Dosimetry Metrology for IMRT II:
Advanced Systems & Data Analysis

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Educational Objectives

- Learn about advanced dosimetry systems for IMRT measurements.
- Understand the benefits and limitations of different analysis tools for IMRT.
- Note: dosimeters and analysis tools must be matched to the task.

Outline

- Advanced dosimeters
  - EPIDs
  - 2D arrays in phantoms
  - 3D dosimeters
- 2D dose analysis techniques
  - Dose difference, distance to agreement
  - Gradient Analysis
  - Gamma Analysis
- Applications

<table>
<thead>
<tr>
<th>System</th>
<th>Task</th>
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<tbody>
<tr>
<td>EPIDS</td>
<td>Verification only; With or without patient</td>
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<tr>
<td>2D phantom arrays</td>
<td>Limited commissioning if a fine spatial resolution</td>
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<td>3D dosimeters</td>
<td>Commissioning</td>
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These systems should be validated against a known dosimetry system, e.g. ion chamber.
**EPIDs**

**Task: QA Verification**

- **Advantages**
  - Mounted to linear accelerator - known geometry with respect to the beam
  - Detector sag must be accounted for at different gantry angles
  - Positioning reproducibility important
  - Real time digital evaluation

- **Challenges**
  - Conversion of image response to “dose” is complex
  - Ghosting, lag

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**EPID Systems for Dosimetry**

- Active matrix flat panel imagers (AMFPiS)
- Portal “dosimetry”
- Often a fluence or response verification

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**Determination of Dose**

- Imager response must be calibrated to a standard
- Absolute calibration to ion chamber at a point over a ROI
  - E.g. ion chamber in a mini-phantom or slab at same SDD as EPID
- 2-D calibration to actual beam distribution at the imager plane
  - Can be measured with film or a diode array

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**Additional Factors for EPID Response**

- Water-equivalent depth of the detector
- Field size dependence and scatter properties within the imager
- Short- and long-term reproducibility
- Dose rate
- Energy dependence
- Spatial integrity
Imager response to Dose: AMFPI

- Example: Varian aS500
- Total area: 40 x 30 cm² (512x384 pixels) with resolution of 0.784 x 0.784
- Water-equivalent thickness is 8 mm
- Continuous frame acquisition


Dose Rate and Energy Considerations

- 6 MV
  - IMRT Prostate Field
  - SDD = 105 cm
- 18 MV
  - Response as a function of field size


EPID for Transit Dosimetry

- Dose distributions are reconstructed from measured EPID images
  - Phantom
  - Patient – first 5 fractions
- Plans for 75 prostate patients were measured
- Elekta system
- 3%/3 mm Gamma criteria
- Degree of field modulation may affect applicability


Example Gamma Results

1 patient

(a) pre-treatment
- 25°: 100%
- 320°: 100%
- 00°: 100%
- 041°: 100%
- 10°: 100%

(b) γ-image
- 5°: 100%
- 0°: 100%
- 5°: 100%
- 10°: 100%
- 5°: 100%

3D Dosimetry
Task: Commissioning, End-to-end test, etc.

- 3D dosimetry has been an investigational topic for many years
- Such a dosimeter must have a stable response and a high spatial resolution
- 3D dosimeters continue to evolve as new formulations and refinements are developed

3D Dosimetry - Example

- Four PRESAGE dosimeters
- Read out multiple times with an optical CT reader
- Phantom: Irradiated with 9 1x3 cm beams
- Doses repeated
  - High, med, low, +penumbra
  - Extreme in-plane spatial variation
  - Low longitudinal variation
- Compared to EBT film

Slide courtesy of Mark Oldham, Ph.D. – Duke University

Multi-planar comparison

3 EBT films

Optical-CT Technique

- OCTOPUS 5X scanner from MGS Research Inc
- Acquisition Parameters:
  - 600 projections per slice over 360°
  - 168 pixels per projection (pixel size = 1 mm)
  - 15 slices per 3D scan (slice spacing = 5 mm)
- 3D attenuation reconstruction using an in-house MATLAB software.
  - Assume linear dose response
  - Prescans
  - Edge effects (RI matching)
  - Flood fields

Slide courtesy of Mark Oldham, Ph.D. – Duke University
EBT film measurement

- EBT Gafchromatic film scanned with an EPSON® Perfection 4990 flatbed scanner was used to scan the EBT film response.

EBT calibration curve

\[ y = 300.391x^2 + 2666x^2 + 6176x^2 + 323.51x + 8.4538 \]

Results

- EBT calibration curve

Profile 1

Profile 2

Depth dose validation – Array vs. ion chamber

PTW Octavius Phantom Task: QA Verification

- Multiple positions
- Multiple ion chamber insert
- Cavity to compensate chamber response to arc delivery
- Heterogeneous inserts

**Dosimetry Analysis Software**
- Transfer patient fluence maps and beam geometry to phantom geometry
- 2-D dose difference displays with colorwash
- Dose volume histogram of detector volume
- Highlight of differences
- Gradient evaluation – dose & distance
- Gamma analysis
  - % agreement and distance-to-agreement

**Isodose lines - Dose Difference Displays**

**Dose Distributions**

**Limitations of Current Tools**
- The steep dose gradients in IMRT fields make it difficult to interpret dose differences with standard comparison tools.
- Isodose lines agree within 2 mm except for small regions of 10 cGy
Limitations of Current Tools
Calculation (cGy) – Film (cGy)

Multiple regions where the calculation is greater than the measurement
Differences are not seen on isodose line comparison

Are these differences significant?

Limitations of Current Tools
Calculation (cGy) – Film (cGy)

+/- 2 cGy agreement in black
+/- 4 cGy agreement in black

Initial Gradient Calculation

For each dose grid point:
- Calculate dose difference between point and nearest neighbors on the calculation grid
- Divide by respective grid distance(s)

\[
\text{Gradient} = \sqrt{\sum \left( \frac{d}{x} \right)^2}
\]

For example:
- \( D = 10 \text{ cGy} \)
- Nearest points = 1 cGy
- 3 mm calculation grid
- Gradient is = 7.4 cGy/mm

Gradient Compensation

- Start with dose difference between 2 plans
- Decrease the displayed dose difference by Gradient \( \cdot x \), where \( x \) is a distance (in mm) chosen for analysis
- Display remaining dose difference
- This highlights differences which cannot be explained by a geometrical error of \( x \) mm
Application of Gradient Tool to IMRT

- Algorithm and leaf sequencer verification
  - Gradient across field
  - Transmission
  - Split fields
- Routine QA
  - Pre-treatment patient QA
- Goal: To delineate planning and delivery differences not due to simple geometric misalignment or grid resolution issues

Static Field Example

Dose Distribution

Gradient Calculation

Dose Difference

1 mm grad applied


IMRT Example

Calculation (cGy) Gradient Map (cGy/mm)

Dose (cGy)

70
60
50
40
30
20
10

Differences due to tongue-and-groove

Calculation – Measurement (cGy)
Dose Area Histogram of Dose Difference
- Can evaluate the # of points within a given criteria
- Approach can be applied with any dosimeter

Dosimetric Analysis: Dose Difference and DTA
- Reference
- Evaluated Dose: ±6%
or 6 mm skew
- 3% Dose Difference
- 3 mm DTA
- Spatial
- Dose
- Unmod

Conclusions
- The detector or system must be matched to the task
- QA verification: EPID and array systems
  - Multiple phantom configurations for 2D arrays provide additional flexibility for new applications.
- Commissioning and end-to-end tests: 3D dosimeters.
  - Still under development
  - Not seen in many clinics at this time

Dosimetric Analysis: Gamma Evaluation
- 3%/3 mm
- 5%/5 mm

Slide courtesy of Dan Low, Ph.D. – Washington University
Conclusions (continued)

- 2D analysis: the tool depends on the need
  - Gamma analysis technique by Low et al. is often to combine dose and distance criteria
  - Parameters for % difference and distance should be chosen with care.
  - Dose difference and gradient compensation techniques help to identify differences and their clinical significance.

Status of Task Group 120 Report

- The report has been reviewed by the Therapy Physics Committee.
- We expect to submit the report to Medical Physics for publication in August.
- Members: Dan Low (chair), James Dempsey, Lei Dong, Mark Oldham, Jean Moran

Future Developments

- With dynamic arc therapy, a new generation of dosimetry equipment is being developed.
- We continue to need electronic systems with automated analysis because of the additional workload requirements for advanced technologies.
- Many of the new systems for arc therapy may provide valuable information for IMRT QA as well.

Tools for IMRT Commissioning: Static & Rotating Gantry
Gary Ezzell, Fang-Fang Yin, and Ying Xiao
Wed 8:30 am Ballroom C