The EPID Strikes Back! - EPID In-Vivo Dosimetry

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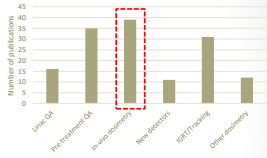
Peter Greer[1,2]
(1) University of Newcastle, Australia,
(2) Calvary Mater Newcastle, Australia

Newcastle Medical Physics Research Group

EPID Research Number of Publications

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



Publications 2014-2015 (~175)

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

Potential errors	Pre-tx	In-vivo at EPID level	In-vivo at patient level
Table/immobilisation device obstruction	no	yes	yes
Anatomical changes in pt	no	yes	yes
Anatomical movements during tx	no	yes	yes
Wrong pt during tx	no	yes	yes
Dose distribution in pt	no	no	yes (CBCT)

Slide courtesy of Boyd McCurdy

Detectable errors: *clinical experience*

Potential error	Error type	References
Machine	Plan Transfer error	(12),(13)
Plan	Dose calculation error	(14),(12),(13)
Patient	Changes in atelectasis and pleural effusion	(15),(14),(12),(13), (16),(17),(18),(19)
Patient	Gas pockets in the planning CT scan resulting in an under-dose in the PTV during treatment	(20),(21),(14)
Patient	Weight loss resulting in an over-dose in the PTV	(20),(21),(12)
Patient	Variation in patient contour due to relaxation	(22),(12),(23)
Plan	Immobilization system not included in the treatment plan	(14)
Treatment	Bar of the treatment couch in the entrance beam	(14),(18)
Treatment	Wrong patient setup	(14),(13)
Plan	Bolus material not taken into account	(13)
Plan	Wrong CT numbers	(13)

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 I. Errors detected by means of EPID dosimetry from the clinical introduction to July 2009, grouped by (a) treatment site and (b) error type.

(a) Site	Clinical introduction	No. of patients	No. of errors
Prostate	02–2005	1018	2
Rectum	07–2006	602	4
Head-and-neck	06–2007	543	4
Breast	01–2008	1319	2
Lung	01–2008	454	2
Others	01–2008	401	3
	Total	**4337**	**17**

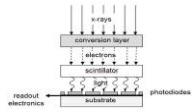
(b) Error type	No. of errors
Patient anatomy	7
Plan transfer	4
Suboptimally tuned TPS parameter	2
Accidental plan modification	2
Failed delivery	1
Dosimetrically undeliverable plan	1
Total	**17**

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%)

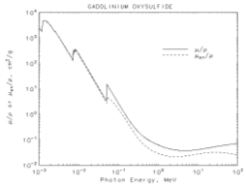
Amorphous silicon (a-Si) EPIDs

1) an overlaying x-ray converter - copper ~ 1 mm
2) phosphor scintillator (gadolium oxysulfide)
3) large area photodiode array
4) an electronic acquisition system and host computer

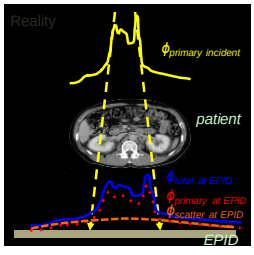


EPID response

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



Energy fluence at EPID level

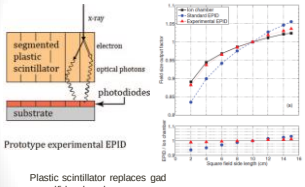


Picture courtesy of Boyd McCurdy

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

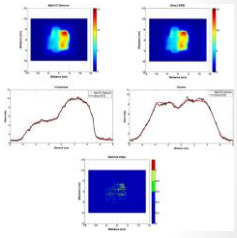
Alternatives to a-Si EPIDs



Prototype experimental EPID

Plastic scintillator replaces gad oxysulfide phosphor

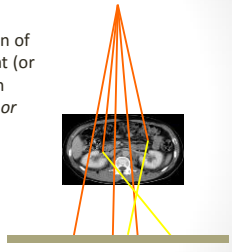
Blake S et al., Med.Phys, 2013
Sabet M et al; Phys.Med.Biol. 2012



EPID with phosphor removed direct detection– transit compare to MatrixX

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*

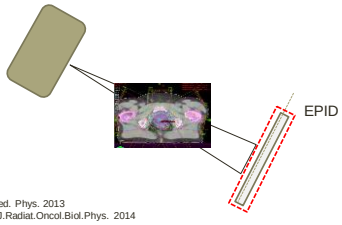


Picture courtesy of Boyd McCurdy

Methods for EPID in-vivo dosimetry

Transit image gray scale values.

- Prediction model that predicts the EPID absolute grayscale
- Monte-Carlo models, empirical models

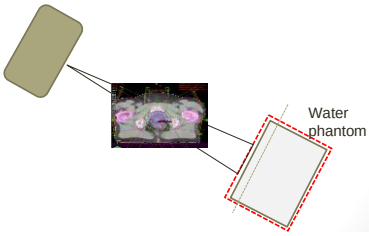


- Chytyk et al. Med. Phys. 2013
- Berry et al. Int.J.Radiat.Oncol.Biol.Phys. 2014

Methods for EPID in-vivo dosimetry

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



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)

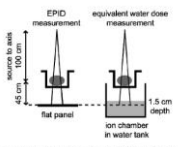


FIG. 1. Measurement configurations for the EPID and for the equivalent water dose. The dose is measured by scanning an ion chamber in a water tank at the detector height and at a depth of 1.5 cm.

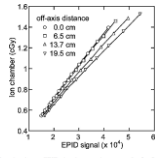
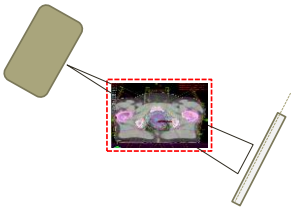


FIG. 2. Ion-chamber vs EPID signal conversion curves for 5 × 5 cm² fields. Conversion curves were measured at four different locations in the detector plane with different off-axis distances, as listed in the legend. Within each curve, each data point represents the EPID signal and dose measured with the beam attenuated through a certain thickness of solid water. The solid water thickness was varied from 0 to 20 cm in 2 cm increments.

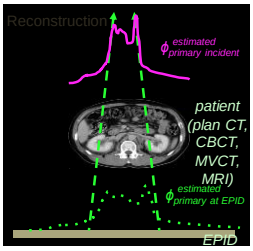
Chen et al. Med. Phys. 2006
Nijsten et al. Med. Phys. 2007

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

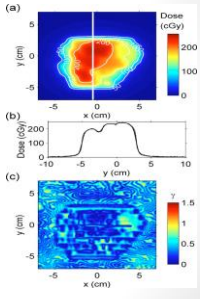


Wendling et al. Med. Phys.
Van Elmpt et al.
Van Uytven et al.

Slide courtesy of Boyd McCurdy

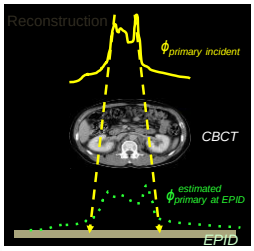
NKI method

- 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



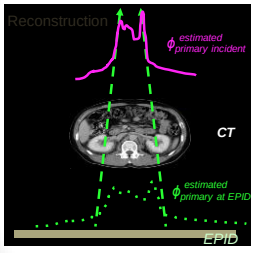
Comparison of EPID and film dose distributions inside a phantom for pre-treatment verification of an IMRT field consisting of eight segments using an 18 MV photon beam.

Back-projection



- The image signal is formed from attenuation through the **treatment anatomy**

Back-projection

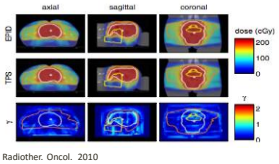


- The dose is calculated by back-projection in the **planning anatomy**
- Fluence changes due to anatomy change are attributed to incident fluence changes
- This does not calculate the delivered dose.
- Changes in dose from the planned dose due to various causes can be detected.

See Siebers et al., SU-F-T-258

VMAT back-projection - NKI

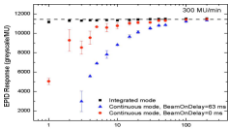
- Cine EPID images required during rotation to backproject dose
- Recorded the gantry angle via an iCom connection to the Elekta treatment machine
- Found a lag of ~0.4 s or about one frame for the gantry angle.



Mans et al. Radiother. Oncol. 2010

VMAT Cine imaging

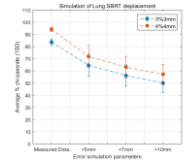
- Currently poor implementations from vendors to acquire and access cine images (new Elekta software)
- Dosimetric issues (missing frames) and scanning artefact issues (interplay between pulsing and readout)



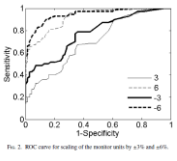
McCurdy BMC et al. *Medical Physics*. 36(7): 3028-3039, 2009.

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.



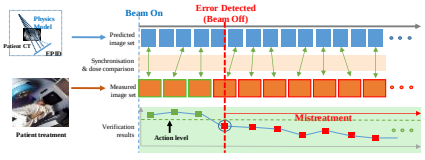
Bojechko et al. Med. Phys. 2015
See Fuangrod et al. TH-CD-207A-11



Curves for varying Gamma (3%, 3mm) pass criteria.

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

watchDOG

- Fuangrod et al. Med.Phys. 2013
- Woodruff et al. Int.J.Radiat.Oncol.Biol.Phys. 2015
- Spreeuw wt al. Int.J.Radiat.Oncol.Biol.Phys. 2016

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