In vivo dosimetry in clinical practice

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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

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 significantly improved ability to detect errors compared to total integrated dose.

- Adaptive position determination algorithm
- To exclude false errors due to position uncertainty
- Urethral dose in HDR prostate brachy measured using scintillation detector
- Continuous readout
- 24 patients
- Agreement within 9%

- 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

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
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
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
• 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
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)

In-vivo Dosimetry - Total Measured v Predicted MOSFET Readings

- Measured (mV)
- Predicted (mV)

Total accumulated voltage (mV)

Needle number
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 \( \sim 40\% \)
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)
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
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
Thank you for listening

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