The Leeds Teaching Hospitals NHS Trust

In vivo dosimetry in clinical practice

Vicky Coleman, Josh Mason – Leeds Cancer Centre

Leeds Cancer Centre

Overview

- Challenges of in vivo dosimetry (IVD) in brachtherapy
- Examples of IVD and treatment verification methods in brachy
- IVD system in Leeds
- Clinical workflow for planner and radiographers
- Results

In vivo dosimetry

- High dose per fraction in brachytherapy, single fraction treatments
- Possibility for errors:
  - Manual procedures
  - Equipment malfunction
- In UK in vivo dosimetry recommended for routine use in all patients in RCR report "Towards Safer Radiotherapy"[1]

1 – The Royal College of Radiologists, Society and College of Radiographers, Institute of Physics and Engineering in Medicine, National Patient Safety Agency, British Institute of Radiology. *Towards Safer Radiotherapy.* London The Royal College of Radiologists: 2008.

Challenges

- Lack of commercially available technology, significant implementation effort
- Access to treatment sites, stable position
- Steep dose gradients – need very small detectors
- Position uncertainties – false errors
- Energy dependence of dosimeters
- Temperature dependence of dosimeters

Real-time in vivo dosimetry

- TLDs often used for IVD but measured dose only determined at end of treatment
- Real-time IVD - treatment could be interrupted if a problem is detected.
- Use dosimeter or device that allows treatment monitoring in real-time
  - Diode, MOSFET, radio luminescence or scintillation detector based device
- Alternative methods use source tracking rather than measuring dose

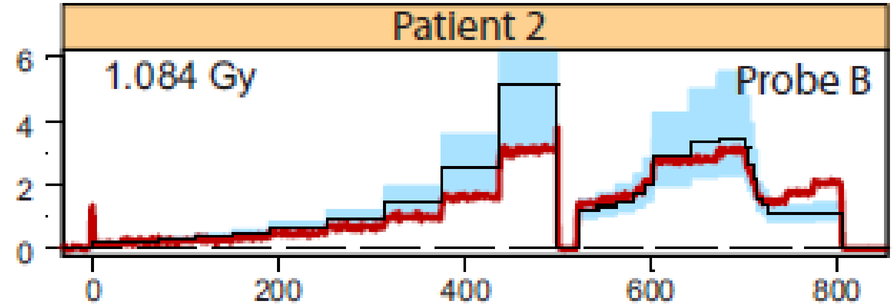
- 5 PDR cervix patients
- fiber-coupled RL/OSL dosimeter placed in needle
- Also simulated treatment errors
-Time-resolved dosimetry signifcantly improved ability to detect errors compared to total integrated dose.

Medical Physics

Time-resolved in vivo luminescence dosimetry for online error detection in pulsed dose-rate brachytherapy

Claus E. Andersen, Søren Kynde Nielsen, Jacob Christian Lindegaard, and Kari Tanderup

Citation: Medical Physics **36**, 5033 (2009); doi: 10.1118/1.3238102



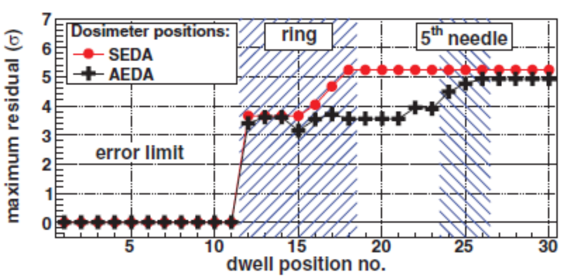
- Adaptive position determination algorithm
- To exclude false errors due to position uncertainty

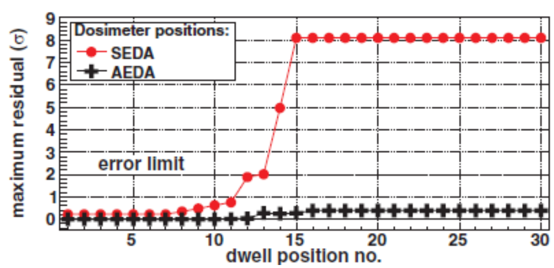
Medical Physics

Adaptive error detection for HDR/PDR brachytherapy: Guidance for decision making during real-time in vivo point dosimetry

Gustavo Kertzscher, Claus E. Andersen, and Kari Tanderup

Citation: Medical Physics **41**, 052102 (2014); doi: 10.1118/1.4870438





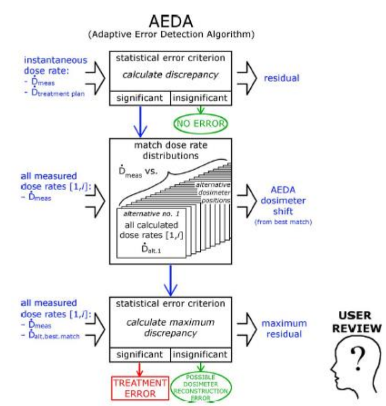
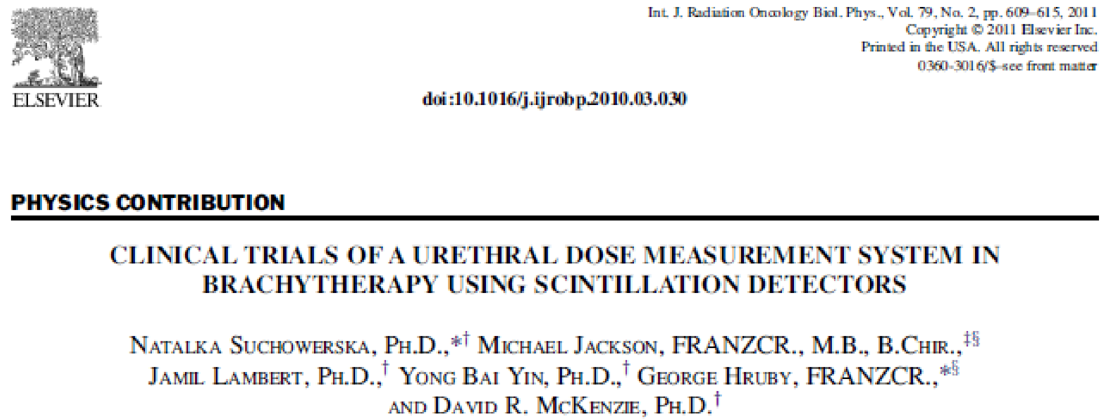


FIG. 1. Illustration of the adaptive error detection algorithm.

-Urethral dose in HDR prostate brachy measured using scintillation detector
- Continuous readout
- 24 patients
- Agreement within 9%


Int. J. Radiation Oncology Biol. Phys., Vol. 79, No. 2, pp. 609–615, 2011

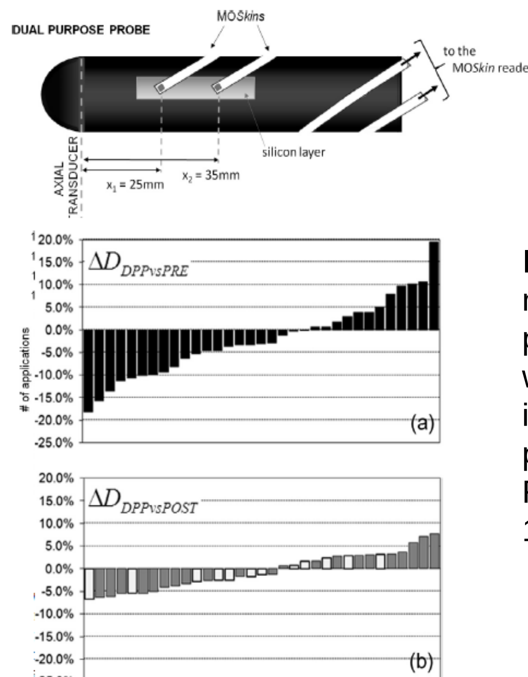
0360-3016/$-see front matter
ELSEVIER
doi:10.1016/j.ijrobp.2010.03.030

PHYSICS CONTRIBUTION

CLINICAL TRIALS OF A URETHRAL DOSE MEASUREMENT SYSTEM IN BRACHYTHERAPY USING SCINTILLATION DETECTORS

Natalka Suchowerska, Ph.D.,*† Michael Jackson, FRANZCR., M.B., B.Chir.,‡§ Jamil Lambert, Ph.D.,† Yong Bai Yin, Ph.D.,† George Hruby, FRANZCR.,*§ and David R. McKenzie, Ph.D.†

- Custom TRUS probe with MOSkin detectors integrated
- 18 HDR prostate treatments
- Compared planning and post-treatment reconstructed doses
- Mean absolute difference 6.7% to plan, 3.6% to post-plan (5.7% uncertainty (k=1))
- Dosimeter position accurately known
- No extra invasive procedure



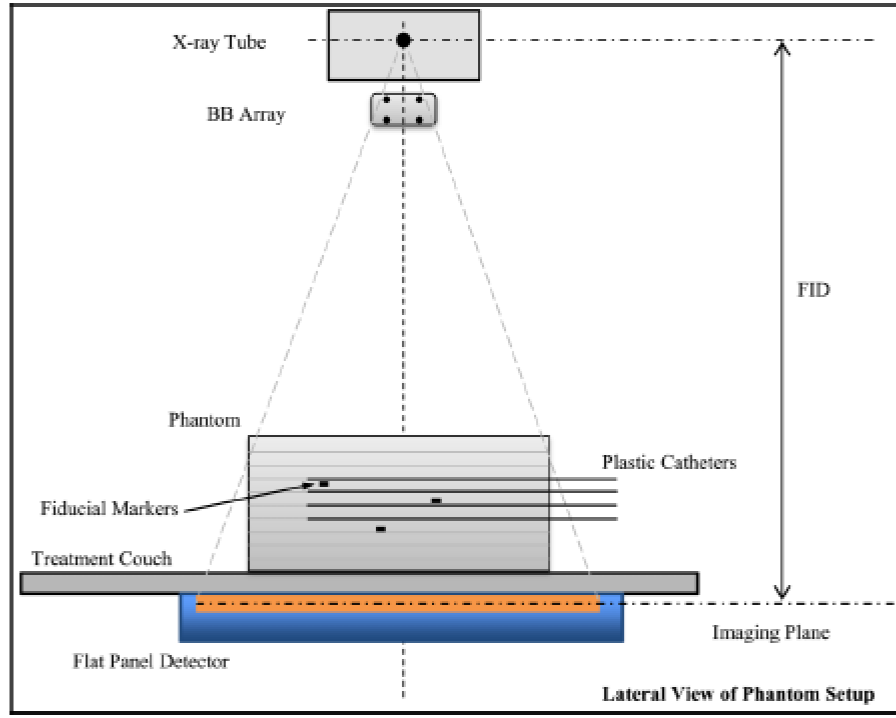
In vivo rectal wall measurements during HDR prostate brachytherapy with MOSkin dosimeters integrated on a trans-rectal US probe..... Mauro Carrara et al , Radiotherapy and Oncology 118 (2016) 148–153

Treatment verification methods

- Alternative to IVD
- Pre-treatment verification/imaging
  - Manual measurements to detect movement
  - Pre-treatment imaging
- Source tracking methods
- Electromagnetic re-construction

Source tracking using flat panel

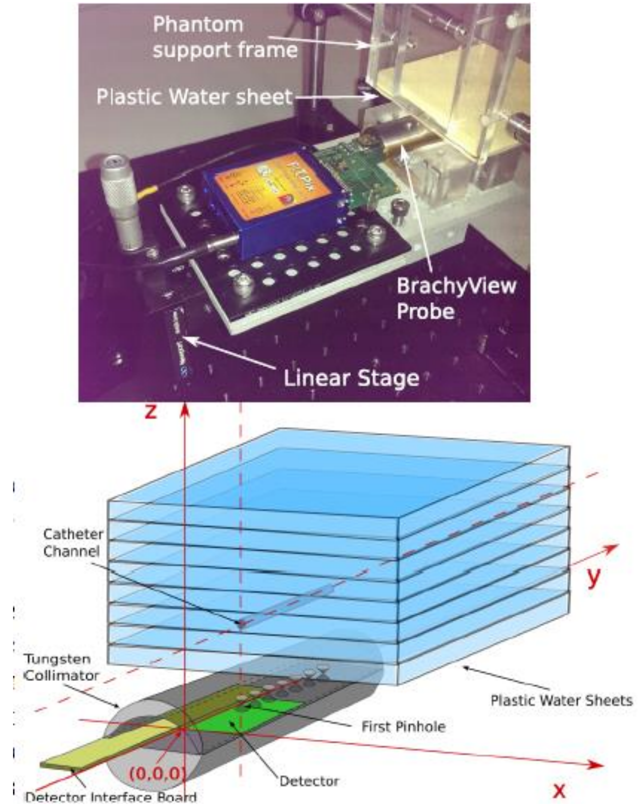
- Image implant before treatment
- Track source during treatment
- Phantom study – catheters within 0.5mm and source within 0.6mm (mean)
- Non-invasive
- 2D



A method for verification of treatment delivery in HDR prostate brachytherapy using a flat panel detector for both imaging and source tracking
Ryan L. Smith, Annette Haworth, Vanessa Panettieri, Jeremy L. Millar, and Rick D. Franich
Medical Physics **43**, 2435 (2016); doi: 10.1118/1.4946820

Source tracking using collimators

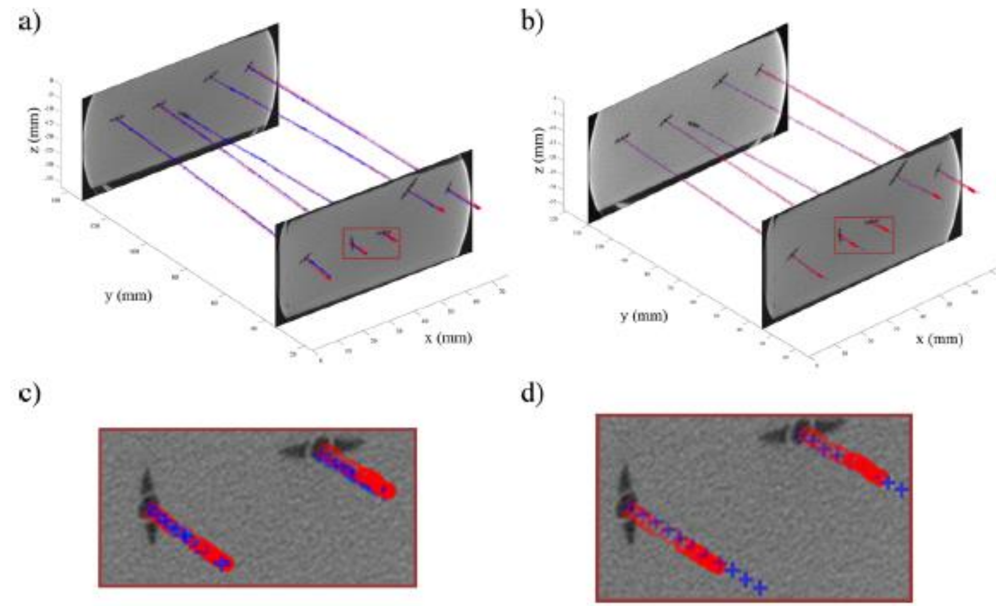
- Pinhole collimators over diode array, in dummy TRUS probe for prostate
- Collimators allow source position to be reconstructed
- Phantom study: 90% of source positions within 1mm
- 3D, measured source height biased in direction of pinhole



BrachyView, a novel in-body imaging system for HDR prostate brachytherapy: Experimental evaluation
M. Safavi-Naeini, Z. Han, S. Alnaghy, D. Cutajar, M. Petasecca, M. L. F. Lerch, D. R. Franklin, J. Bucci, M. Carrara, M. Zaider, and A. B. Rosenfeld
Medical Physics **42**, 7098 (2015); doi: 10.1118/1.4935866

Electro-magnetic reconstruction

- External EM field generator with sensor inserted into catheters.
- Compared to standard planning CT and high resolution CT.
- EM more accurate than planning CT, 0.7 mm reconstruction errors.
- 10s per catheter reconstruction time
- 3D



Fast, automatic, and accurate catheter reconstruction in HDR brachytherapy using an electromagnetic 3D tracking system
Eric Poulin, Emmanuel Racine, Dirk Binnekamp, and Luc Beaulieu
Medical Physics **42**, 1227 (2015); doi: 10.1118/1.4908011

Experience in Leeds

- Routine MOSFET* in-vivo dosimetry for HDR prostate patients ~130 so far
- 15Gy single # +37.5/15 EBRT
- 19Gy single # monotherapy
- 19Gy single # salvage
- Trans-rectal ultrasound real-time planning approach

* Metal Oxide Semiconductor Field-Effect Transistor

MOSFET system

- MicroMOSFET TN-502RDM (Best Medical, Canada), standard bias
- Fits inside interstitial needle
- Lifetime 20,000 mV (~200 Gy)
- Hand held reader, automatic 20s readings
- Oncentra Prostate TPS
- Flexitron v3 afterloader

MOSFET commissioning and calibration

- No corrections for linearity, anisotropy and temperature dependence within measurement uncertainty
- Correction for MOSFET energy dependent response
  - MOSFET relative response increases as photon energy decreases (i.e with increasing source-MOSFET distance)
- Individual calibration, re-calibrate 2-3 times as response decreases (~5%) with accumulated irradiation
- Pre-irradiate 2000 mV as change in response greatest during initial usage

Radiotherapy and Oncology 120 (2016) 333–338
Contents lists available at ScienceDirect
ELSEVIER
Radiotherapy and Oncology
journal homepage: www.thegreenjournal.com

In vivo dosimetry in prostate RT

Real-time in vivo dosimetry in high dose rate prostate brachytherapy

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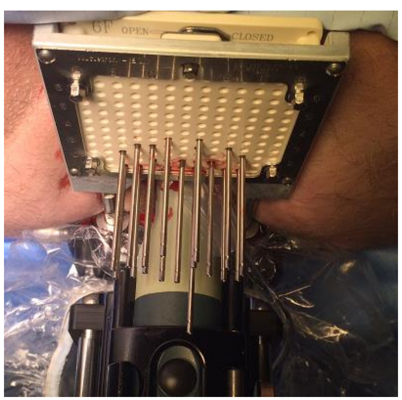
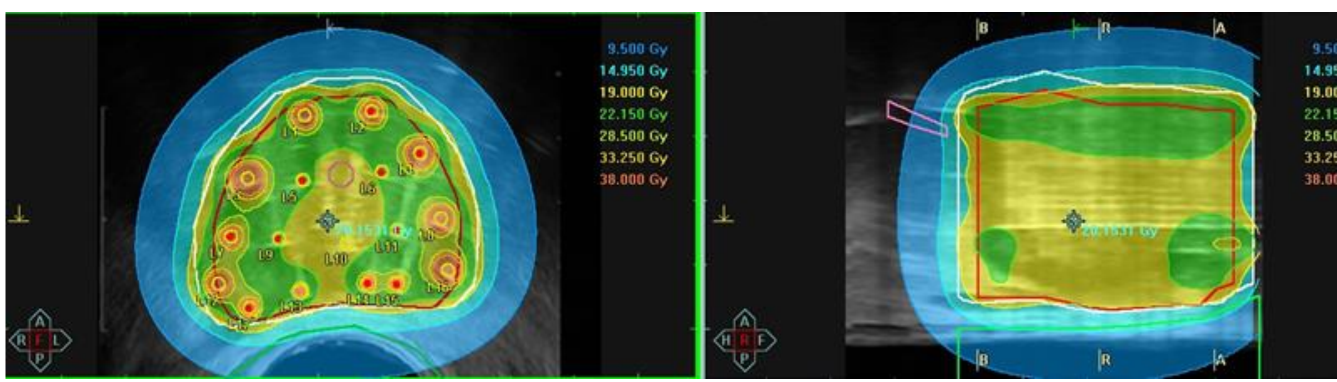
Impact on planning workflow

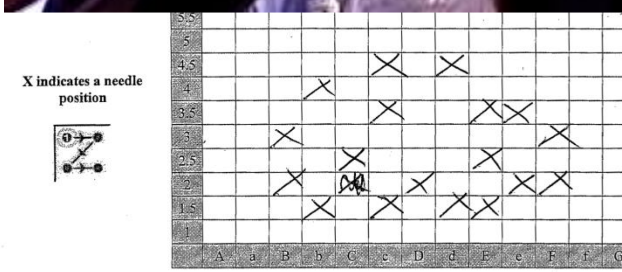
- Additional needle inserted for MOSFET
- Aim to position MOSFET centrally but avoiding urethra
- MOSFET position reconstructed in plan
- MOSFET needle deleted from plan
- Export plan data to predict per-needle reading





Radiographer workflow

- Two brachytherapy radiographers present
- Check free length measurements – 2mm tolerance
- Connect transfer tubes & cross-check



Needle/ Channel	Grid Position	Hub-Surface Template Distance (cm)		Needle/ Channel	Grid Position	Hub-Surface Template Distance (cm)	
		Theatre	Pre Treatment			Theatre	Pre Treatment
1	4.5c	6.1	6.2	11	2.0B	6.1	6.1
2	4.5d	6.1	6.2	12	2.0D	6.2	6.3
3	4.0b	6.1	6.3	13	2.0e	6.05	6.1
4	3.5c	6.2	6.3	14	2.0F	6.2	6.2
5	3.5E	6.2	6.3	15	1.5b	6.15	6.2
6	3.5e	6.0	6.0	16	1.5c	6.2	6.2
7	3.0B	6.2	6.3	17	1.5d	6.1	6.2
8	3.0F	5.9	6.0	18	1.5E	6.0	6.0
9	2.5C	6.2	6.2	19			
10	2.5E	6.2	6.2	20			
Initials		JM	CW / VC	Initials		JM	CW / VC.

Radiographer workflow (cont)

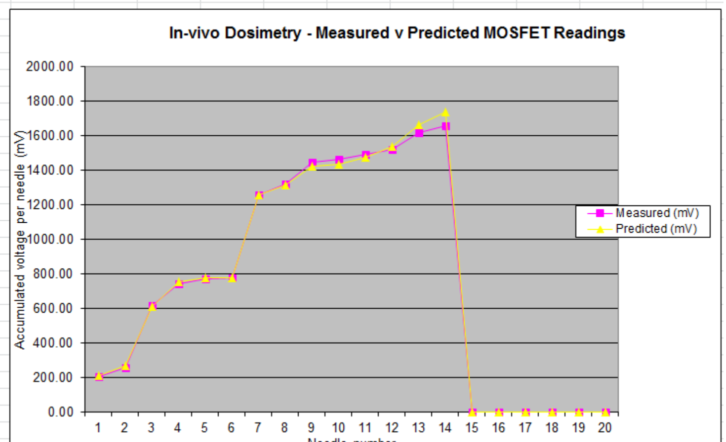
- MOSFET inserted into needle to correct depth and secured with tape
- MOSFET reader positioned so monitored on camera
- Check cable run and final checks

Radiographer workflow (cont)

- Operator one delivers treatment, operator two records MOSFET readings
- 20s readings, Flexitron check cable run ~30s
- This allows reading to be entered at start and after each needle
- MOSFET removed and cleaned at end

Measurements recorded during treatment delivery

Time treatment started	1145	
Catheter	Reading (mV)	Reading per catheter (mV)
Initial	-21.29	
1	182.55	203.84
2	238.84	56.29
3	594.29	355.45
4	722.09	127.8
5	753.28	31.19
6	756.29	3.01
7	1239.58	483.29
8	1298.6	59.02
9	1424.56	125.96
10	1442.53	17.97
11	1474	31.47
12	1500.99	26.99
13	1594.79	93.8
14	1639	44.21
15		
16		
17		
18		
19		
20		
Time treatment ended	1205	



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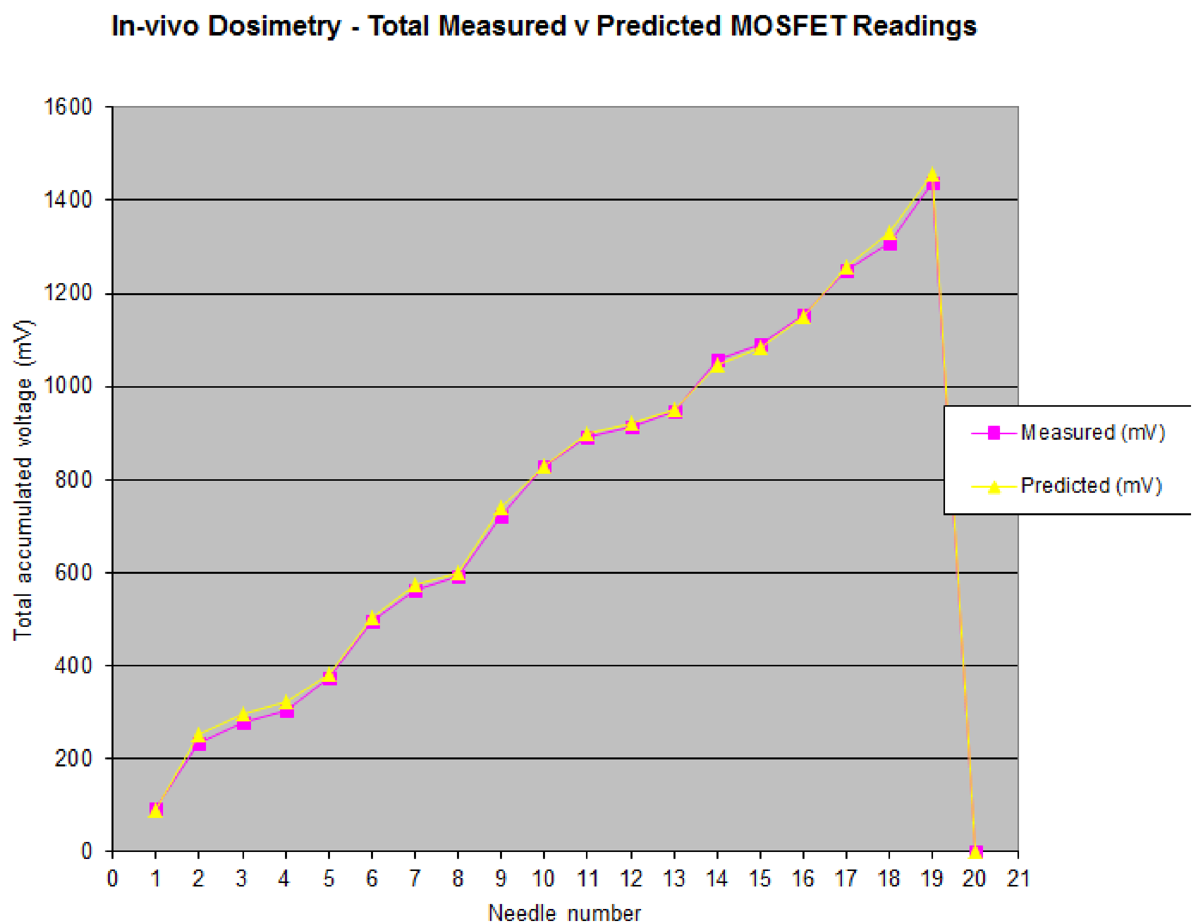
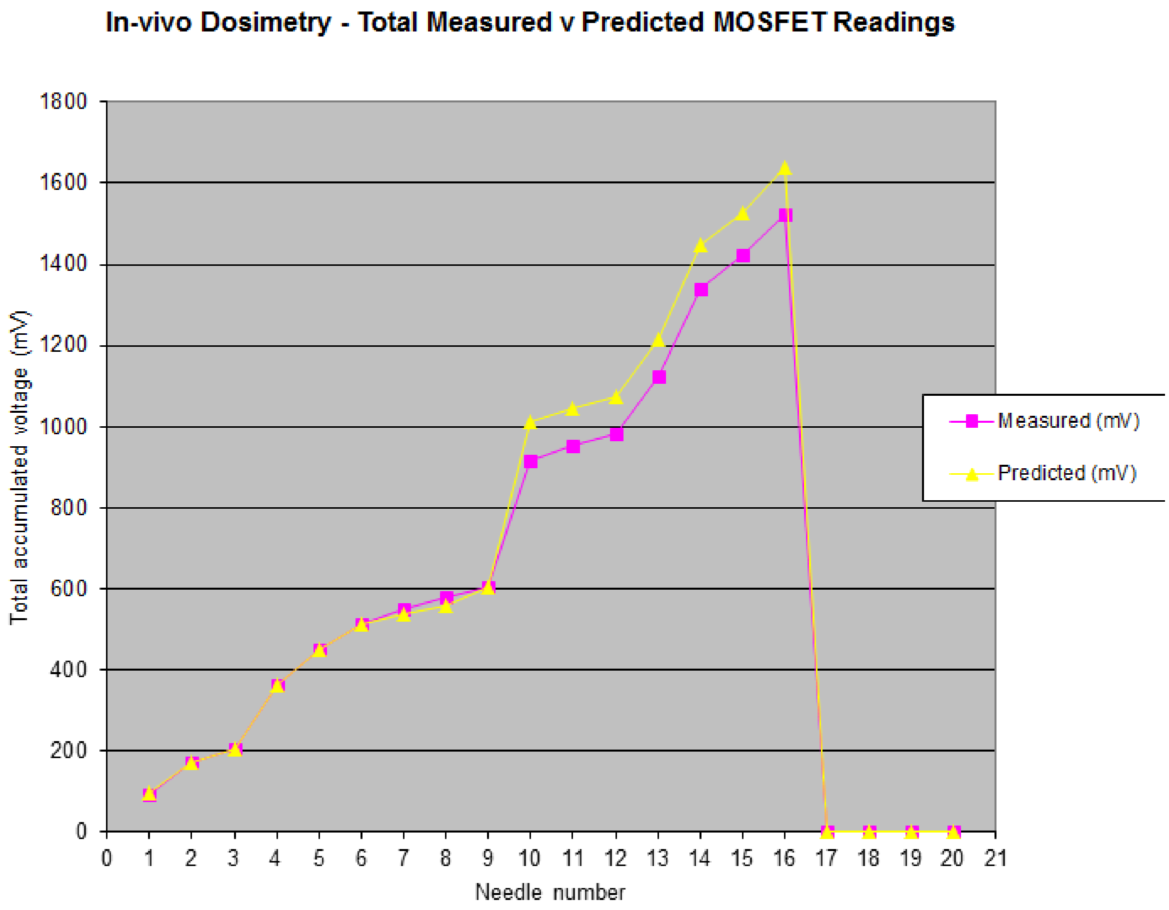
Clinical experience

- MOSFET has not added noticeable time onto treatment length
- Problems
  - MOSFET falling out during treatment
  - Missed readings – stored in reader
- Advantages
  - Safety check
  - Afterloader problems eg lost treatment halfway through

Patient measurements (1)



Patient measurements (2)



Results summary

- Measured dose for plan compared to prediction: mean difference -5% (range +7% to -16%)
- Systematically low
  - Post treatment imaging showed ~2% dose reduction at MOSFET position
  - Ultrasound reconstruction accuracy?
  - Distance correction interpolated at small distances?

Real-time error detection

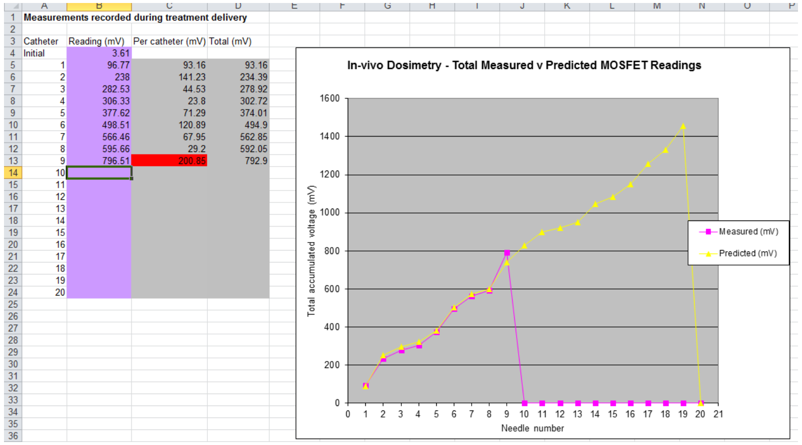
- Error detection threshold for total plan and per-needle based on uncertainty analysis
- Position uncertainty dominates per-needle error threshold
  - At 5mm distance, 1mm position error changes dose ~40%

Description	Type	Per needle uncertainty	Total plan uncertainty
MOSFET calibration (k=1)	A	2.7 %	2.7 %
Energy correction (k=1)	A	1.7 %	0.3 %
Angular dependence (k=1)	A	3 %	0 %
Source calibration (k=1)*	A	2 %	2 %
TPS dose calculation (k=1)*	B	3 %	3 %
Position uncertainty (k=1)	B	13.0% (6.1% - 55.1%)	4.1% (2.7% - 7.2%)
MOSFET reproducibility (k=1)	A	3.4% (0.8% - 47%)	0.4% (0.3% - 0.5%)
Mean total uncertainty (k=2)		31.9 % (18.3 % - 111 %)	12.3 % (10.6 % - 17.0 %)

* Taken from Kirisits et al. Review of clinical brachytherapy uncertainties: Analysis guidelines of GEC-ESTRO and the AAPM. Radiotherapy and Oncology 2014;110:199-212

Real-time error detection

- Use uncertainty analysis to flag plan/needle measurements as potential errors
- Plan: potential error if result outside k=2 uncertainty threshold
- Needle: potential error if result outside k=2 uncertainty threshold and absolute difference > 20mv (~0.2Gy)


Measurements recorded during treatment delivery

Catheter	Reading (mV)	Per catheter (mV)	Total (mV)
Initial	3.61		
1	96.77	93.16	93.16
2	238	141.23	234.39
3	282.53	44.53	278.92
4	306.33	23.8	302.72
5	377.62	71.29	374.01
6	498.51	120.89	494.9
7	566.46	67.95	562.85
8	595.66	29.2	592.05
9	796.51	200.85	792.9
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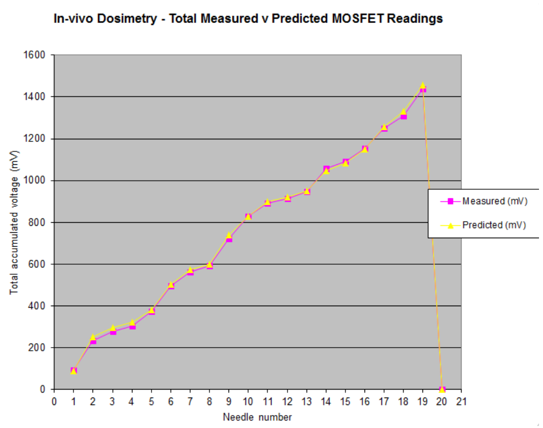
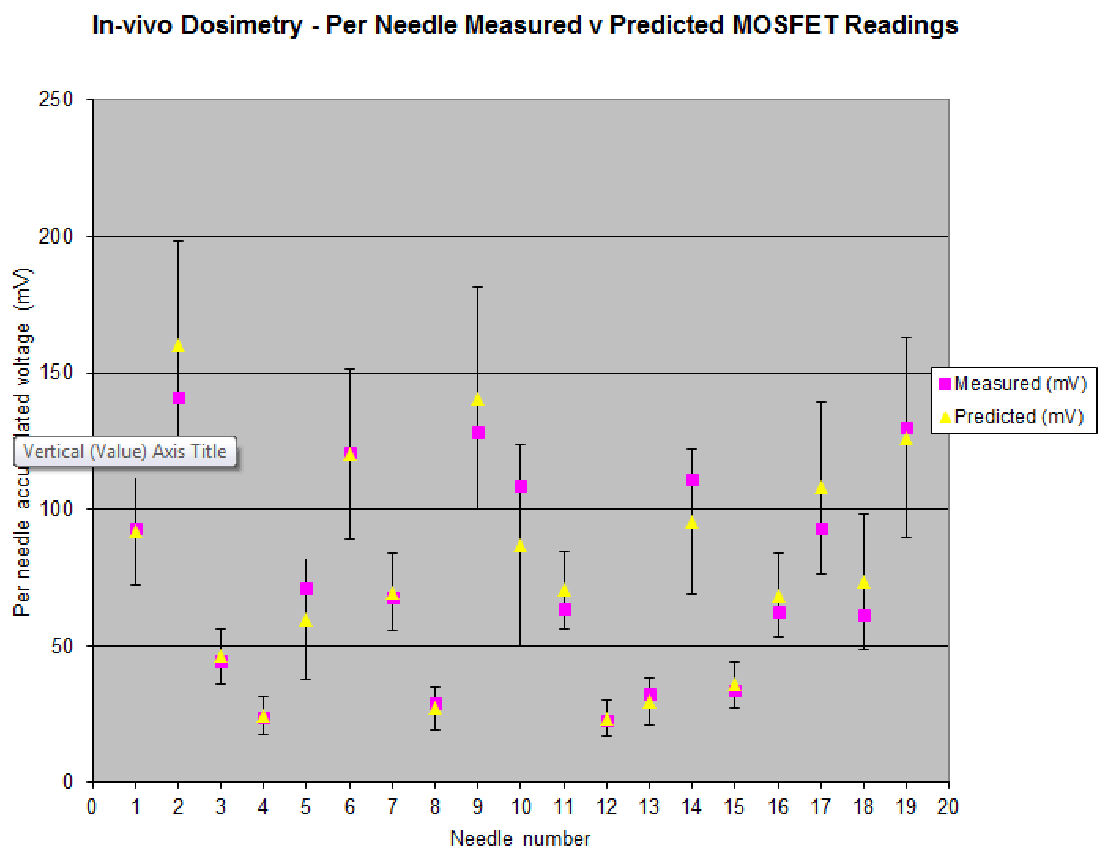
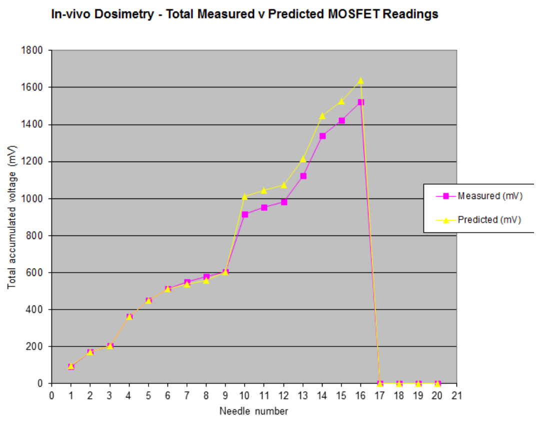
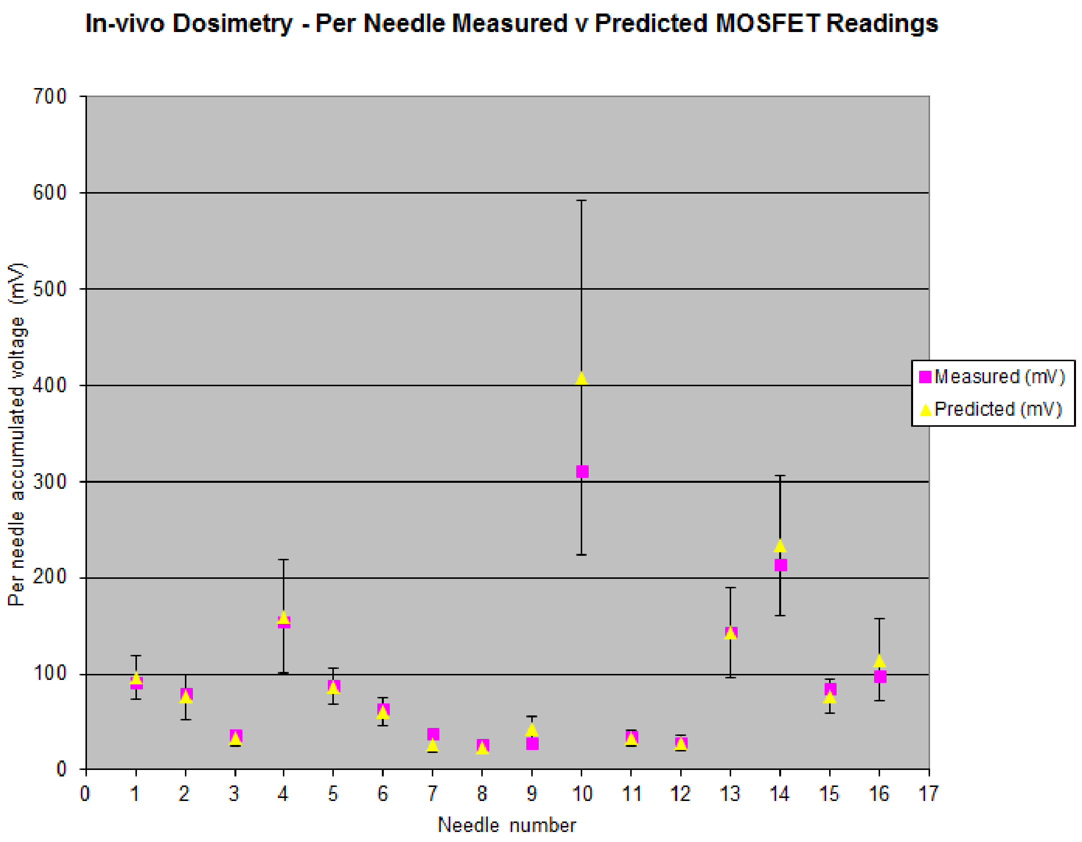
Patient measurements (1)





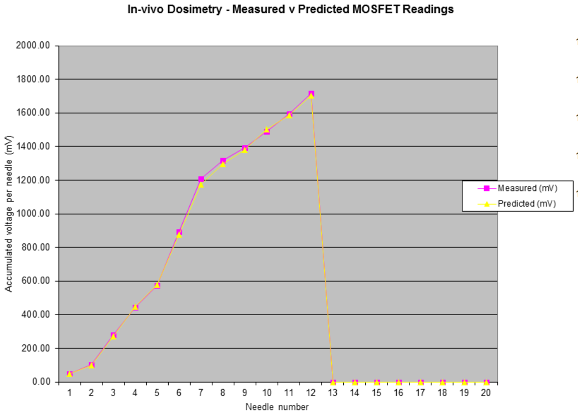
Patient measurements (2)



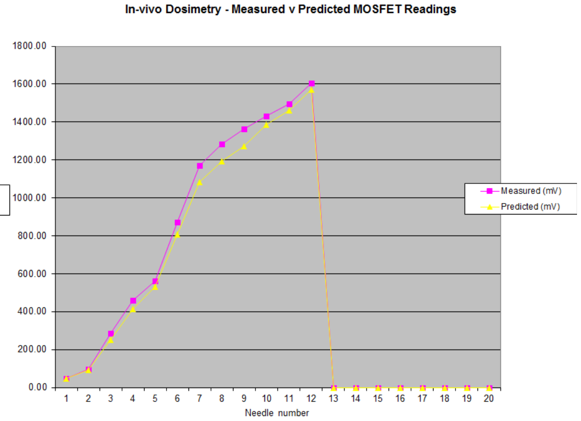


Limitations of single point of measurement – simulated treatment errors

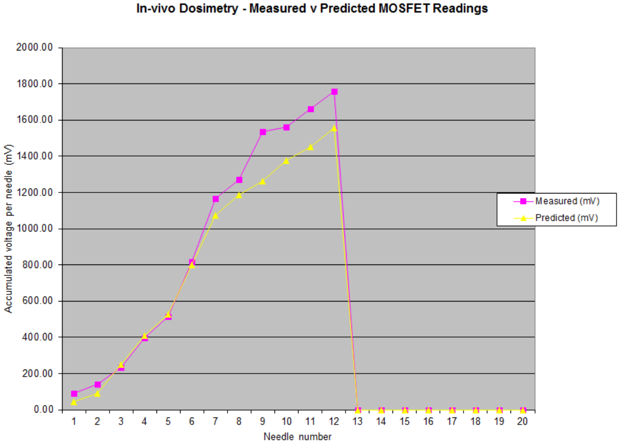
No error



Interchange 3+5, 7+11



Interchange 1+3, 9+10



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Conclusions (1)

- MOSFET is straightforward and cost-effective means for performing in-vivo dosimetry
- Gives confidence in dose we are delivering
- Reassurance in cases where afterloader problems resulted in interrupted treatments being completed on non-standard pathway

Conclusions (2)

- Commissioning and calibration work is significant
- Measurements systematically ~5% less than prediction unexplained
- Single point of measurement – not all errors would be detected, may be hard to assess dosimetric impact of errors
- Difficult access in cases of small prostates

- Thanks to all of our prostate brachytherapy MDT for their work on this: clinical oncologists, radiologists, physics, radiographers and theatre staff.