Dosimetry Metrology for IMRT
Part I
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Outline

• Challenges of IMRT dosimetry
• Detectors
  – 1-D (point) detectors
  – 2-D
• Phantoms
  – Geometric
  – Anthropomorphic

Challenges of IMRT Dosimetry

• Importance of penumbral and peripheral field dose
• Complexity of the dose distribution
  – Numerous steep dose gradient regions, even within the target volume
• Dynamic dose delivery
  – Fluence shape and intensity vary during tx
  – Scan-based dose measurements impractical
  – IMRT limited to integrating dosimetric techniques

TG120 Recommendations

• QA should concentrate on cumulative delivered dose rather than only individual segments
• Verify dose at multiple locations
• Verify absolute position of the dose gradients
Detector Characteristics

- Stability
- Linearity of response
- Directional dependence
- Beam-quality dependence
- Absolute vs. relative
- Size
- Immediacy of results
- Stem and cable effects
- Cost and convenience

Point Detectors

- Small-volume ion chambers
- Diodes
  - Silicon
  - Diamond
- TLDs
- MOSFETs

Small-Volume Ion Chambers

Advantages
- Stability
- Linear dose response
- Small directional dependence
- Energy independence
- NIST-traceable calibration

Disadvantages
- Volume averaging
- Energy response dependence if central electrode of high Z material.
- Stem effect

Use for
- Absolute dose measurements

Do not use for
- Penumbra of profiles used for modeling
- Inter- and intra-leaf measurements

Guidelines
- If high-Z electrode, cross-calibrate under similar conditions
- Dose heterogeneity < 5-10% across chamber
- For comparisons, calculate average dose throughout active volume
### Silicon Diodes

- **Advantages**
  - Very small active volume (smaller than IC)
  - High sensitivity

- **Disadvantages**
  - Over-responsive to low-energy photons
  - Some energy dependence
  - Dose-rate dependent
  - Angular dependence for non-normal incidence
  - Change in sensitivity over time due to radiation damage

### Diamond Detectors

- **Advantages**
  - Very small active volume
  - High radiation sensitivity
  - Nearly tissue equivalent, though much more dense
  - Small directional dependence
  - High radiation hardness

- **Disadvantages**
  - May be dose-rate dependence
  - Expensive

### Diodes

- **Use for**
  - Relative dose measurements
  - Regions of high dose gradient

- **Do not use for**
  - Peripheral region of profiles used for modeling

- **Guidelines**
  - Use unshielded silicon diode detectors
  - Don't use in-vivo diodes for phantom meas.
  - Monitor detector sensitivity
  - Consider/monitor orientation of diode to beam
  - Pre-irradiate diamond detectors to ~5 Gy

### TLDs

- **Advantages**
  - Small size
  - Nearly tissue equivalent, density closer to tissue (LiF)
  - No cable

- **Disadvantages**
  - Nonlinear dose response
  - Some energy dependence
  - Labor-intensive
  - Delayed readout
### TLDs

- **Use for**
  - Geometry which does not allow ion chambers
  - Multiple point measurements
- **Do not use for**
  - Absolute measurements needing precision <3%
- **Guidelines**
  - Use low-atomic number TLDs, e.g. LiF
  - Establish and follow strict handling, annealing, and calibration protocols
  - Use an automatic TLD reader

### MOSFETs

- **Advantages**
  - Very small size
  - Linear dose response
  - Small directional dependence
  - Immediate readout
- **Disadvantages**
  - Not tissue equivalent
  - Some energy dependence
  - Limited lifetime
  - Change in sensitivity over time due to radiation damage

### MOSFETs

- **Use for**
  - Geometry which does not allow ion chambers
  - Multiple point measurements
  - Situations needing real-time readout
- **Do not use for**
  - Absolute measurements needing precision <3%
- **Guidelines**
  - Monitor detector sensitivity
  - Monitor total lifetime exposure

### 2-D Detectors

- **Film**
  - Radiographic
  - Radiographic
- **Array detectors**
  - Diodes
  - Ion chambers
Radiographic Film

- Advantages
  - High spatial resolution
  - Relatively inexpensive
- Disadvantages
  - Light sensitive
  - Oversensitive to low-energy photons
  - Dependence on film batch, processor conditions, digitizer
  - Need to measure response curve for each measurement session

- Use for
  - Relative planar dose measurements
  - Penumbra of profiles used for modeling
  - Relative output factors for small fields
- Do not use for
  - Absolute measurements
- Guidelines
  - Choose a film with appropriate speed (EDR2)
  - Measure response curve for every experiment
  - Follow recommendations of TG69 (Med Phys 34, 2228-2258; 2007)

Radiochromic Film

- Advantages
  - High spatial resolution
  - Does not require processing
  - Not sensitive to indoor light
  - Nearly tissue-equivalent
  - Decreased sensitivity to low-energy photons
- Disadvantages
  - Low OD at clinical doses
  - Susceptible to scanner artifacts
  - Post-irradiation coloration

- Scanner non-uniformity
- Orientation dependence
Radiochromic Film

**OD change after exposure**

Zeidan et al., Med Phys 33:4064-72;2006

Cheung et al., PMB 50:N281-5;2005

- Use for:
  - Relative planar dose measurements
  - Penumbra of profiles used for modeling
  - Relative output factors for small fields
- Do not use for:
  - Absolute measurements
- Guidelines:
  - Characterize scanner response and establish consistent scanning protocol
  - Wait ≥2 hour after irradiation before scanning
  - Measure response curve for every experiment

2D Arrays

- **Advantages**
  - Immediate readout
  - Absolute or relative dose
  - Ease of use
- **Disadvantages**
  - Lower spatial resolution
    - (detector spacing ≥0.7 cm)
  - Limited active area
  - Require normal incidence beam delivery
  - Do not give “true” composite results

2D Arrays – Diode vs. Ion Chamber

<table>
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<th></th>
<th>2%³ cm²</th>
<th>2%² cm²</th>
<th>3%³ cm²</th>
<th>3%² cm²</th>
<th>3%³ cm²</th>
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<td><strong>MeV Field A</strong></td>
<td>97.5%</td>
<td>94.9%</td>
<td>96.1%</td>
<td>98.4%</td>
<td>96.9%</td>
<td>94.9%</td>
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<tr>
<td><strong>MeV Field B</strong></td>
<td>91.9%</td>
<td>97.2%</td>
<td>94.6%</td>
<td>98.8%</td>
<td>95.1%</td>
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<tr>
<td><strong>MeV Field C</strong></td>
<td>99.9%</td>
<td>97.8%</td>
<td>97.8%</td>
<td>97.2%</td>
<td>99.4%</td>
<td>97.8%</td>
</tr>
<tr>
<td>Average (3 MeV)</td>
<td>97.4%</td>
<td>96.7%</td>
<td>96.2%</td>
<td>98.4%</td>
<td>96.6%</td>
<td>96.4%</td>
</tr>
</tbody>
</table>

Li et al., JACMP 10:62-74;2009
2D Arrays

- Use for
  - Relative and absolute planar dose measurements
  - linac and patient-specific QA
- Do not use for
  - initial commissioning
- Guidelines
  - Evaluate array calibration stability before use
  - Pass/fail criteria must take spatial resolution into account

Phantom Characteristics

- Material
  - Water-equivalent or known electron-density
- Homogenous or heterogeneous
- Geometric or anthropomorphic
- Allowable detectors
- Flexibility in detector positioning
- Fiducials for setup accuracy and reproducibility
- Light tight, internally opaque for radiographic film
- CT characterization

Water Tank

- Allows great flexibility in detector position
- Can accommodate variety of detectors
  - Must be water-proof or have water-proof sleeves
- Restricted to gantry oriented straight down (0°)
- Use for
  - Initial commissioning
    - Depth dose, profiles, output factors
    - Beam assessment
      - Flatness/symmetry

Slab Phantoms

- Water-equivalent plastic
- Can include heterogeneities
- Custom cutouts for IC or other detectors
- Limited flexibility in detector position
- Allow film
- May be scribed with lines for setup accuracy
- Use for single or composite beams
- Ease of use
**Slab Phantoms**
- Gammex 473 Planar Phantom
- CIRS Cube Phantom
- Standard Imaging ACE IMRT Phantom
- PTW IMRT Body Phantom

**Cylindrical Phantoms**
- Same properties as slab phantoms but usually not as flexible in detector/film position
- Convenient geometry for composite beams – more “realistic” than slab phantom

**Cylindrical Phantoms**
- Modus Medical QUASAR verification phantom
- PTW Verification H&N Phantom
- Tomotherapy “Cheese” Phantom

**Anthropomorphic Phantoms**
- Useful for assessing overall IMRT planning and delivery process
  - Better simulation of human setup and irradiation
- Limited flexibility in detector and film placement
- More difficult to set up accurately
- Difficult to determine causes of dose distribution discrepancies
  - May require additional measurements in simpler geometric phantoms
Anthropomorphic Phantoms

CIRS IMRT Thorax Phantom

Standard Imaging Dose Verification Phantom

Summary

- Main challenges for IMRT dosimetry are
  - small fields
  - complex dose distributions with steep gradients
  - dynamic dose delivery
- No one detector or detector system is adequate for all IMRT commissioning and QA
- No one phantom is adequate for all IMRT commissioning and QA
- Select the appropriate chamber/phantom combination for each measurement situation