Patient Setup Uncertainties (inter-fraction)

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AAPM Summer School 2011
Inter-fraction Setup Uncertainty

- Unknown/undetected differences between a patient’s position and location at treatment compared to that at treatment simulation
- Difference between fractions, does not include motion within the fraction
- Large setup uncertainties can result in a geographic miss that can compromise tumor control
Time Frames to Consider

Daily Variation
- Differences in patient setup
- Daily anatomical variation

Simulation to Treatment
- Swelling
- Disease progression

Gradual Changes Throughout Treatment
- Weight loss/gain
- Tumor shrinkage/disease progression
Setup Uncertainty-Interfraction

Setup Uncertainty

Errors in reproducing a patient’s position

Internal/organ motion and anatomical changes
Mitigation Strategies

- Efforts to improve setup reproducibility
- Immobilization
- Localization
- Detect and correct positional offsets with image guidance
- Residual Uncertainty
<table>
<thead>
<tr>
<th>Cause of Uncertainty</th>
<th>Magnitude of Uncertainty</th>
<th>Mitigation Strategy</th>
<th>Magnitude of Uncertainty After Implementing Mitigation Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lots</td>
<td>?</td>
<td>Lots</td>
<td>?</td>
</tr>
</tbody>
</table>
Magnitude of Setup Uncertainty?

- Patient specific
- Site specific
- Institution specific
  - Immobilization devices
  - Therapist training
  - Simulation techniques
  - Imaging devices
- Changes with medical practices (chemotherapy, nutritional intervention)
- Varies in importance with selected margins and treatment techniques
How to fill out the table?

- Give up and spend the first week of August at my cottage instead
- Extensive literature search
  - Many studies and approaches
  - Results may or may not apply to you
  - Attempted in the chapter (85 references)
- Collect all my data and talk about my setup errors at McGill
  - You do not work at McGill
- Suggest an approach to determine where these uncertainties might exist and how to reduce them
Main Points for Today

- Patient setup is a process that involves many steps
- As a physicist, you may be able to mitigate uncertainty by getting more involved
- Go to the clinic and observe, be proactive
- Get involved in training and policy making
- Review images
  - Know how to produce the best images with your imaging devices
  - Know when you can see and when you can’t see
- Determine your setup accuracy internally and evaluate the effect of changes
Patient Setup
Reduce Uncertainties Associated with Setting up to Lasers

- Routine QA and calibration (systematic error that can easily be avoided!)
- Install good laser systems
- Document shifts from planning
  - QA documentation
  - Mark shifts appropriately
Improving Simulation Technique

- Policies, procedures and checklists
- Set up training/refreshers—Ensure proper training for everybody, avoid hand offs
- Ensure compliance manufacturers instructions for IDs
- Standardized marking procedures
- Take time to ensure the patient is straight, relaxed and comfortable
- Purchase adequate IDs (type and number) and know where they are and who it belongs to (RFID)
- Ensure consistent/complete/available documentation
Improving Documentation

- Electronic charting
- Documentation protocols
  - Determine what should be documented
  - Create forms
  - Include enough details to avoid losing information at handoff
- Standard language
- Chart QA to check for completeness
- Include pictures
Encourage pictures and make them available at treatment.
Training Examples

- **BodyFix**
  - Even distribution of vacuum
  - No holes
  - No excess clothing
  - Proper placement of cushions

- **Masks**
  - Water bath appropriate temperature
  - Allow adequate time for cooling (opaque)
  - Define nose and chin well
  - Lots of hands in molding
  - Consider claustrophobia, cut eyes if necessary to relax patient
Brain and Ocular

- Minimize movement with respect to mask
  - Head and shoulder mask
  - Bite block
  - Reinforcements
  - Custom head rest
- Reduce voluntary eye movement
  - Suction contact lens
  - Visualization of a light
Head and Neck

- Improve mask making
  - Custom head rest
  - Add shoulders
  - Indexing

- Manage weight loss
  - Dietary intervention
  - Evaluate and replan
Ok but with image guidance as long as we immobilize the target, shouldn’t we should be able to mitigate these uncertainties through image guidance?
Image Guidance
Uncertainty Associated with Image Guidance

Imaging System and Image Quality
- Misalignment of imaging and machine isos
- Poor resolution
- Poor image quality
- Artifacts
- System position accuracy

Image fusion
- DRR image quality
- Differences in modality
- Poor manual fusion technique
- Incorrect autofusion
- Poor soft tissue contrast
- Improper surrogate
- Migration of surrogate
- Artifacts
- Movement between images
- Incorrect reference image
- Incorrect planning image
- Anatomical deformation between images
- Software bugs
### TABLE VI. Imaging

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Application-type tolerance</th>
<th>non-SRS/SBRT</th>
<th>SRS/SBRT</th>
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</thead>
<tbody>
<tr>
<td><strong>Daily</strong></td>
<td></td>
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</tr>
<tr>
<td>Planar kV and MV (EPID) imaging</td>
<td>Functional</td>
<td></td>
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<tr>
<td>Collision interlocks</td>
<td></td>
<td>≤2 mm</td>
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<tr>
<td>Positioning/repositioning</td>
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<tr>
<td>Imaging and treatment coordinate coincidence (single gantry angle)</td>
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<td>≤1 mm</td>
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<tr>
<td>Cone-beam CT (kV and MV)</td>
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<td><strong>Monthly</strong></td>
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<tr>
<td>Planar MV imaging (EPID)</td>
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<tr>
<td>Imaging and treatment coordinate coincidence (four cardinal angles)</td>
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<td>≤1 mm</td>
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<tr>
<td>Scaling</td>
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<td>≤2 mm</td>
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<td>Spatial resolution</td>
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<td>≤2 mm</td>
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<tr>
<td>Contrast</td>
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<td>Baseline</td>
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<tr>
<td>Uniformity and noise</td>
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<td>Baseline</td>
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<td>Cone-beam CT (kV and MV)</td>
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<td>Geometric distortion</td>
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<td>Spatial resolution</td>
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<td>Contrast</td>
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<td>HU constancy</td>
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<td><strong>Annual (A)</strong></td>
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<td>Planar MV imaging (EPID)</td>
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<td>Full range of travel SDD</td>
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<tr>
<td>Planar kV imaging</td>
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<tr>
<td>Beam quality/energy</td>
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<tr>
<td>Imaging dose</td>
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<td>Baseline</td>
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</table>
Imaging and Treatment Coordinate Coincidence

Verify agreement between image and radiation isocenter (line block up to room lasers)
Center of image varies with gantry angle
Diameter of sphere is 2mm. Graticule <2mm away from center
Best to correct in reconstruction if available
OBI – Positioning/Repositioning Test
CBCT – Repositioning Test

Shifts must be <2mm from expected
Ensure Consistent Image Quality
Calibration of Independent Imaging Systems (US, Cameras, etc)

- Many dependent on room lasers
- Must establish relationship between lasers and radiation isocenter
- Daily QA procedure
Novalis TX example: Check Lasers
Point to Machine Isocenter
Define Camera Isocenter
Define X Ray Isocenter
Some Causes of Uncertainties in Image Fusion
#1 Poor visualization of the target
Poor Low Contrast Resolution in CBCT
Image Artifacts
Old Portal Imaging Devices
CBCT User Error
Artifact and Poor Visualization of the Target
Ultrasound....

- Patient size dependent
- Interuser variability
Improving Imaging Techniques

- Setup imaging protocols
- Use image presets with caution
  - Consider size of patient along with the anatomy
  - “Lateral Pelvis” assumes an average size patient
- Training
  - Know how to use the equipment
  - Know how to adjust imaging techniques to get the best image
  - Know when an imaging mistake has occurred
Improve kV Imaging Techniques

Grainy Dark

Increase KV
Brighter/Grainy

Increase KV and mA
Brighter/ Less Grainy

Example provided on www.myvarian.com
Bands of Vertical Stripes

Problem:
- Image is saturated
- X-Ray intensity is too high

Solution:
- Decrease kV

150 kV
3000mAs
Pelvis Lat Technique: 105 kV, 800ms
Grainy Images

- **Problem:**
  - X-Ray intensity is too low

- **Solution:**
  - Increase mAs or kV
  - Increase mAs only if contrast is already good

Head Lat Technique: 70 kV
50ms

Pelvis Lat Technique: 105 kV, 800ms
Improve kV Imaging

- Reduce flaring by adding a bowtie filter
- Collimate to field size

Example provided on www.myvarian.com
Use of Collimation and Filters

Blades Open/No Filter

Dynamic Filter
Avoid Imaging Mistakes

Three consecutive days of imaging

Head with Half Fan

Prostate

Pelvis with Full Fan
Correct and Incorrect Filter – Half Fan
With and Without Filter
Correct and Incorrect Filter – Full Fan
Correct and Incorrect Energy
Quick Scan

- Selects same parameters that were used for the previous CBCT for THAT patient
- Quick Scan (Parameter Display) shows what is being automatically selected
- Ensure that all therapists check scan parameters before scanning
Improving Ultrasound Imaging

- Intact prostate
- Full bladder (aids in image quality, appears dark)
- Empty rectum (appears bright)
- Thin patient (improves image quality and belly stable)
- Relaxed patient (not pushing against the probe)
- Prostate not under the pubis
- Lasers aligned properly (CT/Vault) and daily QA performed
- Constant pace and pressure used by therapists in imaging
- Reduced intrafraction motion (short time between CT and ultrasound at simulation)
Better Visualization of Target
Change Imaging Modalities
#2 Quality of the Reference Image
Improve DRR Quality

- QA to review DRR before treatment
- Small CT slice width
- Good image resolution
- Apply appropriate filter
- Ensure CORRECT DRR if manually imported
Mach Reference and Localization Image Modality

US to US Registration

CT-US Fusion
Match Reference Image Quality
#3 Motion between images that must be analyzed together

Mitigation Strategy: Manage intrafraction motion, reduce time between images
Time delay between images that must be analyzed together

MV/kV pair to localize a liver target
#4 Reliance on Automatic Image Registration Algorithms
Suboptimal Image for Automatic Fusion in SRS

Jaw and neck are not rigid with respect to intracranial targets
Improving Automatic Fusion

- Exclude areas of the image that are not useful
- Manual adjust fusion or position patient as well as possible before fusion
- Reduce region of interest (if possible)
- REVIEW FUSION RESULTS
- Use alternate imaging method
Automatic Fusion to Incorrect Vertebral Body
Investigate Large Shifts

- Be skeptical of large shifts
- Set a threshold for physician intervention
- Use other anatomical features in fusion
- Add an artificial marker on patient
- Ensure scan length is long enough
- Ensure accurate setup prior to imaging
ROI Overlay to Detect Fusion Errors
#5 Manual Image Registration
Manual Registration

- Have physicians clearly indicate where the target is and how to register the images (make a space in the electronic chart)
- Ensure that the scan region is optimal for fusion
- Use appropriate window and level, or presets
- Ensure images are reviewed by a physician
- Notify physicians of target deformations prior to treatment
- Designate a tolerance for physician intervention
- Set up site specific strategies and protocols
- Ensure consistent training of those performing the fusion
Physician Designate Fusion Order

1. Tumor
2. Lens
3. Optic Nerve
4. Calcification
5. Entire Globe

Designate a tolerance for physician intervention
**Santa Cruz Prostate Scanning Protocol**

### Prostate

**Matching Instructions**
1. Begin with grey auto match
2. Zero rotations
3. Manually adjust to match seeds if available. If not, match prostate
4. Double check rectum interface.

**Clipbox**

**Structures to be sent**
- Prostate
- Seminal Vesicles
- PTV
- Markers
- Bladder
- Rectum

**Scanning Presets**
- Prostate only .......... Prostate M10 F1
- Prostate and nodes .... Prostate M15 F1

**Scanning Limits**
- -180 deg – 180 deg

**Frequency**
- Daily for the first 10 fractions, then continue as directed.

Courtesy of Wes Culberson
## Santa Cruz Head Scanning Protocol

### Head

<table>
<thead>
<tr>
<th>Matching Instructions</th>
<th>Structures to be sent</th>
<th>Scanning Presets</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Begin with bone auto match</td>
<td>Target (GTV, CTV, PTV) Spinal cord Brainstem parotids</td>
<td>Head and Neck</td>
</tr>
<tr>
<td>2) Zero rotations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) Manually adjust to line up bony anatomy in the region being treated</td>
<td></td>
<td>Scanning Limits 255 deg – 100 deg</td>
</tr>
<tr>
<td>4) Double check the cord and brainstem match.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Frequency**
- Daily for first five fractions, then continue as directed

**Clipbox**

![CT scan images](image-url)
Notify Physician of Anatomical Changes
#6 Use of Surrogates
Choice of Surrogate

- Use surrogates when cannot see the target but can see something else
- Examples:
  - Boney Landmark
  - Neighboring structure
  - Implanted fiducial
  - Surgical clips
  - Calcification
- Best Features:
  - Visible
  - Rigid wrt target
  - Close to or within target
  - Should not cause excessive artifact
  - Should be identified by physician prior to image fusion

Surgical clips for tumor bed boost
Artifact from Implanted Fiducial
Surrogate Must be Visualized
Surrogate Should Not Migrate

- Time from marker placement to CT important
- Marker matching will not work if markers move
#7 Software Errors

Mitigation Strategy: Know then exist and create proper QA steps to catch them (specific to your systems)
Uncertainty with Image Centering

Patient actually in the correct position but software thinks the patient has not been recentered
Erroneous Shift

Summary: Images (4 New) / Couch Corrections (VAR_IEC scale)

<table>
<thead>
<tr>
<th>Status</th>
<th>CBCT</th>
<th>CBCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vrt [cm]</td>
<td>-0.2</td>
<td></td>
</tr>
<tr>
<td>Lng [cm]</td>
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</tr>
<tr>
<td>Lat [cm]</td>
<td>17.2</td>
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</tr>
<tr>
<td>Pitch [deg]</td>
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</tr>
<tr>
<td>Roll [deg]</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Rtn [deg]</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

FP2 RBREAST  Session Images  Timeline
Errors in Images Presented for Physician Review

Image shifted for first treatment field in software before export. Patient in correct position.
Wrong CT Used for Localization

Field treated 2 cm sup for SRS

Image with a second modality

Exactrac Matches
Studying Interfraction Setup
Uncertainty Internally

- Use image guidance to determine setup error
- Tabulate daily shifts for a large number of patients
- Determine if PTV margins are appropriate
- Determine if image guidance is necessary (and frequency)
- Determine if adaptive replanning strategies should be adopted
Daily imaging for Breast Boosts

- Purpose: To determine if daily image guidance is necessary for patients receiving RapidArc plans for breast boosts
- Shift data collected for the first 20 patients (translations)
- Conclusions:
  - Average shifts are small in all direction (Average 0mm, Range (-8mm-+7mm), SD 3mm)
  - With daily guidance PTV margins are too large
  - Without daily guidance PTV are more than adequate (2SD (6mm) < margin (10mm))
  - Shifts greater for larger patients

Results courtesy of Aleksandra Lazicic, RTT
Tumor Kinetics in Sarcoma Patients

- 10 patients with Myxoid Liposarcoma treated on Tomotherapy
- Shifts data collected for all treatment fractions
- Results
  - Tumors enlarge from simulations to treatment (11-27 days, mean 8%, max 25%)
  - Tumor size stable for two weeks and then decrease steadily for the remaining fractions (36% average, 8%-61% range)
  - Average rate of shrinkage 6cm³/day
  - 4 of 10 patients required replanning
- Conclusions:
  - Myxoid Liposarcoma patients should receive daily image guidance
  - Should be re-assessed for replanning at week 3 of treatment
  - Interval from simulation to treatment should be reduced

Early results courtesy of Dr. Siavosh Vakilian
Tumor Progression: Sim to 1st Fx
Determine Imaging Frequency

IGRT Review Statistical Analysis

| Patient: ID: Physician: Date of Review: 11/12/2010 |
|-----------------------------------|---------|---------|---------|
| Sup (cm)  Lat (cm)  Ant (cm)      |---------|---------|---------|
| 1.1       0.3       0.4       |
| 0.9       0.7       -0.1      |
| 0.4       0.9       0.2       |
| -0.3      -0.8      0.0       |

Average Shifts: 0.5  0.3  0.1

If these values are less than planning margin, consider reducing imaging frequency.

Courtesy of Wes Culberson
Conclusions

• Physicists can play a role in mitigating interfraction setup uncertainty
  • Help to optimize image quality
  • Review simulation procedures
  • Implement electronic charting/forms
  • Use image guidance to study interfraction motion internally

• Imaging does not solve everything
  • Setup precision prior to imaging is still important
  • Sometimes you can’t see and your setup is no more certain with imaging than without
Thank you for your attention!
Anatomical Variation
Uncertainties Due to Anatomical Variations

- Pelvis
  - Bladder/rectal filling
  - Diarrhea
- Abdomen
  - Digestion
  - Respiration
- Thorax and Breast
  - Flaccid/pendulous breasts
  - Atelectasis
- Head and Neck
  - Extreme weight loss
- Brain and Ocular
  - Motion with respect to mask
  - Voluntary motion

- Weight loss
- Obesity

- Disease Progression
- Tumor Response
Reducing Interfraction Pelvis Motion

- Constant bladder filling
  - Drink 2 glasses of water
  - Void before treatment
  - Avoid unexpected wait times
- Empty rectum
- Rectal Balloon
  - Immobilizes prostate
  - Constant rectal volume
- Dietary Intervention
  - No fiber to reduce gas
  - Manage diarrhea
- Body mold
  - Less variation than lying on the table
Reducing Breast Positioning Uncertainty

- Index Breast Board
  - Small to medium breasts
- Body mold
- Tolerable/reproducible arm position
- Prone Position
- Custom bra-type devices or thermoplastic
Reducing Thoracic Motion

- Control respiratory motion AMPLITUDE
  - Gating
  - Vacuum mold (abdominal compression)
- Reproducible arm position
- Body mold (indexing)
- Image to note anatomical changes (atelectasis, pleural edema)
Anatomical Changes Noticed with Image Guidance