IGRT; Implications for Quality Assurance

Luis Fong, Ph.D.
Image-Guided Radiation Therapy (IGRT) concept

RT Process + IGRT

Advantages:

- IGRT FB loop
- Target Localization Technologies
- Plan Validation
- Monitoring Treatment
- Evaluation & Verification
- Treatment Delivery
- Corrective Intervention

Prescription
Setup & Immobilization
Image Acquisition
Treatment Planning & Evaluation
Information Transfer & Management

- IGRT Advantages:
Target Localization Technologies (TLT)

- Ultrasound
- kV Radiographic
- Portal Imaging
- Markers (Active & Passive)

- Siemens PRIMATOM™
- TomoTherapy Hi-Art™
- Elekta Synergy™
- Varian OBI™

- kV CT
- MV CT
- kV and MV Cone-beam CT

Courtesy of Michael Sharpe, Ph.D. Princess Margaret Hospital, Toronto, CANADA
IGRT implementation process

- Decided that it is time for IGRT
- Shop around
- Purchase the technology
- Acceptance tests
- Clinical Commissioning

- Develop QA periodic tests:
  - Daily
  - Weekly
  - Monthly
  - Annual

- Provide proper training
- Ready to Go...
IGRT Feedback Loop

- Prescription
- Setup & Immobilization
- Imaging Acquisition
- Treatment Planning & Evaluation
- Information Transfer & Management
- Corrective Intervention
- Plan Validation
- Evaluation & Verification
- Monitoring Treatment
- Treatment Delivery

IGRT FB loop
Clinical Implementation of ANY New Technology

• Define clinical Questions **BEFORE** You Start!

• **Do your homework:**
  – Understand the IGRT solution: the clinical and technological limitations, the implementation process and the clinical advantages of the particular technology (papers, research, meetings, conferences, workshops, etc.)

• Understand how well the IGRT solution answers the clinical question you want to address.

• Understand how well the IGRT solution fits into the processes and infrastructure of your clinic.

• Get What **you Need and also better fits your Processes!**
Other Implications of new IGRT solutions

- Computing, networks, data storage
- Workload & workflow
  - Planning, Imaging, Treatment time
- Risk/Benefit:
  - Imaging dose to untreated anatomy
  - Geometric miss
- Backup system in case of IGRT solution failure
- Inter-discipline collaboration
  - shifting from traditional roles
- Decision making
  - Professional autonomy, scope of practice
- Training & Education
  - Adoption
  - Practice guidelines, communication and adaptation
  - Organizational learning
IGRT implementation process

- Decided that it is time for IGRT
- Shop around
- Purchase the technology
- Acceptance testing
- Clinical Commissioning
- Develop QA periodic tests:
  - Daily
  - Weekly
  - Monthly
  - Annually
- Provide proper training
- Ready to Go...

There are no specific QA guidelines for all the new technologies
Example of Clinical Implementation of IGRT Solutions

Clinical use of electronic portal imaging: Report of AAPM Radiation Therapy Committee Task Group 58

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(Received 19 January 2001; accepted for publication 1 March 2001)
Definition of the Clinical Application

• The primary applications of EPID include:
  – Verification of patient setup
  – Assessment of target and organ motion.
  – Daily localization for prostate cancer patients

• Current research includes use of EPIDs:
  – for compensator design and verification,
  – treatment machine QA
  – patient dosimetry
Understanding the technology behind the solution

Software Tools:
- Image Acquisition Control
- Image Enhancement
- Image Analysis
- Image Review
- Matching

Converter
Detector
Data Acquisition
Data Conversion
Imager Controller

Beam

Image Storage
Connectivity with other systems

Image Acquisition Control
Image Enhancement
Image Analysis
Image Review
Matching
Understand the Clinical Application of the IGRT solution

EPID for Treatment of Prostate Cancer

Bony Anatomy Vs. Fiducial Markers

**PROSTATE POSITION RELATIVE TO PELVIC BONY ANATOMY BASED ON INTRAPROSTATIC GOLD MARKERS AND ELECTRONIC PORTAL IMAGING**

**John M. Schallenkamp, M.D., Michael G. Herman, Ph.D., Jon J. Kruse, Ph.D., and Thomas M. Pisansky, M.D.**

Division of Radiation Oncology, Mayo Clinic College of Medicine, Rochester, MN


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Effect of Correction: 3D - Target vs. Bones

- **Target** \( p < 0.001 \)
- **Bones** \( p = 0.46 \)

**Target Better**

**Bones No change**
Effect of Correction: Sup-Inf Component

Fiducial Markers Vs. Bony anatomy

Target better $p<0.001$

Bones worse $p<0.001$
## Impact on Margins

Table 4. One-dimensional PTV margin expansions (in millimeters) relative to pretherapy and postcorrection to the target (prostate)

<table>
<thead>
<tr>
<th></th>
<th>Before on-line correction per prostate</th>
<th>After on-line correction per prostate</th>
</tr>
</thead>
<tbody>
<tr>
<td>SI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Sigma$</td>
<td>1.9</td>
<td>0.8</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>2.0</td>
<td>1.6</td>
</tr>
<tr>
<td>Margin</td>
<td>5.1</td>
<td>2.7</td>
</tr>
<tr>
<td>AP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Sigma$</td>
<td>2.5</td>
<td>0.7</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>3.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Margin</td>
<td>7.3</td>
<td>2.9</td>
</tr>
<tr>
<td>RL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Sigma$</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>1.6</td>
<td>1.3</td>
</tr>
<tr>
<td>Margin</td>
<td>5.0</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Expansions are calculated such that the clinical target volume is covered with 95% of the prescribed dose in 95% of the population.

*Abbreviations:* PTV = planning target volume; SI = superior–inferior; AP = anterior–posterior; RL = right–left.

Using formulation proposed by Van Herk IJROBP 2002
Understanding and Testing the IGRT Tool

Detected Field Edge

Reference Field Edge

Anatomy Matching

Difference

IGRT; Implications for QA

SW-AAPM-FMOFM Meeting 2007
# Shift Calculation Spreadsheet

## Analysis of Initial Prostate Alignment: Anterior and Right Lateral Ports

<table>
<thead>
<tr>
<th>Couch Location Before Porting</th>
<th>Couch Vert</th>
<th>10.5 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Couch Long</td>
<td>149.6 cm</td>
<td></td>
</tr>
<tr>
<td>Couch Lat.</td>
<td>998.1 cm</td>
<td></td>
</tr>
</tbody>
</table>

## On-line Correction of Prostate Alignment

<table>
<thead>
<tr>
<th>Move Couch Here to Treat All Four Fields</th>
<th>Couch Vert.</th>
<th>9.9 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Couch Long.</td>
<td>149.8 cm</td>
<td></td>
</tr>
<tr>
<td>Couch Lat.</td>
<td>998.1 cm</td>
<td></td>
</tr>
</tbody>
</table>

## Shift Calculation Spreadsheet

<table>
<thead>
<tr>
<th>Enter Image Mismatch from Anterior Port: Beam Axis Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lat</td>
</tr>
<tr>
<td>Long</td>
</tr>
<tr>
<td>Rot</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Enter Image Mismatch from Right Lat Port: Beam Axis Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lat</td>
</tr>
<tr>
<td>Long</td>
</tr>
<tr>
<td>Rot</td>
</tr>
</tbody>
</table>

## Portal Analysis: Translational Errors

- Sup-Inf Axis: CAK is shifted Sup 0.2 cm
- Left-Right Axis: CAK is shifted Left 0.1 cm
- Ant-Post Axis: CAK is shifted Ant 0.6 cm

## Portal Analysis: Rotational Errors

- Ant-Post Axis: Superior Prostate is Rotated Right 0.2 deg
- Left-Right Axis: Superior Prostate is Rotated Post 1.0 deg

## 3-D Portal Analysis: Displacement Vector Length

Initial Prostate Position Misaligned by 0.62 cm

## On-line Correction of Prostate Alignment

<table>
<thead>
<tr>
<th>Use These Collimator Settings to Correct Rotational Errors</th>
<th>Anterior</th>
<th>Posterior</th>
<th>Right Lat</th>
<th>Left Lat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- deg.</td>
<td>- deg.</td>
<td>- deg.</td>
<td>- deg.</td>
</tr>
</tbody>
</table>

## Date: 6/25/2003

<table>
<thead>
<tr>
<th>Tolerances</th>
<th>3D (cm)</th>
<th>Rot (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient: John Doe</td>
<td>0.5</td>
<td>3</td>
</tr>
</tbody>
</table>

## Export Data and Reset

| Fraction number | 4 |

## Comment

Pt shifted.
Shift Calculation and Assessment

**Pre-port Ant Field**

**Pre-port Right Lat Field**
Patient data base
Implementation of IGRT solution in the Clinic
Process Flow

Gold seeds implanted in the patient → Simulation → Tx Planning: Localization fields are part of Tx Contour seeds and bonny anatomy

Information transfer from TPS to:

Matching Software (Portal-Vision™) → Images Acquired (Localization Fields) → Patient Setup → Monitoring Tx → Patient Tx

Corrective Intervention

R & V System (Multi-Access™)
IGRT Feedback Loop

1. Patient Setup
2. ANT & RT LAT Pre-Tx
3. Matching (Portal-Vision™)
   - Excel spreadsheet Data entree and Calc
   - If 3D > 4mm
     - Yes: Apply shift
     - No: Patient Tx
4. Images during Tx (Two Fields)
5. Physicist reviews shifts (After 5 Tx’s)
   - If Systematic Shift
     - Yes: Recommends Systematic shift
     - No: If 3D > 4mm
6. Matching (Portal-Vision™)
7. Physician reviews & Approves
Gold seeds implanted in the patient → Simulation → Tx Planning: Localization fields are part of Tx Contour seeds and bonny anatomy → Information transfer from TPS to:


Corrective Intervention → Monitoring Tx → Patient Tx

Matching (Portal-Vision™) → Images Acquired (Localization Fields) → Patient Setup → R & V System (Multi-Access™)

Images during Tx (Two Fields) → Patient Tx → Matching (Portal-Vision™)

If Systematic Shift

Physician reviews shifts (After 5 Tx’s) → Yes

Recommends Systematic shift → Excel spreadsheet Data entry and Calc

If 3D > 4mm

Yes

Apply shift → Images during Tx (Two Fields) → Matching (Portal-Vision™)

No

Patient Tx → Physician reviews & Approves

Successful IGRT QA program
General QA points for EPID imager

- **Safety**
  - Arm and imager collision interlock (Monthly)

- **Mechanical Functionality**
  - Arm and imager position (Monthly)

- **Image quality**
  - Calibration (Monthly)
  - Noise (Daily & Monthly)
  - Contrast (Daily & Monthly)

- **Data Transfer**
New Technologies or Technology Upgrades
**MV Image**

- 6 MV
- 6 MU
- 400 MU/min

**kV Image**

- 75 kV
- 80 mA
- 40 ms

---

**COOK™ Coils (Platinum)**

- 0.89 mm
- 0.46 mm

**VisiCoils™ (Gold)**

- 1.15 mm
- 0.75 mm
- 0.35 mm

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IGRT; Implications for QA
Investigate how the new technology fits into our processes and infrastructure
Guideline for QA MV, kV & CB-CT

A quality assurance program for the on-board imager®

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Med. Phys. 33 (11), November 2006
Preparing for 4D IGRT
4D CT & Phase Sorting

- Use time-stamps to correlate:
  - Surrogate Phase
  - Image Phase

- GE Lightspeed™ scanner
- Varian RPM™ respiration management system

Courtesy of Yildirim Mutaf Ph.D.
Improving Temporal Accuracy

• Quality of 4D imaging relies on **accurate** association of the surrogate motion with the target
  – Accurate respiration determination / surrogate information
  – Temporal Accuracy → Spatial Accuracy

• In order to test the validity of the calculations performed by the commercial system, an in-house phase-calculation software was developed
  – Uses the raw data for the amplitude of the surrogate displacement
**PhaseCalc-ulation Software**

- User-friendly interface
- Receives the raw data for the displacement record of the surrogate marker
- Performs an **independent calculation** for the phase of the motion
- Compares the independent result to vendor calculation
- Lists the deviations as a list of slice locations for easier interpretation

Courtesy of Yildirim Mutaf Ph.D.
Example Case

- A valid respiration peak was missed with the commercial software causing sub-optimal phase assignments to be used during image sorting...

  ![Phase Comparisons graph](graph.png)

- Deviations are observed for about 45% of the clinical 4DCT cases
  - As large as 4-5 missing peaks are also observed...
- Similar observations are reported by other investigators

Courtesy of Yildirim Mutaf Ph.D.
Modified Phase Assignments

Original Phase Assignments

Pixel Difference Image

Courtesy of Yildirim Mutaf Ph.D.
Comparing new IGRT solutions with what you already know

- EPID + Fiducial Markers
- New Immobilization Devices
- 2D kV Imaging
- Gating
- Ultrasound
COMPARISON OF DAILY MEGAVOLTAGE ELECTRONIC PORTAL IMAGING OR KILOVOLTAGE IMAGING WITH MARKER SEEDS TO ULTRASOUND IMAGING OR SKIN MARKS FOR PROSTATE LOCALIZATION AND TREATMENT POSITIONING IN PATIENTS WITH PROSTATE CANCER

Christopher F. Serago, Ph.D.,* Steven J. Buskirk, M.D.,* Todd C. Igel, M.D.,† Ashley A. Gale, M.S.,* Nicole E. Serago, M.E.,* and John D. Earle, M.D.*

Departments of *Radiation Oncology and †Urology, Mayo Clinic, Jacksonville, FL

Table: Group I: averages for all patients Limited immobilization

<table>
<thead>
<tr>
<th>Item</th>
<th>Absolute Value Differences (mm)</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item A</td>
<td>EPI vs. skin/lasers</td>
<td>VERT</td>
</tr>
<tr>
<td>Item B</td>
<td>EPI vs. Exactrac skin infrared</td>
<td>VERT</td>
</tr>
<tr>
<td>Item C</td>
<td>EPI vs. BAT ultrasound</td>
<td>VERT</td>
</tr>
<tr>
<td>Item D</td>
<td>EPI vs. Exactrac kV imaging</td>
<td>VERT</td>
</tr>
<tr>
<td>Item E</td>
<td>EPI before vs. EPI after Rx (intrafraction movement)</td>
<td>VERT</td>
</tr>
</tbody>
</table>

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IGRT; Implications for QA

MAYO CLINIC
Radiation Oncology

SW-AAPM-FMOFM Meeting 2007
A technique for respiratory-gated radiotherapy treatment verification with an EPID in cine mode

Ross I Berbeco, Toni Neicu, Eike Rietzel, George T Y Chen and Steve B Jiang

Department of Radiation Oncology, Massachusetts General Hospital and Harvard Medical School, Boston, MA, USA


The residual motion considered in the planning process was around 5 mm

Table 2. The 95% range of residual motion over the entire course of treatment.

<table>
<thead>
<tr>
<th>Field</th>
<th>95% Range (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.5</td>
</tr>
<tr>
<td>2</td>
<td>4.5</td>
</tr>
<tr>
<td>3</td>
<td>4.5</td>
</tr>
<tr>
<td>4</td>
<td>5.3</td>
</tr>
<tr>
<td>5</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Figure 1. (a) An in-treatment gated verification image acquired with the EPID. The three gold seeds are circled in yellow. (b) A DRR of the same field, derived from the planning CT. The seed locations, GTV and PTV can be seen as contours.
Conclusion

• Define the clinical application.
• Create a team representing the different areas of the department, that will use and manage the IGRT solution.
• Take some time to understand the IGRT solution.
• Look for the IGRT solution that addresses your clinical need.
• Understand how well the IGRT solution fits into the processes and infrastructure of your clinic.
• Get What you Need.
• Test, Test, Test…
• Develop a comprehensive QA program that fits your processes.
Contributions

- Michael Herman, Ph.D., Mayo Clinic, Rochester, MN
- Jon Kruse, Ph.D., Mayo Clinic, Rochester, MN
- Yildirim Mutaf, Ph.D., Mayo Clinic, Rochester, MN
- Michael Sharpe, Ph.D., Princess Margaret Hospital, Toronto, CA
Some Useful References

Thanks!

Ready for some questions?