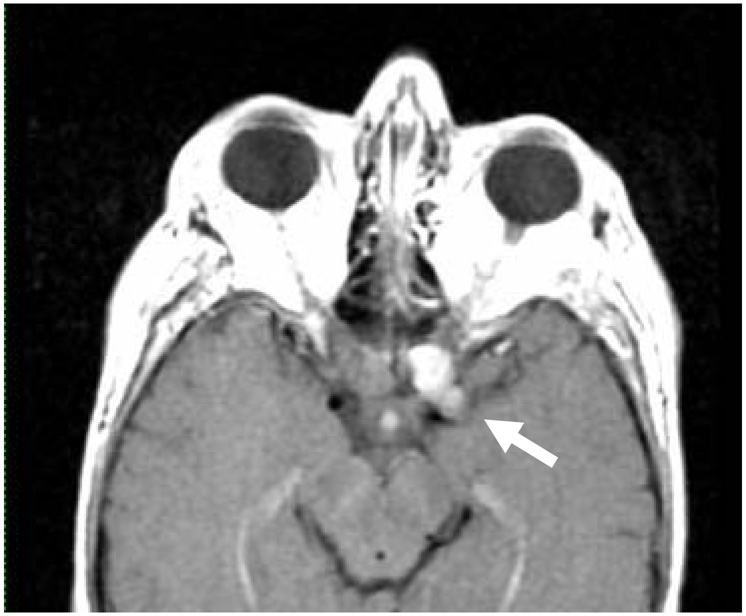


†*Case provided courtesy of Barrow Neurological Institute*

Optic Apparatus Results†

- Patient reports restoration of vision within 4 weeks of treatment

Pre-treatment



2 months post-CyberKnife

†Case provided courtesy of Barrow Neurological Institute

NSCLC Left Upper Lung

St. Josephs Hospital, Phoenix

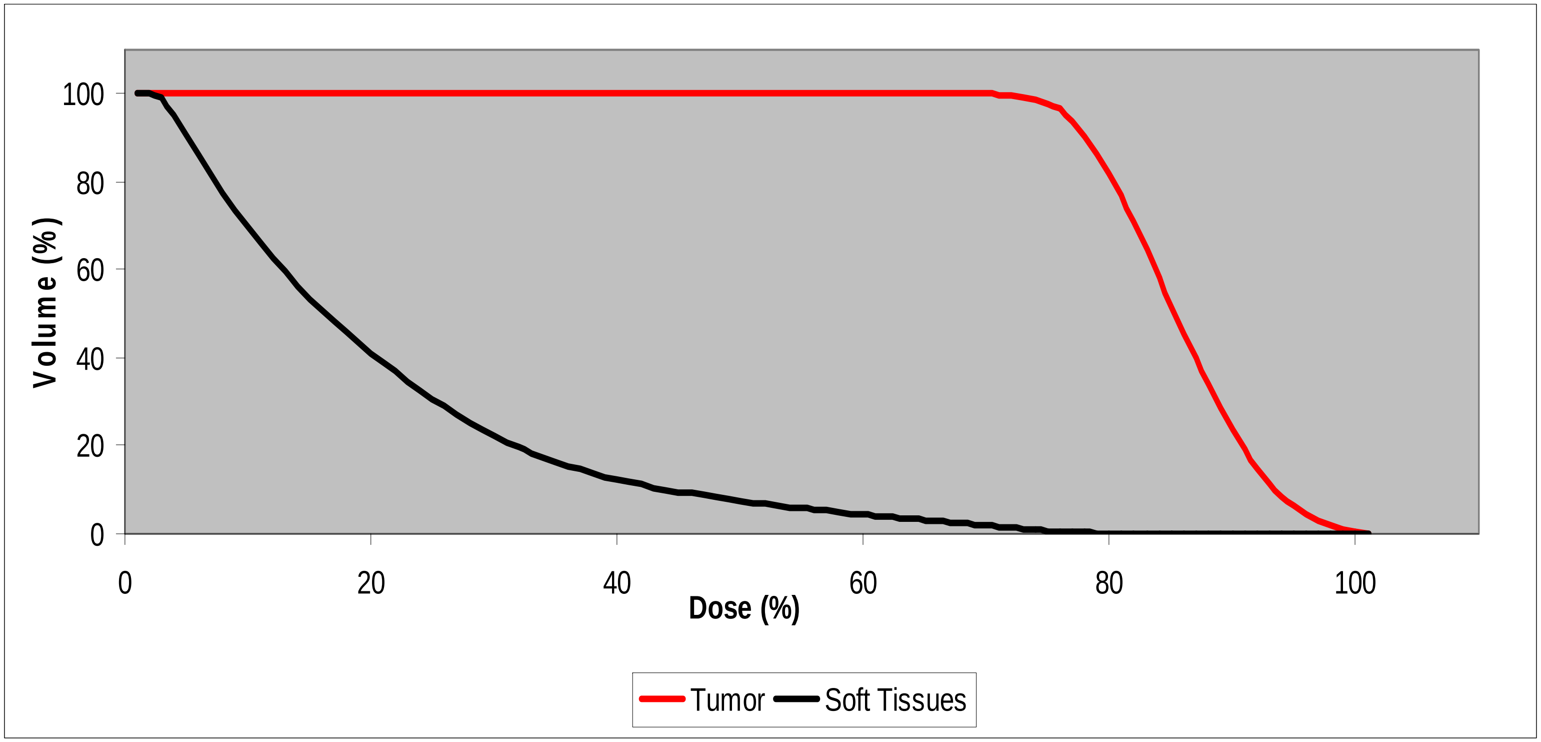
NSCLC Left Upper Lung†

- 65 YO F
- Rx 4800 cGy to 71% isodose in 3 fractions
- Tumor volume = 13.9 cc
- Treatment delivered in 154 beams
- Conformality Index (PIV/TIV) = 1.37
- Treatment time ~ 78 minutes per fraction
  - Includes setup, patient alignment, and respiratory modeling

†Case provided courtesy of St. Josephs Hospital, Phoenix

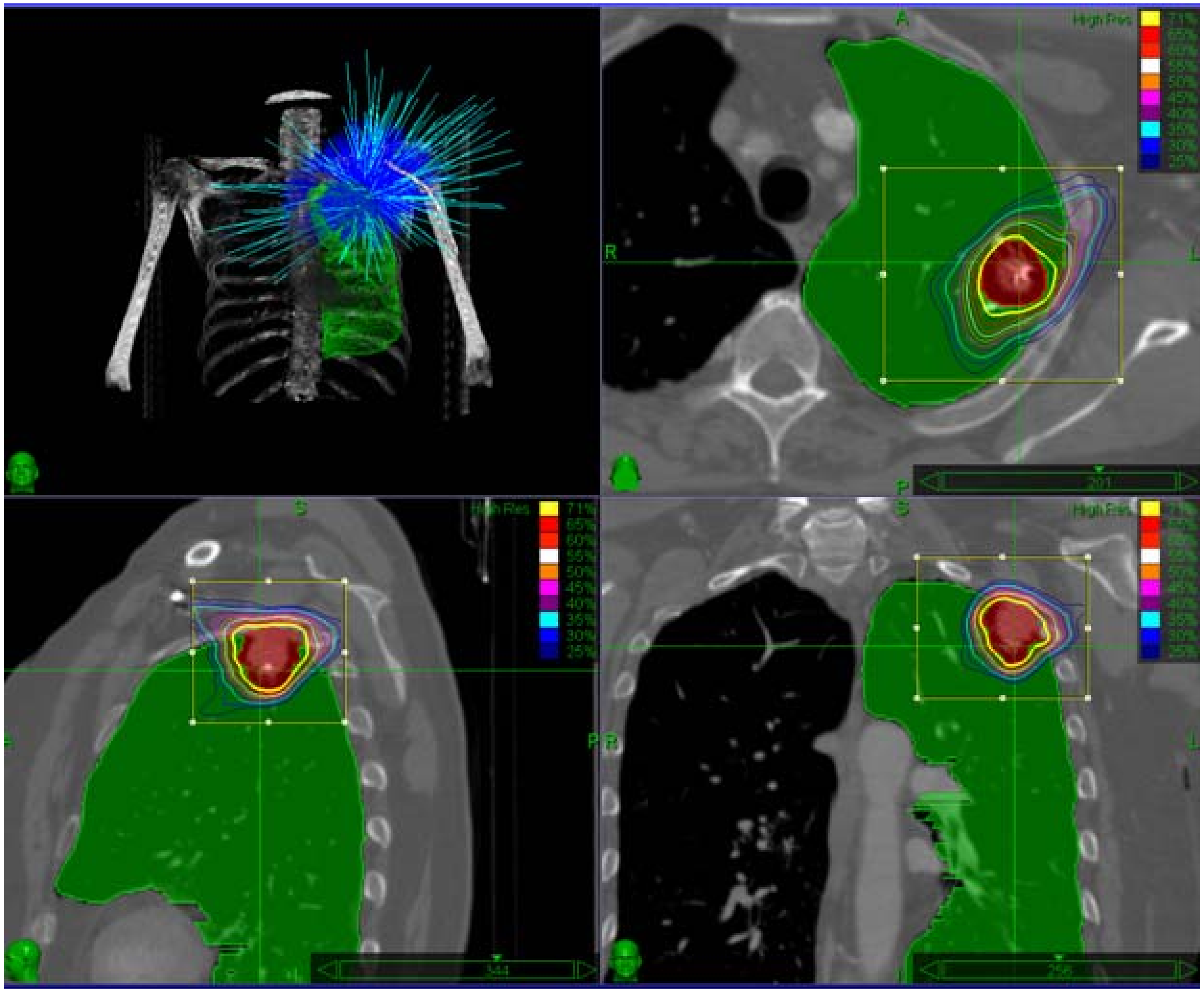
NSCLC Left Upper Lung DVH[†]

- Rx 4800 cGy to 71% isodose in 3 fractions



[†]Case provided courtesy of St. Josephs Hospital, Phoenix

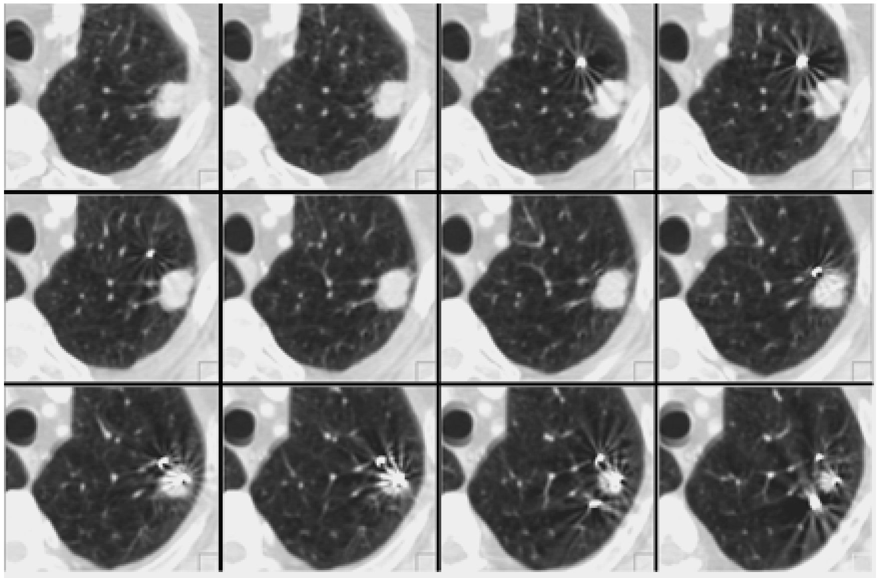
NSCLC Left Upper Lung[†]



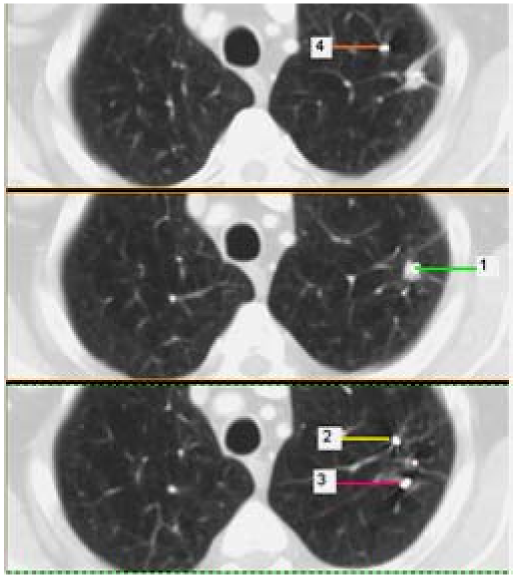
[†]*Case provided courtesy of St. Josephs Hospital, Phoenix*

NSCLC Left Upper Lung Results†

- Radiographically complete response in 15 weeks mistaken for resection by Radiologist



Pre-treatment



15 weeks post-CyberKnife

†Case provided courtesy of St. Josephs Hospital, Phoenix

Left Optic Nerve Meninigioma†

Barrow Neurological Institute

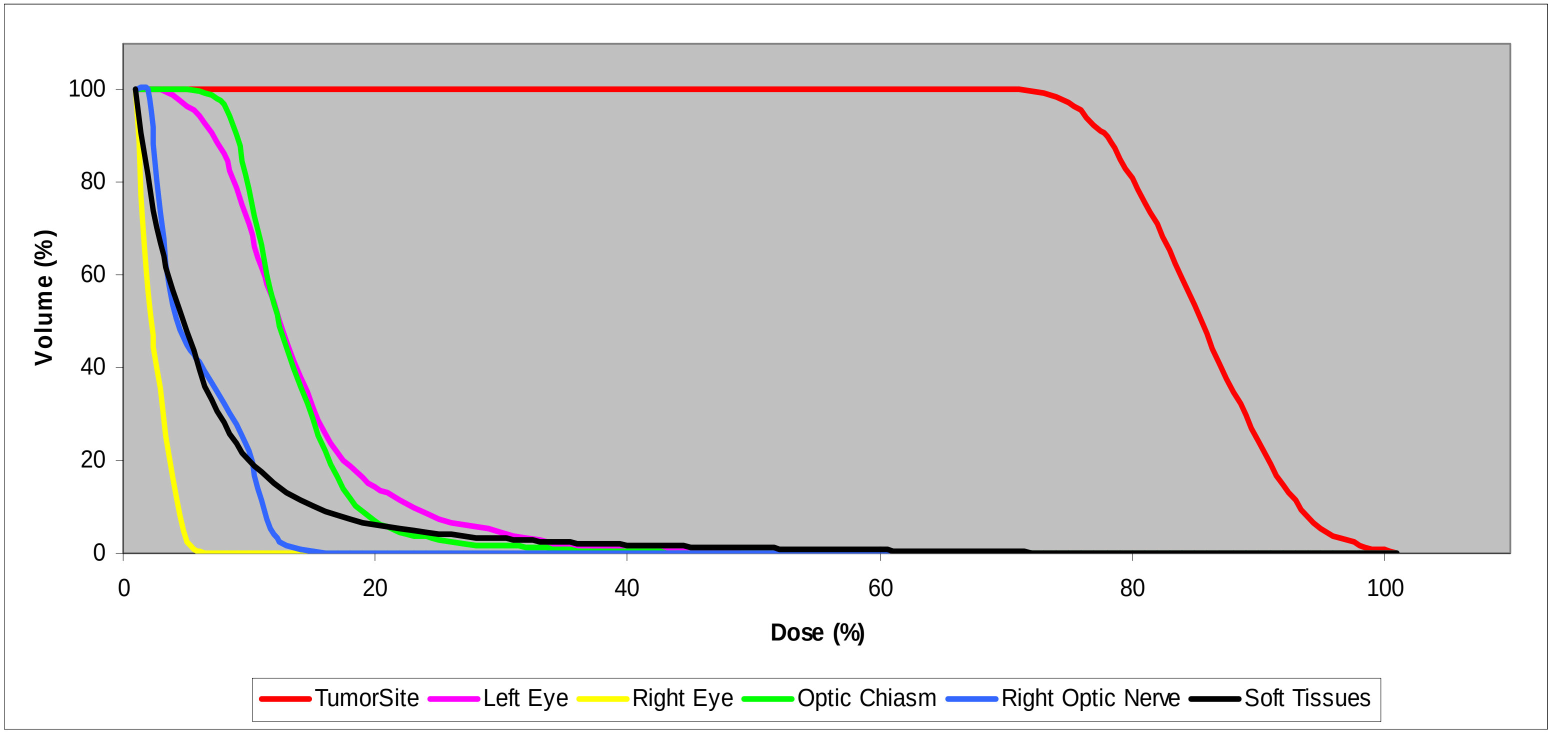
Left Optic Nerve Meninigioma†

- Rx 2500 cGy to 75% isodose in 5 fractions
  - Previously resected
- Tumor volume = 3.1 cc
- Treatment delivered in 170 beams
- Conformality Index (PIV/TIV) = 1.30
- Treatment time ~ 50 minutes per fraction
  - Includes setup and patient alignment
  - Beam on time ~ 15 minutes per fraction
- Tumor is stable following treatment

†Case provided courtesy of Barrow Neurological Institute

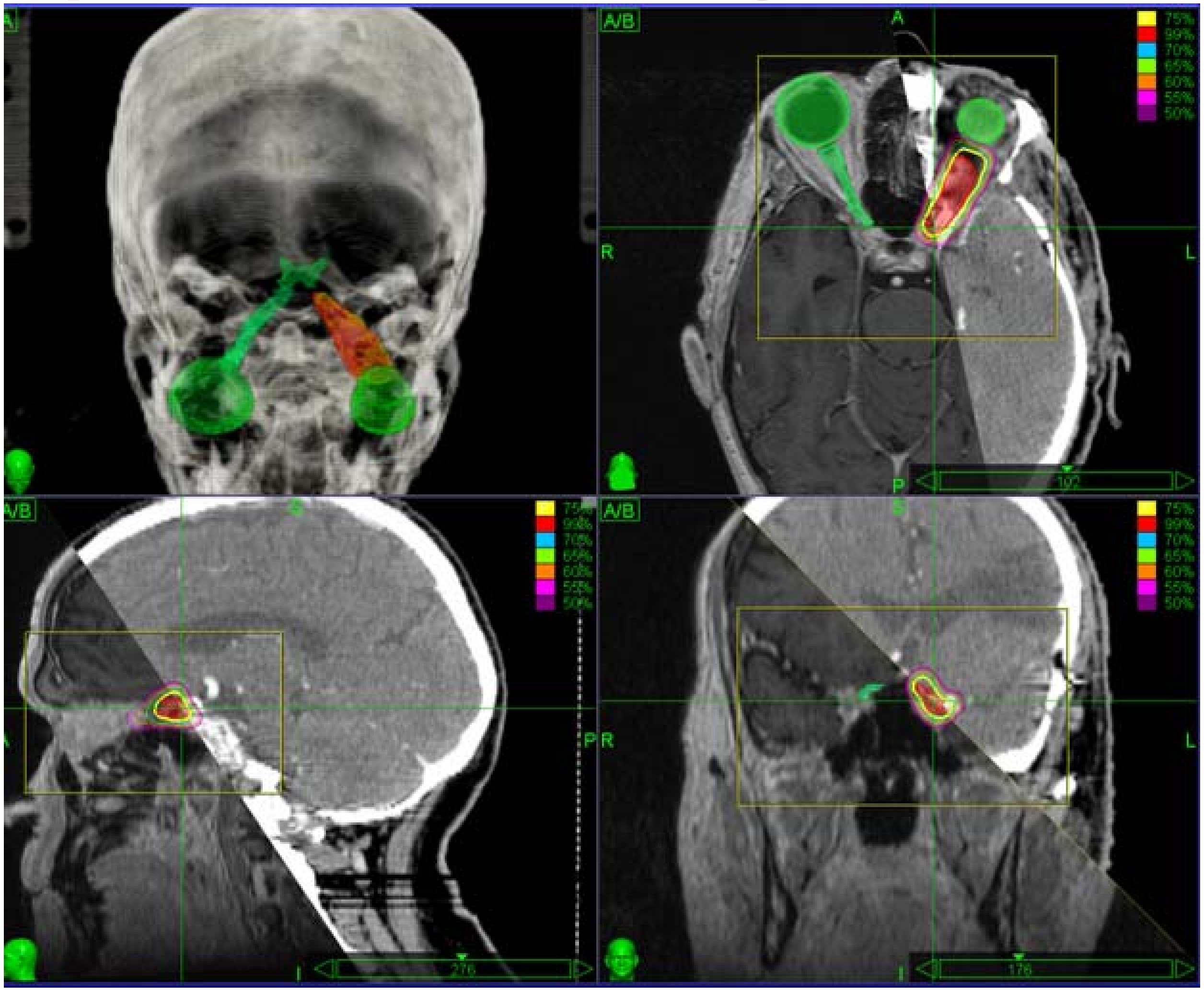
Optic Nerve DVH[†]

- Rx 2500 cGy to 75% isodose in 5 fractions
  - Previously resected



[†]Case provided courtesy of Barrow Neurological Institute

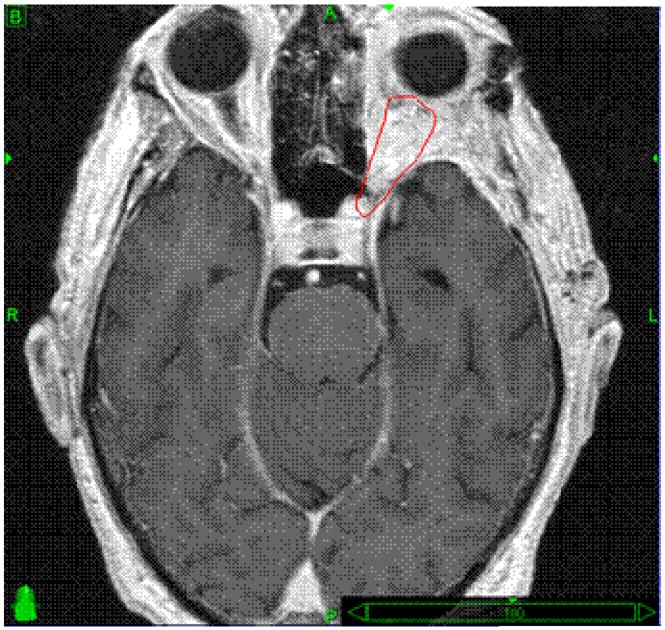
Left Optic Nerve Meninigioma†



†Case provided courtesy of Barrow Neurological Institute

Left Optic Nerve Results†

- Patient is stable at 3 months with no disease progression



Pre-treatment

3 months post-CyberKnife

†*Case provided courtesy of Barrow Neurological Institute*

Conclusions

CyberKnife® Robotic Radiosurgery: Clinical Benefits

- Improved Treatments
  - Less risk to healthy tissue
  - Enables single and multiple session (2-5 fraction) radiosurgeries
  - Treatment of larger lesions than traditional radiosurgery
  - Treatment of complex lesions, previously judged untreatable
  - Access to lesions in all parts of the body
- Improved Patient Quality of Life
  - Reduction of pain
  - Reduction of side effects
  - No risk of infection or general anesthesia
  - No requirement for head or body frames
  - Short treatment course
  - Minimal recovery time

CyberKnife® Robotic Radiosurgery: Conclusion

- Delivers unique benefits
  - Treats anywhere in the body
  - Tracks, detects and corrects for movement throughout treatment
  - Sub-millimeter accuracy
- Proven clinical experience
  - Over 20,000 patients treated worldwide
  - Over 160 clinical and technical papers
  - Over 160 medical centers worldwide have chosen the CyberKnife system

How are resources allocated to Integrated Cancer Programs from MOHLTC?

- *Initial ICP funding based on predicted patient referrals; staff and major capital resources reasonably standardized by CCO/Capital Projects and MOHLTC*
- *Ongoing operational and capital funding based on <u>actual</u> patient referrals, growth, and time (capital depreciation and replacement process)*
- *Achieving funding for new technology (typically expensive) requires ingenuity, persistence, and sound business planning by ICPs*

Why choose Cyberknife over other technologies?

- *Near real time tumor tracking with precision treatment delivery; current pinnacle of IGRT technologies*
- *Tomotherapy collimation provides limited resolution and is limited to arc geometries; pre-treatment imaging assumes no motion during treatment*
- *Modified linac setup cumbersome; micro MLC is not necessarily built into linac head and separate treatment planning system is required*
- *Modified linac employs orthogonally mounted KV verification imaging; real time KV imaging may not be available in direction of treatment beam*

Unique potential for U Waterloo – GRRCC Cyberknife research and development

- *Patient benefit from Cyberknife IGRT capability*
- *U of Waterloo expertise*
- *GRRCC expertise*
- *Currently empty bunker (treatment room)*

Cyberknife Research and Development Possibilities

- *Informatics; development of treatment verification and evaluation tools, image management, Dicom-RT patient data storage and R&V infrastructure*
- *Improvement of real time tumor tracking system*
- *Improvement of treatment planning system; inverse optimization to include dose gradient, MC dose modeling, composite dose distributions*
- *Development of large-field dose delivery with micro-MLC*
- *Basic radiobiology; MTD and hypofractionation*

Going forward with Cyberknife proposal

- *Draft proposal with help of Basadur Creativity; already in progress*
- *Discussion with U of Waterloo to determine interest and potential collaboration*
- *Draft of research and development components*
- *Submit proposal to CCO/MOHLTC in fall*

Conclusions

- *The Radiation Program at GRRCC would like to implement Cyberknife as an alternative IGRT technology to modified linacs and helical Tomotherapy*
- *The likelihood of MOHLTC funding for Cyberknife will be greater if the application includes collaborative research interest from U of Waterloo*
- *This is a unique opportunity for GRRCC and U of Waterloo to work together to develop and improve Cyberknife technology for the patients of K-W region*