The EPID Strikes Back! - EPID In-Vivo Dosimetry

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**EPID Research Number of Publications**

- "EPID" or "electronic portal imaging device" Title, Abstract, Keywords (Scopus) 1989-2015
- Publications 2014-2015 (~175)

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**Why EPID in-vivo? Detectable errors: patient**

<table>
<thead>
<tr>
<th>Potential errors</th>
<th>Pre-tx</th>
<th>Review at EPID level</th>
<th>Review at patient level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table/immobilisation device obstruction</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Anatomical changes in pt</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Anatomical movements during tx</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Wrong pt during tx</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Dose distribution in pt</td>
<td>no</td>
<td>no</td>
<td>yes (CBCT)</td>
</tr>
</tbody>
</table>

Slide courtesy of Boyd McCurdy
Detectable errors: clinical experience

<table>
<thead>
<tr>
<th>Error Type</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine plan transfer error</td>
<td>(12,13)</td>
</tr>
<tr>
<td>Patient changes in patient position</td>
<td>(10,14,15)</td>
</tr>
<tr>
<td>Patient weight loss</td>
<td>(20,21)</td>
</tr>
<tr>
<td>Patient variation in patient contour</td>
<td>(22,23)</td>
</tr>
<tr>
<td>Treatment bar of the treatment couch</td>
<td>(14,18)</td>
</tr>
<tr>
<td>Treatment wrong patient setup</td>
<td>(14,13)</td>
</tr>
<tr>
<td>Treatment wrong CT numbers</td>
<td>(13)</td>
</tr>
<tr>
<td>Treatment wrong bolus material</td>
<td>(13)</td>
</tr>
</tbody>
</table>

Types of errors detected with EPID in-vivo dosimetry (from Clinical 3D dosimetry in Advanced Radiotherapy eds Mijnheer/Thwaites in press)

Netherlands Cancer Institute - clinical experience

<table>
<thead>
<tr>
<th>Error Type</th>
<th>No. of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient changes in patient position</td>
<td>16</td>
</tr>
<tr>
<td>Patient weight loss</td>
<td>15</td>
</tr>
<tr>
<td>Patient variation in patient contour</td>
<td>4</td>
</tr>
<tr>
<td>Treatment bar of the treatment couch</td>
<td>3</td>
</tr>
<tr>
<td>Treatment wrong patient setup</td>
<td>2</td>
</tr>
<tr>
<td>Treatment wrong CT numbers</td>
<td>2</td>
</tr>
<tr>
<td>Treatment wrong bolus material</td>
<td>2</td>
</tr>
<tr>
<td>Treatment wrong CT numbers</td>
<td>2</td>
</tr>
</tbody>
</table>

Errors and in-vivo EPID dosimetry

- Increasing evidence now on types and incidence of errors and where QA needs to be focused
- e.g. Bojechko et al. Med.Phys. 2015
  - Incidents with a high potential severity score one center over 2 years ~225 EBRT incidents
  - Majority related to patient positioning
  - Only a small number of these could be detected by EPID dosimetry when performed prior to treatment (6%).
  - A large fraction could be detected by EPID in vivo dosimetry performed during the first fraction (74%)
Amorphous silicon (a-Si) EPIDs
1) an overlaying x-ray converter - copper ~ 1 mm
2) phosphor scintillator (gadolinium oxysulfide)
3) large area photodiode array
4) an electronic acquisition system and host computer

Epid response
- EPID scatter kernel is different to water
- EPID is highly energy-dependent in response (phosphor Z = 78)

Energy fluence at EPID level
EPID signal depends on:

- EPID response at any pixel will depend on the energy spectrum incident on the EPID
- This spectrum is modified by the patient and varies with the radiological thickness to the pixel and patient scatter to the pixel

Alternatives to a-Si EPIDs

Defining transit EPID dosimetry

- Transit dosimetry – determination of dose in detector/phantom/patient (or incident energy fluence) based on measurements through a patient or phantom
Methods for EPID in vivo dosimetry

Transit image gray scale values:
- Prediction model that predicts the EPID absolute grayscale
- Monte-Carlo models, empirical models


Transit dose to water slab:
- Prediction model that predicts the transit dose in a water phantom
- Calibration of EPID signal to dose in a water phantom

Water phantom

Calibration of EPID signal to dose in water:
- Correct for different scatter kernels of EPID and water
- Correct for response of EPID relative to ion-chamber (energy-dependent)

Dose in patient model from transit EPID

1. Empirical methods
2. Backprojection of fluence derived from EPID to calculate dose

Calculation of dose in patient model

NKI method

- From EPID image, remove scatter, attenuation model through patient CT, patient scatter dose kernels
- Requires in-air image (IMRT)
- 3D using multi 2D dose planes

Comparison of EPID and film dose distributions inside a phantom for pre-treatment verification of an IMRT field consisting of eight segments using an 18 MV photon beam.
Back-projection

• The image signal is formed from attenuation through the treatment anatomy

Back-projection

• The dose is calculated by back-projection in the planning anatomy
• Fluence changes due to anatomy change are attributed to incident fluence changes
• This does not calculate the delivered dose.
• Changes in dose from the planned dose due to various causes can be detected.

VMAT back-projection - NKI

• Cine EPID images required during rotation to backproject dose
• Recorded the gantry angle via an iCom connection to the Elekta treatment machine
• Found a lag of ~0.4 s or about one frame for the gantry angle.
VMAT Cine imaging

- Currently poor implementations from vendors to acquire and access cine images (new Eleka software)
- Dosimetric issues (missing frames) and scanning artefact issues (interplay between pulsing and readout)

In-vivo EPID sensitivity/action levels

- How does the EPID in-vivo result relate to clinically relevant patient dose changes
- Model changes in patient CT data and compare to measured data
- Derive action limits with desired sensitivity/specificity.

Real-time transit dosimetry

- SBRT - post-treatment assessment is ineffective
- Real-time assessment can be performed using real-time image frame stream
Real-time transit dosimetry

• Calculate expected EPID transit image as a function of control point
• Compare to measured EPID images during delivery with quantitative comparison metrics e.g. gamma

• Fuangrod et al. Med. Phys. 2013

Conclusions

• EPID signal for transit in-vivo dosimetry has many contributions and the response is energy-dependent.
• Several methods available to either predict transit EPID image/dose in phantom or back-project into patient CT model
• EPID in-vivo dosimetry can detect changes in delivered dose from the plan but does not usually derive delivered dose
• Challenges are to set clinically relevant action levels, and classify error types
• Real-time verification for high dose deliveries is feasible and should be future developed

Thank you

• Acknowledgements – Boyd McCurdy, Todsaporn Fuangrod, Ben Mijnheer, Jeff Siebers, Henry Woodruff