INTRODUCTION TO STEREOTACTIC BODY RADIOTHERAPY:
(I) Physics and Technology (II) Clinical Experience & (III) Radiobiological Considerations and Future Directions
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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/arc 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 – 2005
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 Arc
4. Repositioning: High precision set-up
   IC/LD Active and Passive markers, US, Video
5. Relocalization: Identify tumor in treatment field:
   * ASi, Dual KV Xray, Implanted markers and/or 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
   * Hamilton et al Stereotactic Funct Neurosurg, 1996

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

* Soet, IJROBP 2002.
Visualization of internal anatomy at the treatment device

X-ray Tubes
- Live X-Rays
- Virtual DRRs
- Comparison with DRRs

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

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)
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

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.


Respiratory Gating

Slide courtesy of P. Keall/VCU
**Respiratory Gating**

*Inhale vs Exhale*

**Varian RPM**

- 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.

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**Inhomogeneity Considerations**

**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.


**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 radioresistant 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)