Patient Positioning, Immobilization, and Target Localization for SBRT

Michael Lovelock Ph.D

Medical Physics Department,
Memorial Sloan-Kettering Cancer Center,
New York City, NY

Outline

- Advantages of the different Image guidance systems
  - 2D / 2D:
    - Room mounted, Gantry mounted
  - 3D
    - Helical fan beam
    - MV, kV cone beam
- Patient immobilization
- Respiratory motion management
- New quality assurance procedures
  - Assessment of the overall geometric accuracy

Goal of Image-guidance

- By imaging the target or surrogates at the time of treatment, the uncertainties associated with target and critical structure positioning can be reduced
- Enables:
  - Planning using tighter margins
  - Dose escalation
  - New treatment modalities (SBRT)
- Increased confidence that dose delivery is correct

Equipment Types

- 2D / 2D
  - Orthogonal MV localization images
  - Orthogonal kV radiographs
    - » Room mounted
    - » Gantry mounted
  - Fluoroscopy (2D)
- 3D
  - Helical MV fan beam (Tomotherapy)
  - KV or MV Cone beam scanning
  - In-room CT
- Immobilization
  - Need to analyze the strengths and weaknesses of the imaging system to determine what is required

2D / 2D imaging - Gantry Mounted

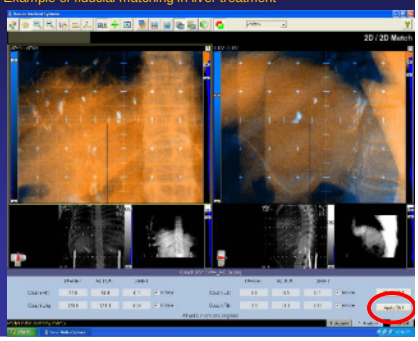
- Advantages
  - Images taken from conventional directions
    - Equipped with online registration with automatic control of the couch, enabling rapid and relatively error free patient positioning
- Disadvantages
  - Soft tissue generally cannot be imaged, may require fiducials to be placed
    - Generally will not see critical structures such as bowel

Registration tools coupled with automatic control over the couch

Both manual and automatic registration tools available at treatment console for use of therapists, physicists and physicians

This functionality will require new QA procedures

- Example of fiducial matching in liver treatment



2D Imaging - fluoroscopy

Two applications:

- Verification that the target is correctly positioned while the gate is open
- Assessment of target motion

  Grid required!

  Check motion is consistent with what was seen at the time of simulation

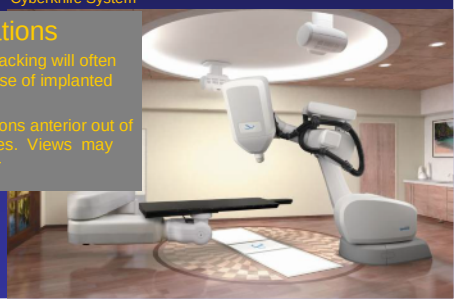
2D imaging - Room Mounted

- Advantages
  - Rapid 3D localization of
    - Implanted fiducials
    - Bone (Spinal vertebrae, cranium
    - Some lung tumors
  - Allows verification of target throughout the treatment delivery. Cyberknife single frac. Spine treatments can involve 30-50 3D localizations
  - Real time update on internal–external correlation model for gated or target tracked treatments
  - Immobilization may be less important

2D imaging - Room Mounted *continued*

Cyberknife System

- Considerations
  - Soft tissue tracking will often require the use of implanted fiducials
  - Beam directions anterior out of plane obliques. Views may be unfamiliar

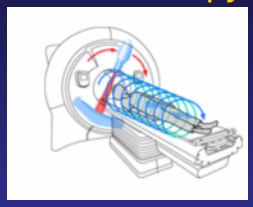


2D imaging - Room Mounted *continued*

Brainlab System

- One of the imaging beams blocked at certain gantry angles,
- 3D localization may require gantry rotation

3D Imaging: Tomotherapy, Cone beam



- MV fan beam
- Designed to image prior to every treatment
- Soft tissue imaging possible

- kV or MV cone beam
- Image acquisition takes approximately 1 minute
  - Organ motion may degrade image quality
- Soft tissue imaging possible

Patient Immobilization

- Importance will depend upon the ability of the system to detect and correct for intra-fractional target motion
  - Less important for systems equipped for intra-fractional imaging
- Initial assessment of performance under clinical conditions by setting up patients receiving standard fractionation.
- QA of clinical process:
  - For systems where intra-fractional imaging is time consuming, assess immobilization performance by imaging either at end or part way through treatment

Immobilization considerations

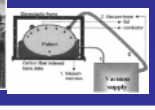
- Patient comfort over long treatment times
  - Can the patient tolerate
    - Mask, or
    - Arms-up position ?
- Bolusing effect of the system - skin dose
    - The frame material may bring the skin dose close to Dmax
    - May reduce skin sparing, especially for 6 MV beams

Immobilization Systems

Original Lax, Blomgren SBF (Elekta)

Pro-lok (www.civco.com)

BodyFIX (Elekta)
www.products.elekta.com



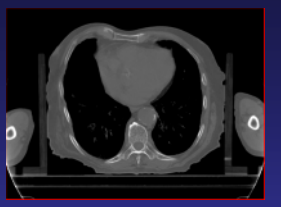
"Stereotactic" setup accuracy

Study	Location	Method	Results
Lax 1994	Abdomen	Stereotactic coords to skin marks	3.7 lat, 5.7 long
Wulf 2000	Lung, liver	Elekta Body Frame	3.3 mm lat, 4.4 mm long
Lohr 1999	spine	Body cast using stereotactic coords	<= 3.6 mm mean vector
Timmerman 2003	Lung	Elekta body frame with abdominal compression	Approx 5 mm
Yenice 2003	Spine	Custom body frame	< 3mm

"Image-guided" setup accuracy (with no respiratory motion)

Murphy 1997	Spine	Real time imaging and tracking	1 mm
Chang 2004	Spine	Body fix with CT on rails	1 mm
Yamada 2008	Spine	Custom immobilization cradle	< 2 mm

MSKCC Immobilization Cradle



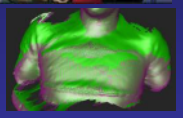
- 4 lateral paddles help maintain patient position
- Designed to maximize patient comfort
- Pre-post shifts in bony anatomy seen:
  - L/R: 0.1 ± 1.3 mm
  - A/P: 0.2 ± 1.0 mm
  - S/I: 0.3 ± 1.2 mm

Immobilization Verification

Commercial Video System

www.visionRT.com

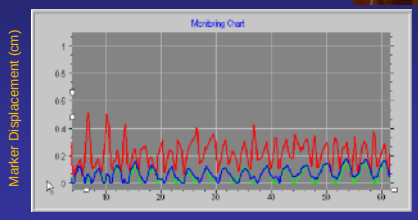
- Red speckled light projected onto the patient's skin
- Cameras reconstruct a 3D surface
- Surface is compared with a reference surface
- Reference surface:
  - Acquire from planning CT external contour
  - Use the system itself to capture patient surface immediately after patient is positioned conventionally



Stereoscopic Infra-Red Cameras

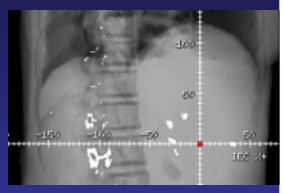
-MSKCC system

- Infra-red reflectors taped to patient's skin
- Positions monitored in real time to check patient still and breathing regularly



Implanted fiducial markers

- Surrogate targets used to facilitate the radiographic localization of soft (and bony) tissues
  - Liver / abdomen
  - Prostate
  - Lung
  - Spine
- Several types:
  - gold cylinder (1 x 3mm)
  - Coiled wire "visicoil"
- Other objects may also be used
  - Stents, spinal hardware, surgical clips
- Require other medical disciplines
  - interventional radiology, neurosurgeons
- Generally an outpatient procedure
- Risks:
  - Liver - Not always possible – bleeding risk
  - Lung - Pneumothorax (air in pleural cavity) (10-30% risk for percutaneous insertion)



DCR RPO Liver,
- (markers contoured)

Safety

- For systems with robotic arms, a malfunction or human error could result in collision with patient
  - Check interlocks (daily)
- Imaging doses
  - Fluoro doses can be very high, and radiation therapists may not be trained in this "formerly diagnostic" technique
  - Generate departmental guidelines for fluoro usage

New quality assurance procedures

- Safety
  - Robotic arms are powerful, present a potential patient collision hazard
    - Daily checks of all touch sensitive interlocks
- Spatial accuracy
  - Not immediately apparent if an imager is incorrectly positioned – could lead to setup errors
    - Daily localization check of independently positioned test object
  - Remote couch control
    - Combine with daily localization check

Sources of spatial uncertainty

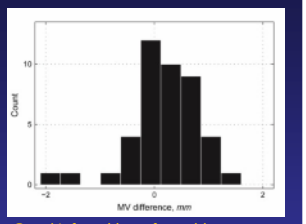
- Random
  - Intra-fractional patient movement
  - Registration errors (patient rotations)
  - Remote couch motion
- Systematic
  - Imaging system origin – radiation isocenter discrepancy
  - Radiation isocenter location
  - Collimation (mlc, …)

- Treatment planning system dose calculation
- DRR generation
- CT slice spacing

Random uncertainties

2D registration accuracy depends on:

- image quality
- DRR quality (CT slice spacing)
- Residual patient rotations



An example:

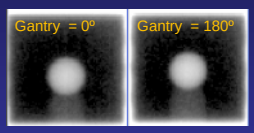
- In 2D – 2D orthogonal imaging the Sup / Inf position of an object should be the same in each image.
- Histogramming the difference gives an indication of the random uncertainties associated with 2D orthogonal imaging
- A distribution of different S/I positions (0.2 ± 0.7 mm) were seen in a study spine setups using orthogonal MV images. (Kriminslki et al, IJROBP 71(5) 2008 1572-80.

Systematic Uncertainty

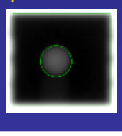
- Objective
  - Require origin of the imaging system to be within “1 mm” of the radiation isocenter (or other reference point)
- Challenge
  - Traditional measurements: (laser, phantom) have an inherent measurement accuracy also about 1 mm
- Solution: use the imaging systems (MV and kV) themselves
  - Intrinsic uncertainties <1mm, Use Winston-Lutz type tests to minimize systematic errors

Winston-Lutz Tests

- Place small sphere at approximate isocenter position



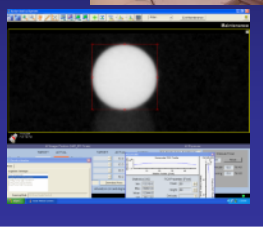
- Using MLC, perform Winston-Lutz tests at Gantry angles 0, 90, 180, 270.
  - See apparent shift in sphere due to gantry sag
- Compute mean position of the Sphere with respect to the radiation isocenter
  - Determine position of sphere with respect to the field, here a 2 x 2 cm mlc aperture



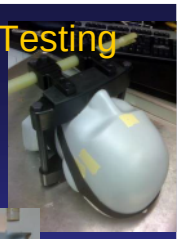
Winston-Lutz Tests

continued

- Image the sphere with the kV system
  - Here, the systematic error of orthogonal kV radiographs was being measured.
- Determine the position of the sphere in the coordinate system of the kV imager
- The systematic error is the difference in position of the sphere as seen by the kV and MV imaging systems



Total System Accuracy Testing



- Assess accuracy of the entire process:
  - CT scan
  - Contouring
  - Dose calculation (leaf motion files)
  - Imaging systemic accuracy
  - Registration
  - Remote couch control
  - Radiation delivery

Compare Center of gravity of planned distribution with what was actually delivered

Commercial Phantom (CIRS Model 605)
Loaded with radiochromic film

Cyberknife papers:
Ho et al. Neuros. 2007 60(2sup1) ONS 147-156
Yu et al Neuros. 2004 55(5) 1138-49

Respiratory Motion Management

Enhanced with kV imaging:

- 4DCT + ITV – free breathing cone beam
- Gating with fluoroscopic or gated radiographic verification
- External – internal motion model built at time of treatment using infra-red tracking of external surrogate with less frequent radiographic imaging
  - Cyberknife tumor-tracking
  - Brainlab gate verification

Resources

- TG101 - coming soon
  - Chairmen: Benedict, Yenice
- I.J.R.O.B.P:
  - 71(1) 2008 Supplement 1
- Books:
  - Stereotactic Body Radiation Therapy 2005 (Eds. Kavanagh, Timmerman)
  - Extracranial Stereotactic Radiotherapy and Radiosurgery 2005 (Eds. Slotman, Solberg, Verellen)
  - Spine Radiosurgery 2009 (Eds. Gerstzen, Ryu)
  - …
- 100's of publications in Pub Med

Summary

- Image guidance enables reduced spatial uncertainty of all targets
- Degree of immobilization required depends on the type of image guidance installed
- The actual accuracy the can be achieved requires realistic assessment of all contributing uncertainties, including the random components
- A careful QA program

We have come a long way…

how we used to assess respiratory target motion

Future plans…

Cone beam scan of a liver tumor, respiratory motion eliminated, targeting accuracy +/- 2 mm during a single fraction 24 Gy treatment

Sagittal cut

Transverse cut