Initiation of an IGRT Program

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Acknowledgments

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Initiation of an IGRT Program
• Define the intended goal
• Select Equipment
• Develop clinical protocols
  • Patient Selection
  • Targeting Process
  • QA
• Training
• Effectiveness assessment
  • Accuracy
  • Resource allocation
**Definition of Program Goal**

- Decide what its purpose is (MD guided):
  - On-line pre-treatment setup
  - Intra-treatment monitoring
  - Feeding adaptive treatment protocols
- Choose targeting method (MD/Physics collaboration)
  - Bony anatomy
  - Soft tissue guidance
  - Fiducials
- These items guide equipment selection

**Resources for Equipment Selection**

- ASTRO White Paper: Assuring Quality and Safety in Image-guided Radiation Therapy *To be published in PRO.*
- AAPM TG-58: Clinical Use of Electronic Portal Imaging
- AAPM TG-104: The Role of In-Room kV X-Ray Imaging for Patient Setup and Target Localization
- AAPM TG-179 In-room CT Localization
- AAPM TG-147 Non-radiographic Localization

**IGRT Systems: Ideal Properties**

- Accurate, precise
  - Explicit interpretation, minimal training, operator independent
- Efficient, integrated
  - Rapid
  - Integrated with machine for remote intervention
- Broad/Universal application
  - Large number of anatomical sites
  - Large field of view
- Reduce radiation dose
  - Non ionizing, or efficient detectors.
  - Account for imaging dose?
- Real-time
  - Continuous monitoring
- Images for planning & evaluation
Clinical Example: IGRT for Protons

- Goals:
  - Pre-Tx online setup guidance
  - Intra-Tx monitoring
  - Adaptive planning feedback

- Clinical priorities
  - Quick and efficient
  - Low dose

Clinical Example: IGRT for Protons

- Treatment Sites (MD defined)
  - Head and neck
    - Bony Anatomy is a good surrogate
  - CNS: Brain and Craniospinal Axis
    - Bony Anatomy
  - Pelvis: Prostate and Gyn
    - Bony Anatomy not great
  - Lung
    - Want CT localization

Fixed Radiographic System

- Fast image acquisition and analysis
- Fast Intra-Tx imaging at any gantry/couch position
- Fluoroscopy capable
- Low dose
- Large FOV
CT Localization for Protons: Pelvis

- Change in position of bony anatomy alters dose distribution
- CT localization may be of limited use

CT Localization for Protons: Lung

- Change in position of rib causes minimal disturbance of dose distribution
- We want CT localization
  - Scanning beam treatments – always gated
  - Need respiratory correlated CT
  - Need reliable HU for adaptive planning

CT on Rails

- 4DCT capable for guidance of gated treatment
- Fast acquisition for single breath hold imaging
- Reliable CT numbers for adaptive planning
Developing Clinical Protocols

• Multi-disciplinary team
  • Physicians
  • Physicists
  • Therapists
  • Dosimetrists
• Excellent guidance in ASTRO IGRT White Paper

Issues for IGRT Protocols

• Imaging Parameters
  • Image Quality vs. Dose
  • Reference Images
• Targeting Process
  • Manual or Automatic Match
  • Anatomy for Matching
  • Regions of Interest
• Documentation!!
• QA
  • End to end tests

Imaging Parameters

• Imaging dose, if not managed properly, can be substantial
• Many times a low dose ‘good’ image works as well as a high dose ‘great’ image
• For guidance:
  • AAPM TG-75: The management of imaging dose during image-guided radiotherapy
  • Consider X-ray Technique: kVp, mAs
  • Consider Imaging Volume
Optimizing Reference Images

Inter-vertebral spaces visible in high resolution reconstruction
Crucial for alignment of head and neck treatment

Depth Control used to accentuate critical features

Target Identification in Reference Images

Post Prostatectomy Surgical Clips
Target Identification in Reference Images

- Clips are contoured in CT scan and projected in DRR
  - Red for clips within PTV
  - Blue for clips outside PTV

- Color coding tells therapists which clips to match with, which to ignore

Targeting Process

- Patients are not rigid bodies
- Lots of prominent anatomy that is not correlated with target tissue
- Physicians must describe the target and correlated anatomy
- Therapists should weigh in on the matching process
  - What’s visible
  - Difficulty
Targeting Process: Automated Algorithms

- Increasing application of automated matching algorithms
- Patients are not rigid bodies
- Lots of prominent anatomy that is not correlated with target tissue
Automated 6DOF Matching

- Masking of non-pertinent anatomy is critical for successful implementation

Documentation

- Therapists should have easy access to instructions for every case
  - Imaging protocol
  - Matching instructions
  - Adjustment thresholds
  - Adjustment limits
  - Re-imaging/Consult thresholds
  - Contingency plans
  - Language
- Greatly reduces therapist stress levels
- Happy therapists are effective therapists

OBI Instruction Sheet

- Document which anatomical feature is to be matched
- Contingency plan if imager is not available
- Request to be present for 1st day
- Therapists know exactly what to do
Protocols: Language Standardization

• Everyone must agree on a common language for IGRT analysis/adjustment
• What does “shift left 4 mm” mean?
• Critical that Physicians, Physicists, Dosimetrists, and Therapists all speak the same language

QA

• A single IGRT protocol may have many independent parts
  • Simulation hardware
  • Treatment planning software
  • IGRT imagers
  • Image analysis software
• Each must be monitored independently to verify proper performance

QA Guidance

• AAPM TG-142: Quality Assurance of Medical Accelerators
• AAPM TG-58: Clinical Use of EPID
• AAPM TG-104: The Role of In-Room kV X-Ray Imaging for Patient Setup and Target Localization
• Many other reports coming
• Manufacturer literature
• Acceptance documents
**End-to-End Test**

- Simulation, planning, setup, and treatment of a phantom
- Done exactly as a patient would be
- Tests individual components, but also how they interact
- Critical for complex, multi-vendor processes

**End To End Example**

- We have used up to four software vendors in the planning/IGRT process
  - Virtual Sim
  - Treatment Planning
  - ROIS
  - IGRT
- Some manufacturers may make assumptions about data coming from other sources that could lead to errors
- Location of CAX, for example.

**QA: “Sanity checks”**

- Couch Coordinate Predictions
- Maximum Shift Protocols
- Oversight with another technology (EPID – free imaging)
**Couch Coordinate Prediction**

- 1 straight, 1 angled wire in sim couch top can be digitized in treatment planning

**Couch Coordinate Prediction**

- Patients are indexed to couch top – if coordinates are much different from prediction there may be a problem

**IGRT “Oversight” with EPID**

- Nearly all linacs have an MV EPID
- Lower image quality than OBI/ExacTrac, but can image with the treatment beam with no additional dose to patient
- Imaging along treatment direction, with treatment source
- Verify shifts from radiographic setups, provide sanity checks for CBCT shifts
- Monitor intra-fractional motion
- See TG-58
Training

- Consider developing therapist/physicist experts or ‘protocol champions’ for a given technique
- Disseminate information to rest of clinic through them
  - Justification
  - Goals
  - Processes

Training: Justification for Extra Work

- Distended rectum during sim leads to systematic displacement of prostate during treatment (de Crevoisier, IJROBP 2005)

Repeated With IGRT

- Kupelian et al., Red Journal 70, 2008
- Understanding leads to better enthusiasm and effectiveness
Effectiveness Assessment

- Are we achieving what we hoped to do?
- Are we matching limited resources to the correct patients?
- These questions can guide future directions in the clinic
  - Great topics for in-service seminars; continued enthusiasm
  - Peer-review of our work

Prostate with Gold Seeds

- Mean 3D Initial Translation = 5.6 mm
- Mean 3D Final Translation = 2.8 mm
- 54% of Fx Adjusted

Herman IJROBP 2003

OBI Impact on Patients
Planar kV Image Analysis

- 55 patients, 4 groups: head and neck (7), abdomen (12), pelvis (20) and lung (6)
- Extract patient setup information
- Analyze data in terms of:
  - Amplitude and frequency of shifts
  - random and systematic errors
- Try to identify patient population who benefits most
Available Data from OBI patients

Treatment flow:
- Patient set up with lasers
- Pre-shift kV images acquired laser alignment
- Match kV images to DRRs
- Shift applied (no threshold)
- Post-shift kV images recorded kV alignment

Post treatment data analysis

Amplitude of 3D Shifts & Offsets

Head and Neck
- Laser: applied shift
- OBI: residual offset between post kV image and DRR

Laser: 5.1 ± 1.2 mm
OBI: 1.3 ± 0.4 mm

Shifts and Offsets for All Sites

Head and Neck
- Laser: applied shift
- OBI: residual offset between post kV image and DRR

Laser: 5.1 ± 1.2 mm
OBI: 1.3 ± 0.4 mm
**Systematic Error (Σ_{group}) Reduction**

Factor 6 reduction in Σ_{group}

**Random Error (σ_{group}) Reduction**

Factor 3 reduction in σ_{group}

**Inter-system Consistency Checks/Accuracy Comparisons**

- CBCT is our preferred localization technique for SBRT lung pts.
- How much better than OBI localization
  - Bony anatomy localization
  - Soft tissue visualization
OBI/CBCT Comparison

• Acquire CBCT, localize patient based on visualization of tumor
• Acquire OBI images post-shift
• Compare:
  * CBCT soft-tissue localization to OBI bony alignment
  * CBCT bony anatomy localization to OBI bony alignment

CBCT-OBI Bony Alignment

• Usually comparable, with a few exceptions
• Occasional ~cm differences between CBCT and OBI
  * Intra-treatment patient motion?
  * Technological problems?
  * User error?

Sub-Optimal OBI Implementation
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Sub-Optimal OBI Implementation

Technology Inter-comparison

• Justified clinical application of higher dose, higher workload technology for a certain application (Lung SBRT)
• Illustrated shortcomings in our process for training, documentation, and continuing education
Summary

- Effective IGRT requires a multi-disciplinary approach
- Substantial potential for patient harm if things are done badly, but incredible potential for great things when well crafted protocols are expertly executed
- Thanks

Which strategy is most likely to lead to uniform, clinically efficacious image guidance of head and neck treatments?

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>1. Documentation of physician instructions for anatomy matching</td>
</tr>
<tr>
<td>21%</td>
<td>2. Automated mutual information matching algorithms</td>
</tr>
<tr>
<td>20%</td>
<td>3. Extended treatment schedule slots that allow more time for imaging and analysis</td>
</tr>
<tr>
<td>21%</td>
<td>4. Manual matching algorithms based on chamfer matching</td>
</tr>
<tr>
<td>19%</td>
<td>5. Six degree of freedom robotic couch tops</td>
</tr>
</tbody>
</table>

Answer:

- Documentation of physician instructions for anatomy matching
- Reference: IGRT QA Whitepaper, Jaffray et al., to be published in PRO
Which patient trait at time of simulation was found by de Crevoisier et al. to correlate with higher rate of biochemical failure after external beam therapy for prostate cancer?

- Body mass index (BMI) (21%)
- Prostate volume (21%)
- Cross-sectional area of rectum (18%)
- Respiratory period (19%)
- Bladder volume (21%)

Answer:

- Cross-sectional area of rectum

Which of the following QA strategies would most likely detect a problem arising from differing image interpretation by two commercial elements of an IGRT process?

- Analysis of DICOM image headers (20%)
- Check-sum analysis before and after image transfer (21%)
- End-to-end test of the IGRT process (19%)
- Careful study of each product’s user manual (21%)
- Pre-treatment chart review of each patient’s imaging parameters (19%)
Answer:

- End-to-end test of the IGRT process

A primary advantage of Ceiling/Floor mounted planar kV imaging systems is:

- 18% 1. Tomographic imaging capabilities
- 21% 2. Rapid acquisition of dual radiographs
- 21% 3. Large field of view
- 22% 4. Easy interpretation of oblique patient views
- 19% 5. Coincident imaging/therapy x-ray sources

Answer:

- Rapid acquisition of dual radiographs
Which equipment could be used to monitor intra-fractional patient motion without administering any imaging dose?

- **22%** 1. Cone-beam CT
- **20%** 2. EPID
- **19%** 3. 4DCT on rails
- **19%** 4. BAT Ultrasound
- **20%** 5. Stereoscopic x-ray tubes

Answer:

- EPID

Which treatment scenario best justifies the increased dose associated with intra-fractional CBCT imaging?

- **20%** 1. Prostate IMRT with gold markers
- **18%** 2. Lung
- **21%** 3. Head and neck
- **19%** 4. SBRT spine
- **22%** 5. Breast
Answer:

- SBRT Spine