Clinical impact of EPID *in vivo* dosimetry


Radiotherapy Safety

“The purpose of radiotherapy is to safely, accurately, and efficiently deliver radiation to treat various types of malignant and nonmalignant abnormalities. Recently, a number of radiation incidents in various countries have been reported. ¹–⁸ In addition to incidents caused by human errors, suboptimal patient treatments may also occur because one or more of the parameters involved in a patient irradiation may have a systematic error (e.g., see Holmberg et al. ⁹).”

Agenda

• Overview of EPID in vivo Dosimetry research
  o EPIDs ability to detect errors
  o EPID in vivo use in Radiation Oncology
  o Is TG-142 machine QA enough?
  o EPIDs vs Logfiles

• Clinically available commercial solution
  o PerFRACTION overview
  o Supporting research/publications
Where does EPID *in vivo* Dosimetry Fit?

Diagram showing the process flow with stages labeled as Plan Quality Assessment, Secondary Check Calculation, IMRT Pre-Treatment Measurement, and EPID Per Fraction Exit Measurement. The diagram also highlights errors with sections for Assessment, Calculation, and Measurement.
Why in Vivo dosimetry?

“A quantification of the effectiveness of EPID dosimetry and software-based plan verification systems in detecting incidents in radiotherapy”
Bojtechko C, Phillips M, Kalet A, Ford E.C.
Department of Radiation Oncology, University of Washington
Med Phys 42(9), Sept 2015

• Study over 2.5 years of all failure modes - 343 incidents rated “potentially severe” or “critical”

• Looked at:
  o Failure Modes
  o Detectability of errors via –
    – Pre-Tx QA
    – First fraction in vivo QA
    – All fraction in vivo QA

<table>
<thead>
<tr>
<th></th>
<th>Photon EBRT (%)</th>
<th>Nonphoton EBRT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretreatment</td>
<td>14(6)</td>
<td>0</td>
</tr>
<tr>
<td>First fraction</td>
<td>169(74)</td>
<td>0</td>
</tr>
<tr>
<td>All fraction</td>
<td>46(20)</td>
<td>0</td>
</tr>
</tbody>
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- Most common sources of error:

<table>
<thead>
<tr>
<th>Failure mode</th>
<th>n</th>
<th>Example cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrong isocenter information</td>
<td>56</td>
<td>Error in the localization of the coordinate system in the CT scan or treatment plan. Leading to an incorrect setup to the treatment isocenter.</td>
</tr>
<tr>
<td>Error in CT data</td>
<td>30</td>
<td>Error in CT scan data used for planning. For example, wrong breathing scan used for planning.</td>
</tr>
<tr>
<td>Missing or incorrect documentation</td>
<td>16</td>
<td>Missing or incorrect information about prior patient treatments, or no approval of plan by physician or physicist.</td>
</tr>
<tr>
<td>Prescription error</td>
<td>15</td>
<td>Error in plans fractionation, location or total dose.</td>
</tr>
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Conclusions –

- Pre-Tx EPID dosimetry detected 6% of errors (physics calculation errors, treatment machine error, and corrupted plans) – all modes with low number of occurrences
- First Fraction in vivo QA detected 74% of all failures – incidents with the highest occurrence (patient setup, CT dataset errors)

“The most effective EPID-based dosimetry verification is in vivo measurements during the first fraction”
Why in Vivo dosimetry?

“A quantification of the effectiveness of EPID dosimetry and software-based plan verification systems in detecting incidents in radiotherapy”
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Conclusions –

- All Fraction in vivo QA added the ability to detect other common errors (movement on the table, treatment machine error, and setup errors)

“In vivo all fraction dosimetry gives an added benefit to 20% of events”

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<th>Nonphoton EBRT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>229</td>
<td>114</td>
</tr>
<tr>
<td>EPID</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretreatment</td>
<td>14(6)</td>
<td>0</td>
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**AAPM Vision 20/20 Paper - “In vivo dosimetry in external beam radiotherapy”**

Ben Mijnheer, Sam Beddar, Joanna Izewska, Chester Reft

Department of Radiation Oncology, The Netherlands Cancer Institute-Antoni van Leeuwenhoek Hospital, Amsterdam 1066 CX, The Netherlands, Department of Radiation Physics, The University of Texas MD Anderson Cancer Center, Houston, Texas 77030, Division of Human Health, International Atomic Energy Agency, Vienna 1400, Austria, Department of Radiation and Cellular Oncology, University of Chicago Medical Center, Chicago, Illinois 60637

*Med. Phys. 40 (7), July 2013*

- “It is the authors’ opinion that all treatments with curative intent should be verified through in vivo dose measurements in combination with pretreatment checks.”
Other Markets

- Italy has commissioned a national project to develop an in vivo dosimetric procedure –

- Italy’s study results - “The results of 480 tests showed errors exceeding the 5% tolerance level in 10% of the measurements, which were due to incorrect setup, the presence of an attenuator in the beam, or patient morphological changes.”
Is Machine QA enough?


A Templeton, Y Liao, G Redler and H Zhen,¹
Rush University Medical Center, Chicago, IL
Med. Phys. 42, 3395 (2015); http://dx.doi.org/10.1118/1.4924635

• States TG-142 machine QA could be insufficient as a means to ensure that patient IMRT/VMAT plans are delivered accurately.
• Method – Two errant simulation treatment machines were designed in Varian’s Eclipse TPS. Error magnitudes remained within TG-142 testing limits.
Is Machine QA enough?

A Templeton, Y Liao, G Redler and H Zhen,¹
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• “Unacceptably large changes in dose delivered are possible….despite the machine passing routine QA.”
• “By following the minimum standards for machine QA, large dose errors (greater than 10%) may be produced.”
• “Conclusion: The cumulative effect of many small errors can, in worst case scenarios, produce large ones. This amalgam should be considered as part of the QA process.”
EPIDs vs. Log files

- Can log files detect the most frequent cause of treatment errors?

“Catching errors with in vivo EPID dosimetry”
Department of Radiation Oncology, The Netherlands Cancer Institute-Antoni van Leeuwenhoek Hospital, Plesmanlaan 121, 1066 CX Amsterdam, The Netherlands
(Received 9 July 2009; revised 5 March 2010; accepted for publication 29 March 2010; published 18 May 2010)

- They detected 17 treatment errors out of 4337 treatments using an EPID based per fraction QA approach

- “By routine clinical use of in vivo EPID dosimetry, 17 serious errors were detected among the treatment plans of 4337 patients. Nine of these errors would have been missed with pretreatment verification only.”
EPIDs vs. Log files

“Catching errors with in vivo EPID dosimetry”
A. Mans\textsuperscript{a)}, M. Wendling\textsuperscript{b)}, L. N. McDermott\textsuperscript{c)}, J.-J. Sonke, R. Tielenburg, R. Vrijbrief, B. Minjnheer, M. van Herk, and J. C. Stroom
Department of Radiation Oncology, The Netherlands Cancer Institute-Antoni van Leeuwenhoek Hospital, Plesmanlaan 121, 1066 CX Amsterdam, The Netherlands
(Received 9 July 2009; revised 5 March 2010; accepted for publication 29 March 2010; published 18 May 2010)

• A log-file solution alone will never be able to detect because it ignores the patient

• Patient changes detected
  o Weight loss
  o Setup error
  o Obstructions from table arms or immobilization devices
  o Tumor or internal anatomy changes - postoperative cavity drainage, atelectasis shrinkage, etc
EPIDs vs. Log files

“Monitoring daily MLC positional errors using trajectory log files and EPID measurements for IMRT and VMAT deliveries,”
A. Agnew¹, C E Agnew¹, M W D Grattan¹, A R Hounsell¹,² and C K McGarry¹,²
¹ Radiotherapy Physics, Northern Ireland Cancer Centre, Belfast Health and Social Care Trust, Northern Ireland, BT9 7AB, UK
² Centre for Cancer Research and Cell Biology, Queen’s University Belfast, Belfast, Northern Ireland, BT9 7BL, UK

• “In this study it was found that the trajectory logs created during the delivery of a picket fence test did not detect leaf positional errors that were detected using an EPID.”

Colors indicate detected errors - Note the lack of color change in the Log files.
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• “In this study it was found that the trajectory logs created during the delivery of a picket fence test did not detect leaf positional errors that were detected using an EPID.”

Note the detected errors (and the resolution for each) – yet the Log files never shows the error!

Figure 6. Sub-optimal leaves over time for EPID (a–d) and trajectory logs (e–h).
PerFRACTION™

Your Most Valuable QA and Dosimetry Tools
What is PerFRACTION?
What is PerFRACTION?
Fraction 0™ / Fraction n™

- **Fraction 0**
  - Pre-Treatment IMRT QA without a phantom

- **Fraction n**
  - In-Vivo verification of every treatment
Peace of Mind

• Detects Patient Issues
  o Patient setup errors
  o Patient movement intra-treatment
  o Anatomical issues including weight loss and tumor growth/shrinkage

• Detects Machine Issues
  o Machine errors – MLC, gantry, output, jaws, collimator, and more

• Independent
  o No reliance on machine generated log file data

• Consistent
  o Every Patient, Every Fraction, Every day
Complete Automation

PerFRACTION

Automated Capture → Automated Processing → Device
Flexibility

- PerFRACTION 2D
  - Automated 2D EPID image comparisons
  - Compare per-fraction images to baseline image or predicted image

- PerFRACTION 3D
  - Automated 3D patient dose volume comparisons
  - Compare Clinical Goals and DVH (Target and OAR) metrics

- Support
  - Varian, Elekta, Aria and Mosaiq
PerFRACTION Publications – AAPM 2015

SU-C-BRD-06: “Sensitivity Study of An Automated System to Acquire and Analyze EPID Exit Dose Images”
A Olch and A Zhuang
Med. Phys. 42, 3193 (2015); http://dx.doi.org/10.1118/1.4923802

• Study of the Sensitivity of new PerFRACTION software to induce errors. Excellent sensitivity found – author states that PerFRACTION is, “sensitive enough to detect small positional angular and dosimetric errors within 0.5mm 0.2 degrees and 0.2% respectively.”

SU-E-T-139: “Automated Daily EPID Exit Dose Analysis Uncovers Treatment Variations”
A Olch
Med. Phys. 42, 3363 (2015); http://dx.doi.org/10.1118/1.4924501

• Discusses initial experience with PerFRACTION, including its detection of patient setup, deliver, and anatomy changes. This study was performed with very stringent gamma criteria (2%/1mm) in order to review as many cases as possible. Interesting finding – pass rates were higher for IMRT/VMAT plans than for Conventional fields, indicating patient setup may be an issue.
SU-E-T-133: “Assessing IMRT Treatment Delivery Accuracy and Consistency On a Varian TrueBeam Using the SunNuclear PerFRACTION EPID Dosimetry Software”
S Dieterich, E Trestrail, R Holt, S Saini, I Pfeiffer, M Kent and K Hansen
Med. Phys. 42, 3362 (2015); http://dx.doi.org/10.1118/1.4924494

- Initial experience with PerFRACTION – 96% of fields passed at 3%/3mm criteria – 84% of fields passed at 1mm DTA.
Thank you