Current Status of Electronic Portal Imaging

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An updated handout will be made available on the morning of the course

Acknowledgments

James Balter, University of Michigan
Michael Herman, Mayo Clinic
David Jaffray, William Beaumont Hospital
Shlomo Shalev, Masthead Imaging Corporation
Marcel Van Herk, Netherlands Cancer Institute
### Slide 4

#### Estimates of Setup Error

<table>
<thead>
<tr>
<th>Sites</th>
<th>No. of Studies</th>
<th>No. of Patients</th>
<th>No. of Images</th>
<th>Sys. Error</th>
<th>Random Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head &amp; Neck</td>
<td>8</td>
<td>6 – 95</td>
<td>120 – 380</td>
<td>3.4</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0 – 5.0</td>
<td>1.0 – 3.2</td>
</tr>
<tr>
<td>Thorax</td>
<td>3</td>
<td>10 – 19</td>
<td>97 – 341</td>
<td>4.4</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.4 – 5.2</td>
<td>1.2 – 5.7</td>
</tr>
<tr>
<td>Breast</td>
<td>5</td>
<td>6 – 20</td>
<td>41 – 2120</td>
<td>3.9</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.8 – 4.7</td>
<td>2.0 – 4.4</td>
</tr>
<tr>
<td>Pelvis</td>
<td>8</td>
<td>9 – 62</td>
<td>105 – 288</td>
<td>2.9</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.7 – 6.0</td>
<td>1.2 – 6.0</td>
</tr>
</tbody>
</table>

### Slide 5

#### EPID : Outline of presentation

- Physics Review
- Clinical Implementation
  - Setting up an EPID for clinical use
  - Tools to support EPID (software and QA)
- Clinical experience:
  - Strategies to improve patient setup using EPID
- Cost-effectiveness
- Ensuing new technology

### Slide 6

#### EPID : Current status

- Commercially available from accelerator companies and two 3rd party vendors (TheraView and PORTpro).
- Varian: scanning liquid ionization chambers on a robotic or manual arm.
- Others: fluoroscopic systems with 45° mirrors with retractable, dismountable, or portable assemblies.
- A compromise of several factors: convenience, field of view, rigidity, reproducibility, etc.
**EPID: Current Status**

- Most produce 8-bit images; Varian ~ 10-bit images.
- Images are:
  - (256 x 256) to (512 x 512) pixels
  - acquire with dose ~ 2 to 8 MU
  - acquire in < 1 sec; display in < 3 sec.
- Image quality adequate, in comparison with film:
  - 65% comparable, 30% inferior, 5% superior
- Purport to be more convenient; *not true*

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**Informal Survey (a) – Interest group from TG58**

<table>
<thead>
<tr>
<th>No. of Institutions: 69</th>
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<tbody>
<tr>
<td>Portal Film Practice</td>
</tr>
<tr>
<td>Weekly</td>
</tr>
<tr>
<td>66%</td>
</tr>
<tr>
<td>EPID utilization</td>
</tr>
<tr>
<td>Clinical use only</td>
</tr>
<tr>
<td>49%</td>
</tr>
<tr>
<td>Reviewer</td>
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<tr>
<td>RTT as first pass</td>
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<td>58%</td>
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**Informal Survey (b) – Interest group from TG58**

<table>
<thead>
<tr>
<th>No. of Institutions: 69</th>
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<tbody>
<tr>
<td>Of the 69 institutions with EPIDs</td>
</tr>
<tr>
<td>75%-100% of patients</td>
</tr>
<tr>
<td>Imaged everyday</td>
</tr>
<tr>
<td>Imaged once per week</td>
</tr>
<tr>
<td>Once or twice only</td>
</tr>
<tr>
<td>Not at all</td>
</tr>
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</table>
Informal Survey (c) -- Interest group from TG58
No. of Institutions: 69

<table>
<thead>
<tr>
<th>Viewing</th>
<th>Primary Station only</th>
<th>Secondary EPID Station</th>
<th>In-house Review Station</th>
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<tbody>
<tr>
<td>On-line Evaluation</td>
<td>Visual only</td>
<td>Using EPID system</td>
<td>Using in-house system</td>
</tr>
<tr>
<td></td>
<td>88%</td>
<td>57%</td>
<td>20%</td>
</tr>
<tr>
<td>Off-line Evaluation</td>
<td>Using EPID system</td>
<td>Using 3rd party tool (PIPS)</td>
<td>Using in-house tool</td>
</tr>
<tr>
<td></td>
<td>68%</td>
<td>38%</td>
<td>19%</td>
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</table>

Informal Survey (d) -- Interest group from TG58
No. of Institutions: 69

<table>
<thead>
<tr>
<th>No QA</th>
<th>Mechanical Only</th>
<th>Image Quality Only</th>
<th>Mechanical + Image Quality</th>
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<tbody>
<tr>
<td>35%</td>
<td>10%</td>
<td>16%</td>
<td>39%</td>
</tr>
<tr>
<td>Daily QA</td>
<td>Weekly QA</td>
<td>Monthly QA</td>
<td>Infrequent QA</td>
</tr>
<tr>
<td>8%</td>
<td>8%</td>
<td>8%</td>
<td>45%</td>
</tr>
<tr>
<td>Port Film Superior to EPID</td>
<td>EPID saves time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>71%</td>
<td>69%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Poor Image Quality</th>
<th>Poor User Interface</th>
<th>Poor Archive/Network</th>
<th>Inconvenient to use</th>
</tr>
</thead>
<tbody>
<tr>
<td>45%</td>
<td>27%</td>
<td>15%</td>
<td>13%</td>
</tr>
</tbody>
</table>

Portal Imaging: Elements

- X-ray Source
- Incident Spectrum
- Transmission and Scatter Spectra
- X-ray Radiographic
- X-ray Detector


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Slide 16

**Portal Imaging: X-ray Source Distribution**

- **Focal region**
  - varies from accelerator-to-accelerator
  - determined by accelerator design
  - ~1mm for modern accelerators
  - should not significantly limit on-line

- **Extra-focal region**
  - large source, ~10% of apparent output
  - reduces contrast performance

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**Portal Imaging: X-ray Scatter**

- reduces the contrast of objects in the image
- introduces additional x-ray quantum noise

Mathematical expressions:

- SF = \( \frac{I_s}{I_p + I_s} \)
- \( C = \frac{(I_p - I_s)}{(I_p + I_s)} \)
- DSNR = \( \frac{(I_p - I_s)}{\sqrt{(I_p - I_s)^2 + I_s^2}} \)

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**Scatter Fluence: Spatial Distribution**

- **E**: 6MV
- **Air Gap**: 0cm
- **T**: 17cm PMMA

Graph showing the spatial distribution of scatter fluence with distance from the field center.
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X-ray Scatter: Reduction in Contrast

Field Size on a Side(cm)

Contrast Degradation Factor (CDF)

0 5 10 15 20 25 30 35

0.5
0.6
0.7
0.8
0.9
1.0

6MV
24 MV

800 um Lead Plate/Kodak AA Film
17 cm scattering slab, 30 cm air gap

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X-ray Scatter: Reduction in DSNR

Air Gap: 20cm
T: 17cm PMMA

DSNRscatter / DSNRno scatter

0.8
0.9
1.0

Compton Recoil Detector
Copper Plate/Gd2O2S Detector

6MV
24 MV

Setting up a EPID

- Installation: System calibration
  - lens focus and aperture, flood field images, synchronize scan rate, etc.
- Acceptance: use simple contrast-detail phantoms;
- Additional checks: baseline phantom images, gantry stability, image quality with different phantom thicknesses.
- Establish a QA program:
  - QA frequency, integrity of mechanical assembly, image quality (and image transfer)
EPID: Starting out

- Establish imaging protocols:
  - provide prescription images on the EPI system,
  - sites requirement, e.g. optimal imaging dose
  - verification frequency,
  - archive: save every image? hardcopy?
- Correction strategies
  - decision criteria
  - on-line, off-line, or combinational
- Install a secondary review station.

EPID: Need of a QA program

- Factors leading to sub-optimal performance:
  - non-rigid detector housing
  - sub-optimal maintenance
  - improper system settings
  - optical components out of alignment/focus
- Consequences:
  - poor image quality and increased imaging dose
  - wasted efforts leading to rejection of the device.
- Physics involvement imperative.

A QC test system for EPID (Shalév)

- A set of test phantoms and procedures for acceptance and routine quality control
- Develop quantitative and objective tests for analyzing image quality.
- Derive accept/reject action levels for maintenance.
- Adapting a common test system allows:
  - inter- and intra-comparison of EPID systems
  - a baseline for future improvements.
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Isocenter EPID

Varian Clinac 74 (2100 CD)
Tom Baker Cancer Centre
6 MV

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The phantom contains five sets of high contrast rectangular bars with spatial frequencies:

- A - 0.75 lp/mm
- B - 0.4 lp/mm
- C - 0.25 lp/mm
- D - 0.2 lp/mm
- E - 0.1 lp/mm

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OUTPUT VARIATION

x = 0

E

∆E

1/f

1

INPUT VARIATION

x = 0

∆E

1/f

1

OUTPUT VARIATION
Determining the SWMTF
(Square Wave Modulation Transfer Function)

- SWMTF is defined as:
\[
SWMTF(f) = \frac{\Delta E(f)}{\Delta E_0}
\]
where \(\Delta E_0\) is the input modulation and \(\Delta E(f)\) is the output modulation

A relative measure of SWMTF can be obtained by defining
\[
RMTF(f) = \frac{\Delta E(f)}{\Delta E(f_\text{low})}
\]
where \(\Delta E(f)\) is the output modulation for the lowest frequency

For sinusoidal output, \((\Delta E)^2\) is proportional to the variance \((M^2)\)
\[
RMTF(f) = \frac{M(f)}{M(f_\text{low})}
\]

In the presence of random image noise, \(M(f)\) can be obtained by
\[
M^2(f) = \sigma^2_\text{tot}(f) - \sigma^2(f)
\]
where \(\sigma^2_\text{tot}(f)\) is the total variance and \(\sigma^2(f)\) is the variance due to random noise
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ROIs for Spatial Resolution

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Determining the CNR

(Contrast to noise ratio) — Shalev

- CNR is defined as:
  \[ \text{CNR} = \frac{I_k - I_{11}}{\sigma} \]

where \( \sigma \) is the random image noise.

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ROIs for Noise Measurements
**Slide 34**

**Summary of Results for f50 (Spatial Resolution (lp/mm)/mm)**

<table>
<thead>
<tr>
<th>EPID</th>
<th>6 MV</th>
<th>25 MV</th>
<th>All Energies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philips</td>
<td>0.180 ± 0.016</td>
<td>0.179 ± 0.014</td>
<td>0.180 ± 0.014</td>
</tr>
<tr>
<td>Siemens</td>
<td>0.214 ± 0.027</td>
<td>0.192 ± 0.005</td>
<td>0.204 ± 0.023</td>
</tr>
<tr>
<td>Infimed</td>
<td>0.231 ± 0.011</td>
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</tr>
<tr>
<td>Varian</td>
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<td>0.251 ± 0.007</td>
<td>0.258 ± 0.009</td>
</tr>
<tr>
<td>ELIAV</td>
<td>0.352</td>
<td>0.255</td>
<td>0.180 ± 0.016</td>
</tr>
</tbody>
</table>

**Slide 35**

**Range of values of f50 on EPID**

<table>
<thead>
<tr>
<th>EPID</th>
<th>6 MV</th>
<th>25 MV</th>
<th>All Energies</th>
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<td>0.300</td>
</tr>
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<td>0.300</td>
<td>0.350</td>
</tr>
<tr>
<td>Varian</td>
<td>0.300</td>
<td>0.350</td>
<td>0.400</td>
</tr>
</tbody>
</table>

**Slide 36**

**Summary of Results for f50 (Spatial Resolution (lp/mm)/mm)**

<table>
<thead>
<tr>
<th>EPID</th>
<th>6 MV</th>
<th>25 MV</th>
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</tr>
</tbody>
</table>

**Range of values of f50 on EPID**

<table>
<thead>
<tr>
<th>EPID</th>
<th>6 MV</th>
<th>25 MV</th>
<th>All Energies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philips</td>
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<td>0.300</td>
</tr>
<tr>
<td>Infimed</td>
<td>0.250</td>
<td>0.300</td>
<td>0.350</td>
</tr>
<tr>
<td>Varian</td>
<td>0.300</td>
<td>0.350</td>
<td>0.400</td>
</tr>
</tbody>
</table>
Slide 37

**Range of values of f on EPID**

<table>
<thead>
<tr>
<th>EPID</th>
<th>10 MV</th>
<th>15-25</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRI-100</td>
<td>0.15</td>
<td>0.20</td>
</tr>
<tr>
<td>TheraView</td>
<td>0.20</td>
<td>0.25</td>
</tr>
<tr>
<td>PORTpro</td>
<td>0.25</td>
<td>0.30</td>
</tr>
<tr>
<td>BEAMVIEW</td>
<td>0.30</td>
<td>0.35</td>
</tr>
<tr>
<td>PortalVision</td>
<td>0.35</td>
<td>0.40</td>
</tr>
</tbody>
</table>

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**EPID : Clinical Application**

**Verification of treatment setup**

- Treatment verification with portal images involves the comparison of a reference image (simulation, DRR, a reference portal image) with a treatment portal image.
- Field placement error (FTE) is determined by identifying the patient setup with respect to the proper field shape – often involves double-exposed image, particularly for small fields.

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**EPID : Software tools**

- The advent of EPIDs leads to the development of many image handling tools.
- Three main types of software tools:
  - image processing
  - field shape or edge detection
  - patient setup measurement
- snap shot analysis vs time-sequence studies
- These tools need to be integrated
  - NKI, PIPS, electronic view box, etc.
EPID: Methods of analysis

- Requirements:
  - objective, accurate, fast and automatic

- Interactive
  - Pro: applicable to a wide range of treatment sites
  - Con: subjective, labor intensive

- Automatic
  - Pro: objective, fast, reduce workload
  - Con: mostly optimized for few specific sites

EPID: Image processing

- Simplest manual approaches are to adjust display “window and level”, and to use measure distance.

- Image processing tools:
  - improve visualization, at least subjectively
  - pre-process for measuring field placement error

- Many software tools (e.g. in PIPS):
  - smoothing to suppress noise (e.g. Gaussian)
  - sharpening for edge detection (e.g. highpass)
  - contrast enhancement: histogram equalizations
Slide 43

An example of contrast enhancement by AHC (courtesy of Shlomo Shalev)

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EPID: Field edge detection

- Automatic algorithms available for quantitative description of shapes and alignment errors
  - few, if any, are implemented on the commercial systems and/or used clinically
- Interactive block template
  - define template once, and overlaid on subsequent Fx
  - require user examination; subjective
- Computer controlled MLC and accurate repositioning of EPID likely to change the use of field edge detection tools.

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EPID: Measurement of setup error

- Most tools to determine setup error assume 2D in-plane rigid body variation.
- Basic approach:
  - Identify homologous anatomical features on the reference image and the treatment portal image.
- Selected features
  - Point: Meertens, Balter
  - Gray scale regions: Munro, Dong and Boyer
  - Curves: Gilhuijs and van Herk, Fritsch
  - Interactive template: van Herk, Wong
Image Registration - point based

General comment on EPID software tools
- Comprehensive software tools to analyze portal images are typically not available from the EPID vendors
  - e.g. secondary review stations are generally not available
- Software suites are available from 3rd party:
  - PIPS, Electronic view-box from the NCI CWG
  - Mostly snapshot tools
- The general lack of tools and infrastructure precipitates how EPIDs are used currently.

Setup error detection: Reality check
- Patient setup is a 3D problem
- Simple patient shifts, even if only translational, may lead features changes; caution when choosing anatomical points.
- Out-of-plane rotation
  - Cannot be quantified
  - May lead to interpretation of in-plane translation/rotation
- Oblique beams
  - Images are difficult to interpret
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**Setup error detection : 3D models**

- Takes advantage of the anatomical information from 3D CT dataset for treatment planning.
- Assume rigid body variation.
- Approaches to match portal image with CT data:
  - Interactive or automatic adjustment of CT to align DRRs with portal images (Gilhuis)
  - Registration of features on pre-calculated DRRs (Lujan)
  - Registration of 3D homologous features with their 2D projections (Pisani)

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**Gilhuis**

- 3D CT alignment
- pisani CT alignment
**EPID : 3D setup error**

- Presently a research topic, methods not quite ready for clinical use.
- Need to establish the clinical frequency of 3D setup error.
- Rigid models do not account for deformable rigid elements: joint flexing, or non-rigid organ motion.
- Rule of thumb:
  - Small setup errors == small out-of-plane components
  - Large setup errors == potentially a 3D problem.

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**EPID : Current status of clinical use**

- At present, there is no standard recommendation on the clinical use of EPID for the community at large.
- EPIDs are used to acquire more images than with film (sometimes, in those clinics that use EPIDs).
- Analysis of the images are mostly still based on the model of weekly port film.
- Cost-effectiveness is of major concern.