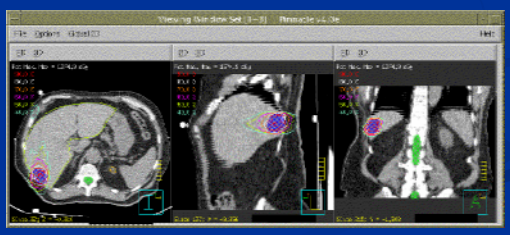
INTRODUCTION TO STEREOTACTIC BODY RADIOTHERAPY:

(I) Physics and Technology (II) Clinical Experience & (III) Radiobiological Considerations and Future Directions

Stanley H. Benedict, Ph.D., Danny Song, MD, and Brian D. Kavanagh, MD, MPH



STEREOTACTIC BODY RADIOTHERAPY (SBRT)

Part 1:
Physics and Technology
Presented by Stanley H. Benedict, PhD
Virginia Commonwealth University, Medical College of Virginia Hospitals

Part 2:
Overview of Clinical Experience
Presented by Danny Song, MD
Virginia Commonwealth University, Medical College of Virginia Hospitals

Part 3:
Radiobiological Considerations and Future Directions
Presented by Brian Kavanagh, MD, MPH
University of Colorado Health Sciences Center, Anschutz Cancer Pavilion

STEREOTACTIC BODY RADIOTHERAPY (SBRT)– What's in a name?

- SBRT is the use of external beams to treat lesions of the body with "surgical" doses and high precision tumor identification and relocalization employing "stereotactic" image guidance or implanted fiducials.
- Extracranial stereotactic ….
  Radioablation / Radiosurgery / Radiotherapy
- Surgery vs. Ablation vs. Therapy vs. …
- According to the chief CPT code developer it will be called:
  Stereotactic Body Radiotherapy

SBRT REQUIRES:

- Higher confidence in tumor targeting
- Reliable mechanisms for generating focused, sharply delineated dose distributions
  * Ability to shape the prescription isodose surface to the outline of the target volume surface itself.
  * This requires a relatively large number of non-opposing beams/arcs to avoid entrance/exit beam interactions, preferably non-coplanar.
- Specifically:
  - Reliable accurate patient positioning accounting for target motion related to time dependent organ movement

* Timmerman et al, *Technology in Cancer Research and Treatment* – 2003

SBRT PHYSICS AND TECHNOLOGY

- **1. CT simulation**: Assess tumor motion
- **2. Immobilization**: Minimize motion, breathing effects
- **3. Planning**: Small field dosimetry
  Inhomogeneity corrections, Hot spots in GTV
  Fixed fields, IMRT, Dynamic Arcs
- **4. Repositioning**: High precision set-up:
  IR/LED Active and Passive markers, US, Video
- **5. Relocalization**: Identify tumor in treatment field:
- * ASi, Dual KV Xray, Implanted markers and/or set-up fiducials
  * Motion tracking and gating systems, automated breathing control systems
  * Real-time tumor tracking systems and EPID Image guidance systems for on-line treatment verification
- **6. Treatment delivery techniques**
  - High precision fixed fields, Novalis, Cyberknife, Cones, mMLC
  - * Hadinger et al *Med Phys*. 2002.
  - * Hamilton et al, *Stereotactic Funct Neurosurg*, 1996
  - * Lohr, et al *Int J Radiat Oncol Biol Phys* 1999

ACKNOWLEDGEMENTS

- A REVIEW OF SYSTEMS EMPLOYED TO INCREASE CONFIDENCE, PRECISION, AND VERIFICATION FOR ESRT.
- NO INSTITUTION EMPLOYS ALL OR EVEN THE SAME MEASURES!

- Sanford Meeks, PhD – University of Iowa
- Tim Solberg,PhD – UCLA
- Martin Murphy, PhD – Accuray - CyberKnife

- Elekta Stereotactic Body Frame, Image Guidance Synergy Platform
- BrainLab ExacTrac IR patient positioning, Novalis Image Guidance
- Accuray Cyberknife – Robotic image guided radiosurgical system
- Precise Therapeutics/Medical Intelligence- BodyFix immobilization
- NOMOS, Bat Ultrasound Guidance system
- Helical Tomotherapy
- Zmed Linac Scalpel™ System

ELEKTA STEREOTACTIC BODY FRAME

- Reference indicators for CT /MR determination of target coordinates
- Diaphragm control attached to the frame minimizes respiratory movements.
- Horizontal positioning of the frame, in the scanner or on the treatment couch,
- Longitudinal alignment is controlled by skin marks over the tibia using a frame-mounted laser.
- Co-ordinates used for patient positioning can be easily read on the arc-ruler and on the longitudinal ruler

* Lax, Blomgren, *Acta Oncologica* 1994
* Blomgren, Lax, *Acta Oncologica* 1995

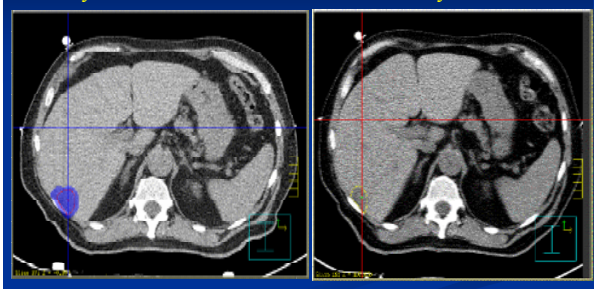
IMMOBILIZATION: Medical Intelligence - BodyFix:

- Integrated indexed patient positioning
- Minimizes respiratory motion
- Accurate Non-Invasive Repeat Positioning
- Dual vacuum technology: Custom-Mold and Patient Immobilization
- Radio-translucent materials

CT VERIFICATION PRIOR TO TX

Day 1: CT Simulation

Day 2: Treatment



What is Optical Tracking?

- Optical tracking is a means of determining in **real-time** the position of an object by tracking the positions of either active or passive infrared markers attached to the object. The position of the point of reflection is determined using a camera system. Phantom precision is sub-millimeter.

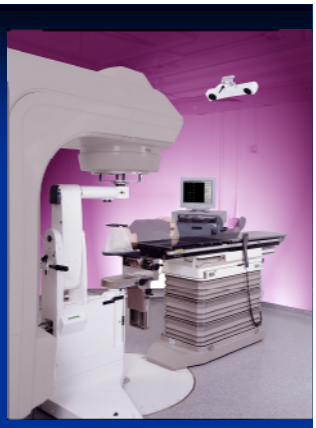
Active markers

Passive markers

IR Camera

Optical guidance for frameless stereotaxis

- For high-precision radiotherapy and frameless radiosurgery, optical guidance can track the patient position using passive markers

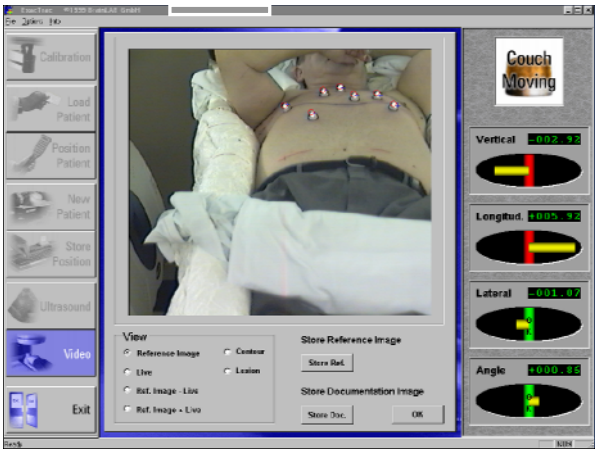


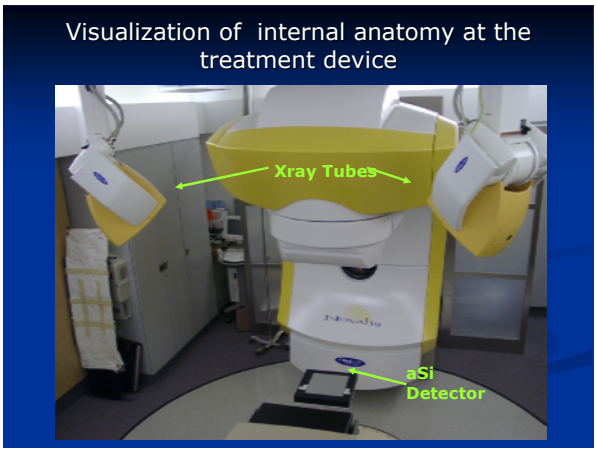
BRAINLAB – EXACTRAC REPOSITIONING VERIFICATION

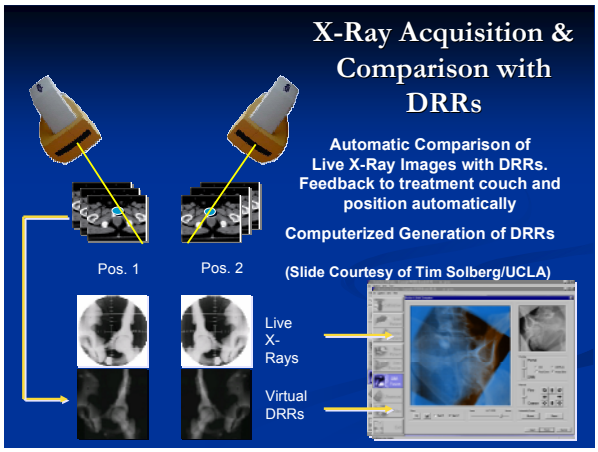
- Reflective Body Markers for infrared Camera Technology Detection of patient position
- Video Camera for Independent Verification and Documentation Images
- 150 kV X-ray sources - imaging of bony structures or implanted markers and amorphous silicon detector.

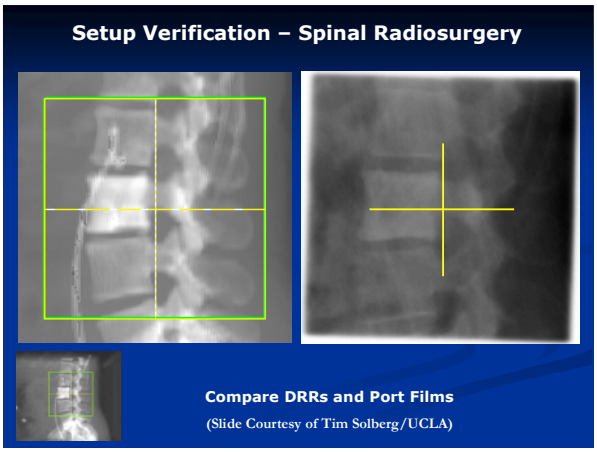
* Soet, *IJROBP* 2002.

* Wang *Comput Biol* Med. 2001


Calibration
Load Patient
Position Patient
New Patient
Store Position
Ultrasound
Video
Exit
Couch Moving
Vertical
Longitud.
Lateral
Angle
View
Reference Image
Contour
Live
Lesion
Ref. Image - Live
Ref. Image + Live
Store Reference Image
Store Ref.
Store Documentation Image
Store Doc.
OK


Visualization of internal anatomy at the treatment device
Xray Tubes
aSi Detector


X-Ray Acquisition & Comparison with DRRs
Automatic Comparison of Live X-Ray Images with DRRs. Feedback to treatment couch and position automatically
Computerized Generation of DRRs
(Slide Courtesy of Tim Solberg/UCLA)
Pos. 1
Pos. 2
Live X-Rays
Virtual DRRs


Setup Verification – Spinal Radiosurgery
Compare DRRs and Port Films
(Slide Courtesy of Tim Solberg/UCLA)

CYBERKNIFE

- (1) Real-time diagnostic imaging system with dual amorphous silicon detectors
- (2) Robotically-mounted 6MV X-band LINAC with circular collimators
- (3) Control loop from imaging system to robot for automatic beam alignment & tracking
- (4) Cranial target localization based on bony anatomy
- (5) Spine target localization based on implanted fiducials
- (6) Soft tissue tumor localization based on implanted fiducials
- (7) Synchronous tracking of breathing motion at a few selected Beta test sites

* Chang et al , Neurosurgery. 2003

CyberKnife

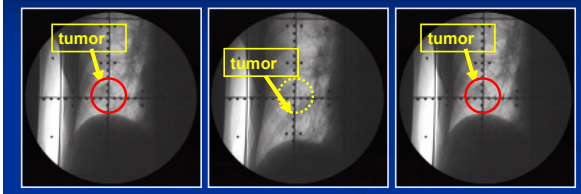
1. Utilizes the skeletal structure of the body as a reference frame — no invasive frame is needed.
2. Continually monitors and tracks patient position during treatment.
3. Ceiling-mounted KV X-ray image patient's tumor treatment system correlates patient location detected by image guidance system with reconstructed CT scan and directs robot to adjust position accordingly
4. Compact linear accelerator mounted on a computer-controlled robotic arm which adjusts position to maintain alignment with target, compensating for any small patient movement uses X-band technology for mobility

ACTIVE BREATHING CONTROL

- Active Breathing Coordinator™
- Allows clinicians to pause a patient's breathing at a precisely indicated tidal volume and coordinate delivery with this pause.
- ABC has shown a median reduction of 12% lung mass in the irradiated field.
- By treating only when the heart is visibly out of the field, clinicians can reduce significantly or even eliminate irradiation of cardiac tissue.

Sixel, et al *Int J Radiat Oncol Biol Phys.*, 2001.

Respiratory Gating



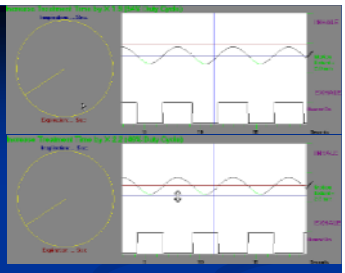
Beam ON | Beam OFF | Beam ON

Slide courtesy of P. Keall/VCU

Respiratory Gating (Inhale vs Exhale)

Varian RPM

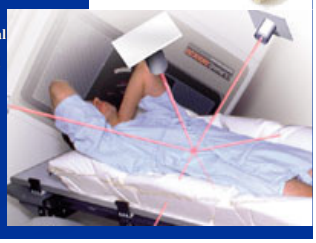
* Courtesy of P. Keall/VCU



- Gated tumor tracking with IR monitor allows maximum dose to tumor & minimum dose to normal tissue.
- Varian's RPM Respiratory Gating system features the Predictive Filter which analyzes the patient's respiration, establishes a baseline respiratory pattern, and detects any deviations from the expected pattern.
- Deviations from the "predicted" respiratory pattern result in an automatic hold of treatment delivery until the baseline respiratory pattern is re-established.

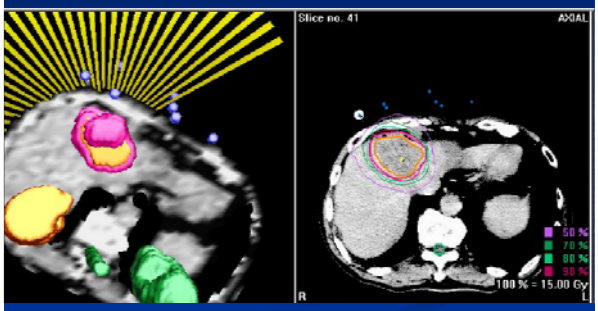
Med Tec pReference® frameless stereotaxy

- **Implanted fiducial technology**
- **Tiny gold markers establish a permanent, accurate, internal patient reference system.**
- **Isoloc: Image-guided software verifies submillimeter localization accuracy for all setups.**
- **Gold Markers for bone are pure gold spheres placed during a simple 20-minute outpatient procedure under local anesthesia. Tools to facilitate marker placement include drill bits, guides, and a tool for holding the marker during implantation.**
- **The soft tissue marker surface is specially treated to prevent migration after implantation. The markers are implanted under ultrasound or CT guidance.**



* K. i-Hwan Kim *IJROBP*, 2003

Inhomogeneity Considerations



INHOMOGENEITY CONCERNS

INHOMOGENEITY TISSUE/CALCULATIONS

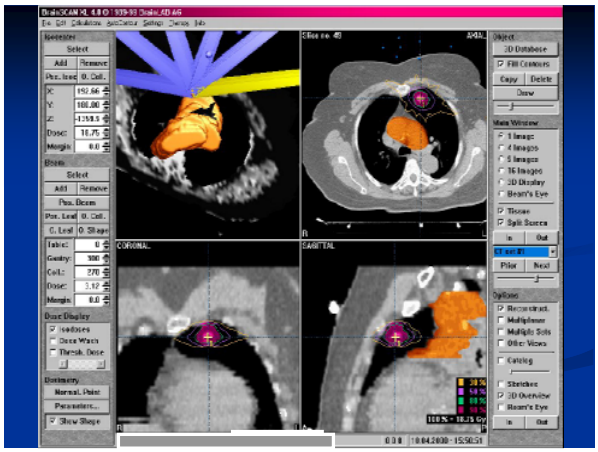
- Very significant with lung/abdomen vs cranial – interface effects are not accounted for with TPS using only a TMR LUT.
- Calculations with small/narrow fields require verification because of the complicated geometry, minimized lateral scatter, and loss of electronic equilibrium

* Solberg 1998, Jones 2003, Rustgi 1998, Wang 2001

DOSE: HOT SPOT VERSUS UNIFORMITY

- Dose gradient within the target are acceptable for ESRT: targets contain no normal tissue.
- Higher target doses (hot spots) may be desirable if they facilitate steeper normal tissue dose fall-off outside of the target within normal tissue.
- Hot spots may be useful in treating hypoxic radioresitant cells in the tumor core.

* Lax et al, *Acta Oncol*, 1994



Clinical Implementation of ESRT –

"These techniques are unusual in the high technology realm of radiation treatment in that they require more specialized training of physicians and physicists rather than specialized equipment."

* Timmerman et al, *Technology in Cancer Research and Treatment* – 2003

SUMMARY: Technical elements of QA

- The physicist should be responsible for all technical QA procedures:

• Imaging equipment
• Localization and simulation equipment
• Treatment planning and evaluation system
• Treatment delivery equipment
• Treatment verification equipment

SUMMARY: Clinical elements of ESRT QA

- A physician and physicist should carry out all clinical QA procedures:

• Consistent target volume and organs–at–risk delineation
• Quantitative assessment of target and organ motion during imaging and treatment
• Quantitative assessment of setup variation during imaging and treatment
• Patient–specific QA

NEED TO ESTABLISH TERMINOLOGY AND REPORTING CONVENTIONS

- Prescription considerations: GTV, margins, dose inhomogeneity/uniformity
- Biological evaluations: EUD, NTCP, etc
- Dose and Fractionation strategy: (1 to 5 fractions, QOD, QD, etc)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