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Working Together to Shape the Future of
Brachytherapy

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***In Vivo* Dosimetry in Brachytherapy: Feasible and Needed?**

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Disclosure

Annette Haworth, PhD, FACPSEM, does not have any financial relationships or products or devices with any commercial interest related to the content of this activity of any amount during the past 12 months.



In Vivo Dosimetry in Brachytherapy: Feasible and Needed?

- Is it needed?
 - Is there any evidence that *in vivo* dosimetry could have prevented accidents/mis-administrations?
 - Will it be of benefit for future developments in brachytherapy?
- Is it feasible?
 - What systems are currently available?
 - What's in development?

Needed?

We deliver high doses in small numbers of fractions, often under high-pressure situations

- What can possibly go wrong?
 - ICRP Publication 97 & 86, IAEA RS17, WHO 2009
 - *Incidents are mostly related to procedural errors*
 - *Malfunctions are noted*
 - We have minimal R&V
 - *Might tell us what the system thought it delivered, but doesn't tell us if we connected the catheters correctly, selected the correct indexer length, etc*
 - Conclude
 - *Lack of good systematic evidence makes it difficult to justify to administrators, but there is sufficient evidence to show errors can and do happen in brachytherapy*



Is *in Vivo* Dosimetry Needed to Further the Developments in Brachytherapy?

- Are our current dose constraints based on accurate knowledge of the dose we delivered to our patients?
- Can we safely dose escalate?
- Can we be confident it is safe to deliver increasingly conformal dose distributions?
- Do we want to assure our patient's brachytherapy is a safe and accurate treatment option?



Feasible?

Let's first look at what's available

- Broad categories
 - Real time vs post processing
 - Invasive vs passive
 - LDR/HDR/PDR
 - Gross error vs high accuracy
 - Dose to OAR, PTV other?
 - What are we trying to detect?
 - Needle/applicator slippage
 - Organ motion
 - Malfunction
 - Human error
 - What can we measure:
 - Source position in 3D?
 - Source position relative to anatomy?
 - Dose rate?
 - Integral dose?

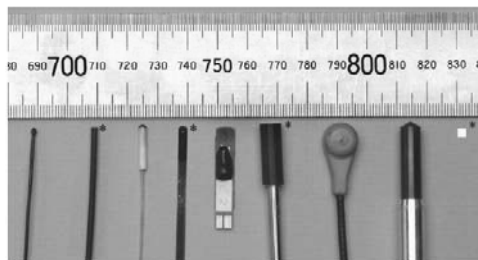


FIG. 1. A pictorial view of nine types of dosimeter; from left these are 0.5 mm BrachyFOD™, 1 mm BrachyFOD™, scintillation detector with a silica optical fiber, Thomson and Nielsen RD502 MOSFET*, PTW-Freiburg OneDose MOSFET, PTW-Freiburg type 60003 diamond detector*, *in vivo* diode, ionization chamber, and a 3 × 3 × 0.9 mm³ LiF TLD*. *Used in this study.

Lambert et al. *Med Phys*. 2007



Challenges in *in Vivo* Dosimetry in Brachytherapy

- High dose gradients
 - Slight detector displacement = large dose discrepancy
 - Close to source = high signal + large dose gradient
 - Far from source = low signal
- Detectors placed within tumor or cavity
 - Clinically relevant dose (rate) readings
 - Risk needs to be offset by benefit
 - Additional needle insertion
 - Infection
 - Prolonged workflow
- Threshold for error detection
 - Compromise on sensitivity and specificity

What Systems Have Been Reported in the Literature?

- Few commercial systems
- Few clinical trials (mostly phantom studies)
- Cost largely unknown
- General vs site specific
- Single vs multiple detectors
- Refer to Vision 20/20 paper (next slide) for comprehensive overview



TABLE III. Characteristics of detectors and dosimetry systems of importance for precise routine IVD in brachytherapy. The items are rated according to: advantageous (++), good (+), and inconvenient (-).

	TLD	Diode	MOSFET	Alanine	RL	PSD
Size	+	+/-	+++	-	++	++
Sensitivity	+	++	+	-	++	+/++
Energy dependence	+	-	-	+	-	++
Angular dependence	++	-	+	+	++	++
Dynamic range	++	++	+	-	++	++
Calibration	+	++	++	-	-/+	+/++
procedures, QA, stability, robustness, size of system, ease of operation						
Commercial availability	++	++	++	++	-	+
Online dosimetry	-	++	+	-	++	++
Main advantages	No cables, well studied system	Commercial systems at reasonable price, well studied system	Small size, commercial system at reasonable price	Limited energy dependence, no cables	Small size, high sensitivity	Small size, no angular and energy dependence, sensitivity * Stem effect *
Main disadvantages	Tedious procedures for calibration and readout, not online dosimetry	Angular and energy dependence	Limited life of detectors, energy dependence	Not sensitive to low doses, tedious procedures for calibration and readout, not online dosimetry, expensive readout equipment not available in clinics	Needs frequent recalibration, stem effect, not commercially available	

From Tanderup et al. *Med Phys.* 2013

*See comments on stem effect in Therriault-Proulx, *Med Phys*, 2011

What Makes a Good *in Vivo* Dosimeter?

- Small (high spatial resolution)
- Low energy dependence
- Temperature insensitivity
- Patient compatible
 - (eg, can be sterilized, etc)
- Doesn't impact workflow
- Calibration is stable (minimize physics QA time)

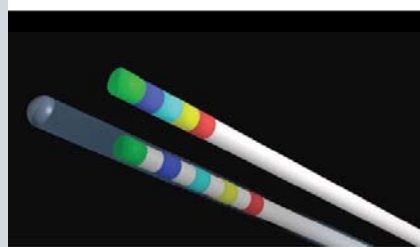
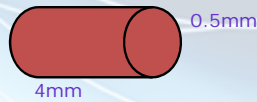
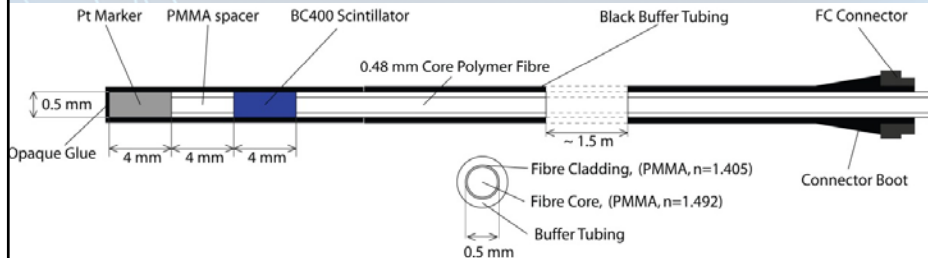


FIG. 2. mPSD line detector inserted into a flexible catheter.

Therriault-Proulx 2012, see Tanderup 2013



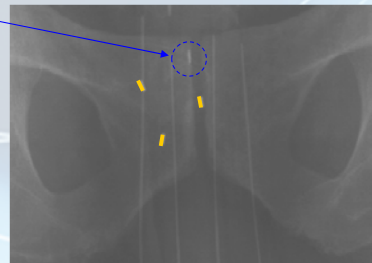
What's Out There? Example 1 FOD Scintillation Dosimetry



Slides courtesy of Natalka Suchowerska, Chris O'Brien Lifecare, Sydney *This is the urethral FOD design only*

Clinical Trial

- Prostate HDR brachytherapy patients
- Detector in urethra
- 10 patients recruited
- Measured dose to urethra
- 3 fiducial markers localize prostate
- RFOD is clearly visible
- LED self check facility to verify optical integrity of RFOD system



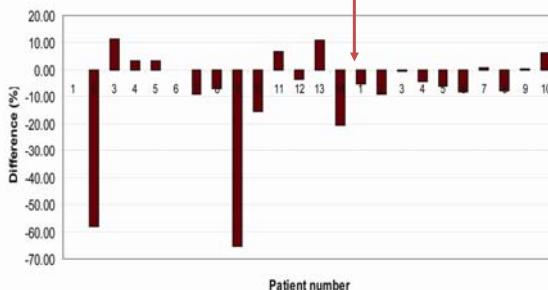
Yin et al. *Phys Med Biol.* 2008

Slides courtesy of Natalka Suchowerska, Chris O'Brien Lifecare, Sydney



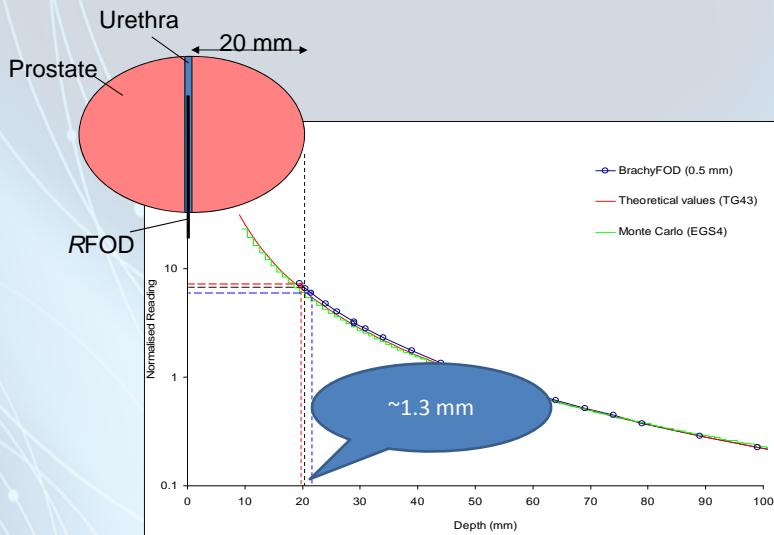
Clinical Trial Results

- Overall increase in time for procedure 2 minutes
- Delivered dose was within 9% of calculated dose after introduction of LedFOD and RFOD



Slides courtesy of Natalka Suchowerska, Lifehouse, Sydney

Dose Gradient

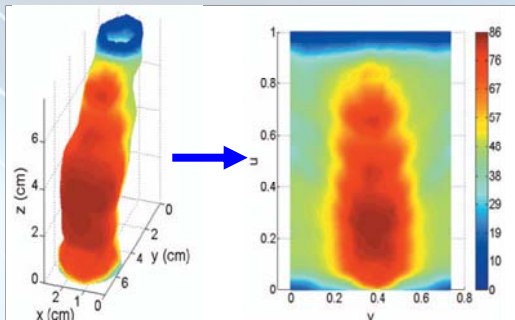


Slides courtesy of Natalka Suchowerska, Lifehouse, Sydney



Array Dosimetry

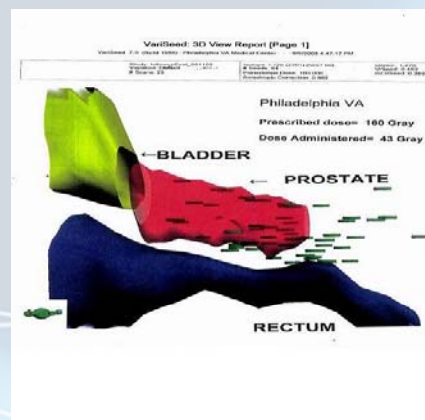
- A dosimetry system capable of measuring the dose to the rectal wall
- To provide a dose map on an unfolded rectum
- To track the radioactive source progression in real time



Slides courtesy of Natalka Suchowska, Lifehouse, Sydney

What's Out There for LDR?

- *Because the quality of the procedure is only evaluated using postimplantation computed tomography (CT), less than optimal dosimetric outcomes only become apparent to a physician when reviewing the postimplantation CT scans; thus, making amends for a flawed implant requires an additional surgical procedure.*
 - Zelefsky, 2011

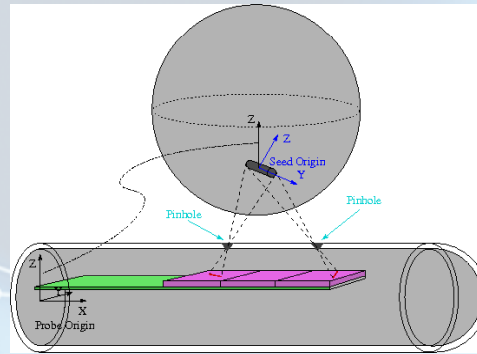




What's *coming* here for LDR?

Example 2 BrachyView, 3D Seed Position for LDR

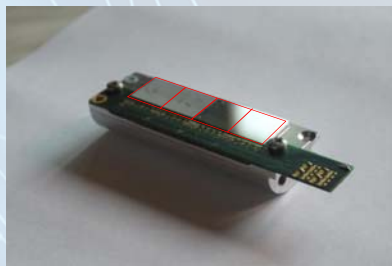
- Combines high spatial resolution pixelated silicon detector (Medipix2) with volumetric information from TRUS
- Detectors are embedded in the probe
- Provides anatomically correct seed positions for intraoperative planning and real-time dosimetry



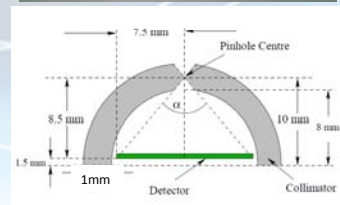
Slides courtesy of Anatoly Rosenfeld, CMRP, UOW Australia

Works in Progress

- Assembling of the quad device with the cylindrical Tungsten collimator designed and manufactured at CMRP



Cross section of the collimator 25.4-mm outer diameter

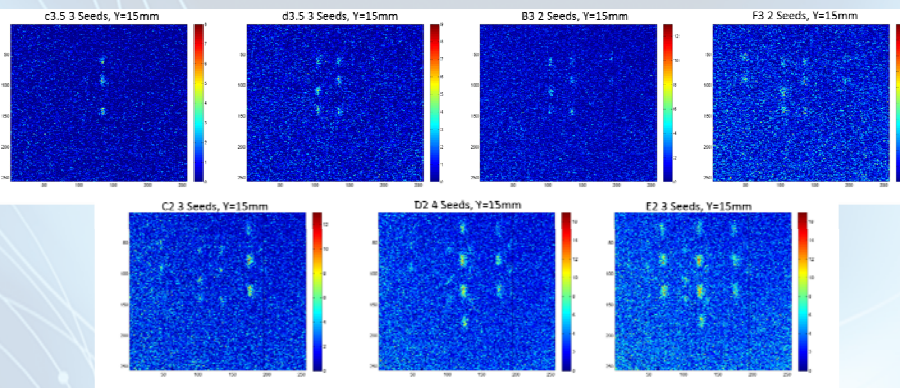


Slides courtesy of Anatoly Rosenfeld, CMRP, UOW Australia



How it Works

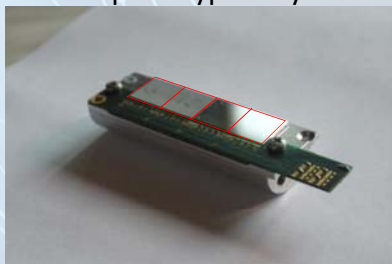
- Projection images show the progression of the implant as it occurs
- Measurements are designed to simulate the presence of multiple detectors coupled with multiple pinholes
- Obtain center of mass of each seed's projection



Slides courtesy of Anatoly Rosenfeld, CMRP, UOW Australia

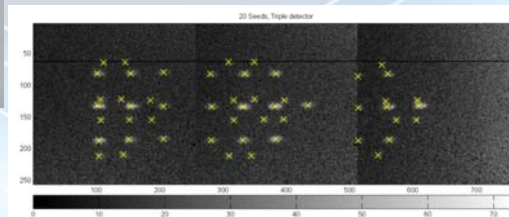
Works in Progress

- Tiled triple or quad chip design for seamless image and single acquisition
- Refinement of pinhole and probe design
- First prototype fully functioning manufactured



Yellow crosses represent the center of mass of the seed automatically recognized by the software

Single 60 seconds acquisition of 3 pinholes on a triple detector



Slides courtesy of Anatoly Rosenfeld, CMRP, UOW Australia

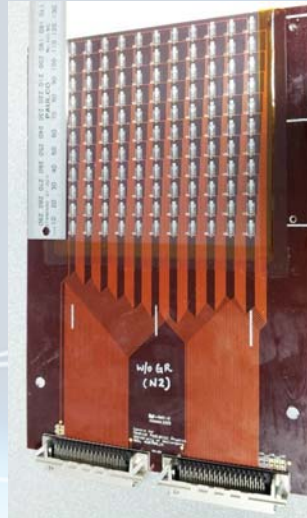


Also From CRMP: The Magic Plate

Prototype for BrachyPix System:

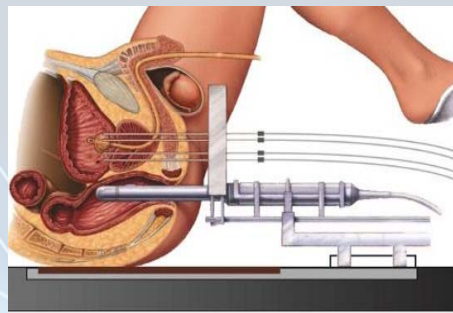
- CMRP Silicon Epitaxial diode
 - Radiation hard by design
 - Sensitive volume $\sim 0.8 \times 0.8 \times 0.05 \text{ mm}^3$
- 121 Epitaxial diodes in 11 x 11 array
- Size - $16 \times 25 \text{ cm}^2$
- Magic Plate thickness - 0.4 mm
- Utilizes fast readout system within user set time frame (1-100 ms)

Patent: WO2008/148150 AI
PCT/au2008 000788 (2008)
Patent China, issued, 2012
Patent USA, issued, 2014



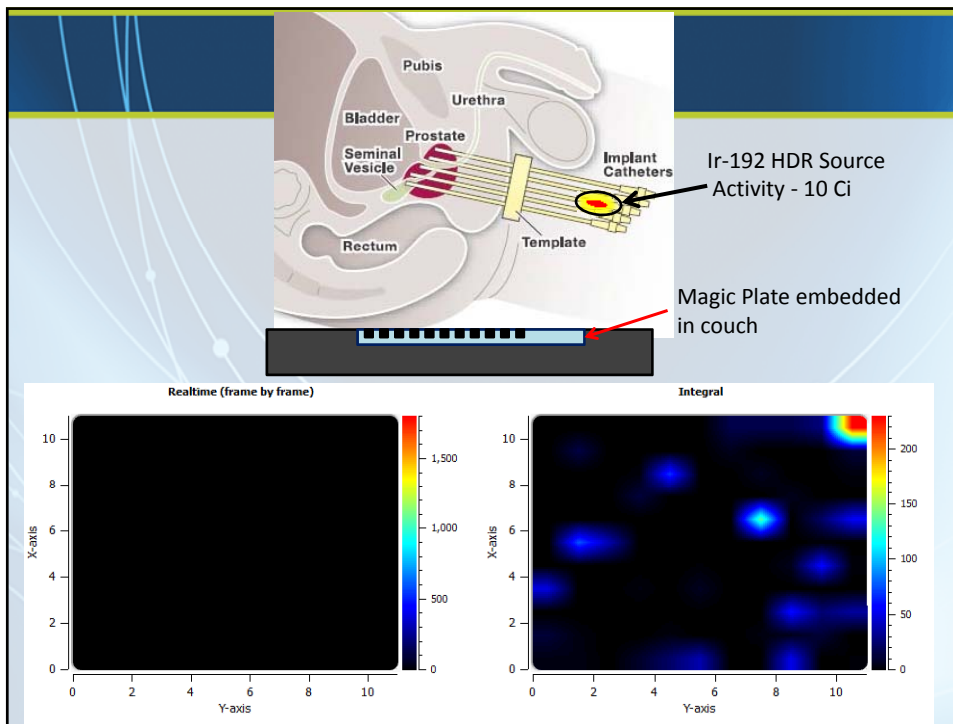
Slides courtesy of Anatoly Rosenfeld, CMRP, UOW Australia

In Vivo QA in HDR Brachytherapy



BMP512 is embedded in a couch and placed below prostate. TRUS probe stepper frame is fixed on a couch making rigid alignment with a BMP512.

Slides courtesy of Anatoly Rosenfeld, CMRP, UOW Australia



A New Metric: Position-Time Gamma Index

The graph shows Position (mm) on the y-axis (ranging from 50 to 55) and Time (s) on the x-axis (ranging from 32 to 37). Two data series are plotted: 'Measured' (red line) and 'TPS' (black line). Both series show a step-wise increase in position over time, with the Measured data closely following the TPS data.

- Position-time gamma index based upon comparison between measured and calculated dose distributions introduced by Low *et al* (1998)
- Applying to HDR brachytherapy QA
 - Possibility to compare the measured and expected source position and timing patterns
- Technique assesses plan based on
 - Distance-to-agreement (DTA) and
 - Time-to-agreement (TTA)

Slides courtesy of Anatoly Rosenfeld, CMRP, UOW Australia



Now for Something Completely Different

Using a **flat panel imaging array (AKA EPID)**

- For source position verification
- +
 - Dosimetric verification

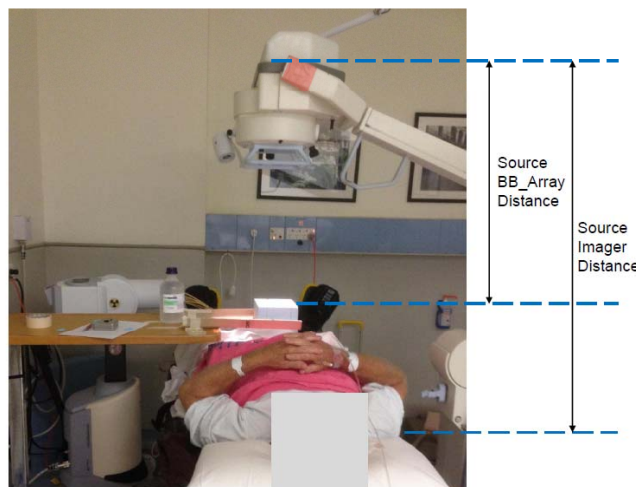


System addresses the issue of unknown/uncertain detector-source geometry, by explicitly measuring/confirming the geometric relationship between source and detector while measuring the source distribution as well as dose.

Smith et al. *Med Phys*. 2013

HDR Prostate With Catheters and Fiducial Markers *in Situ*

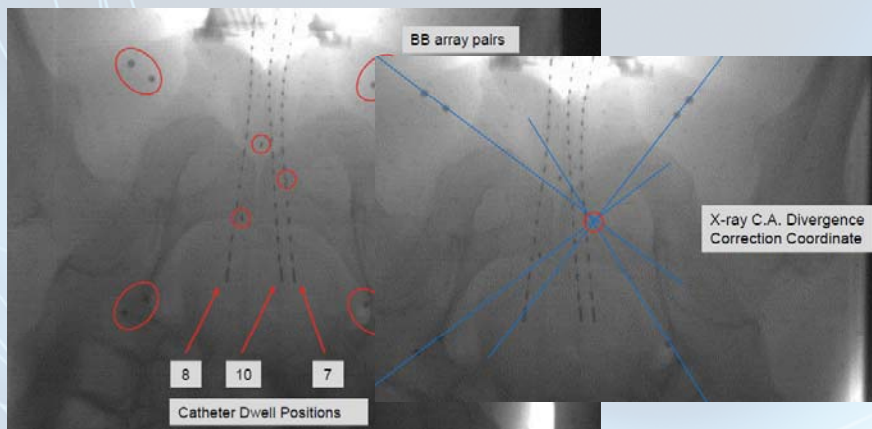
Align mobile x-ray unit and BB frame



Slides courtesy of Ryan Smith, William Buckland, Australia

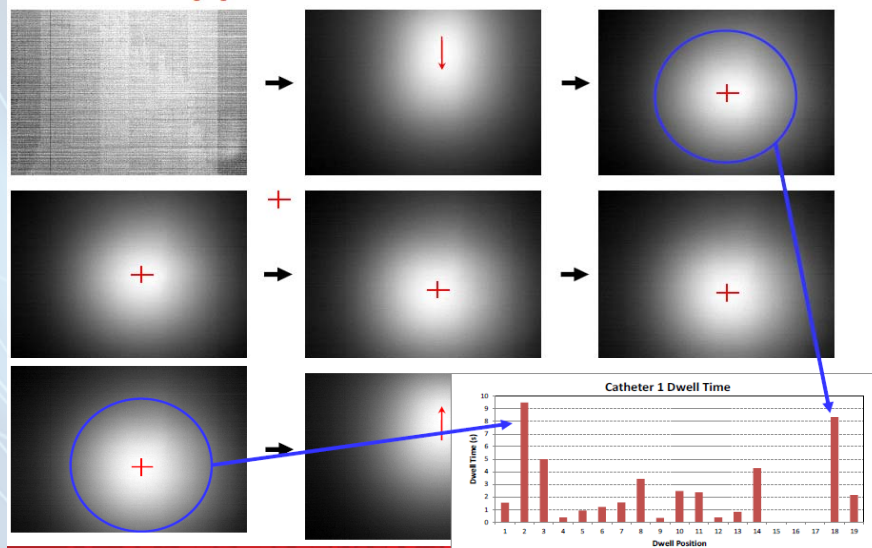


Acquire the Radiograph



Slides courtesy of Ryan Smith, William Buckland, Australia

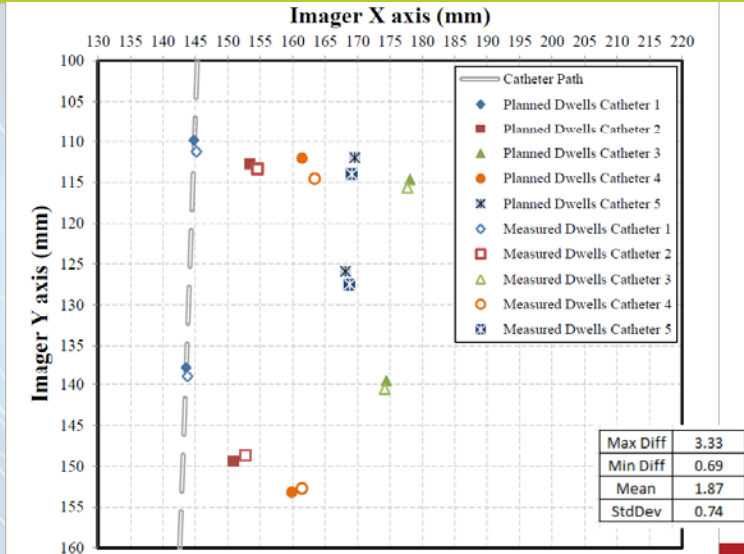
Images Are Captured as Source Steps Through Catheter



Smith et al. *Med Phys.* 2013



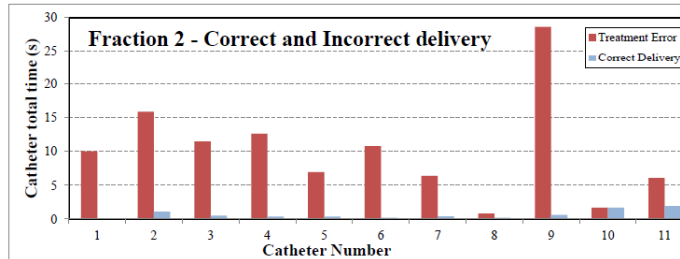
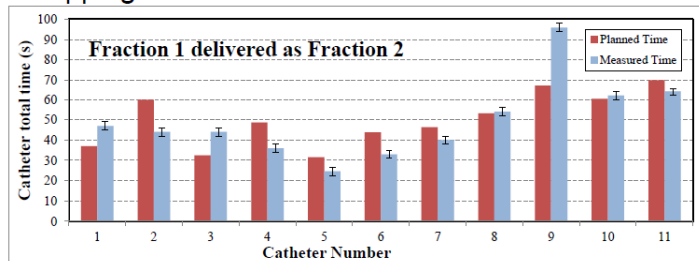
The System Compares Measured vs Planned Dwell Positions



Slides courtesy of Ryan Smith, William Buckland, Australia

...and

Error Trapping - Total Catheter Time



Slides courtesy of Ryan Smith, William Buckland, Australia



Feasible? Summary

- No perfect system exists
- Define what you are trying to do and what accuracy you need
 - How does it compliment your existing QA program?

**Remember: "treatment verification" doesn't only mean *in vivo* dosimetry, and *in vivo* dosimetry doesn't necessarily achieve treatment verification
You really need to do both.**

Rick Franich

Conclusions

- Needed?
 - Incidents have been reported that could have been prevented by use of *in vivo* dosimetry
 - But under-reporting and lack of systematic data collection makes developing business cases challenging
 - Our patients need to be assured that brachytherapy is safe and accurate
 - Future developments in brachytherapy require precise knowledge of the treatment that was actually delivered



Conclusions

- Feasible?
 - Several options exist/are in development
 - Choose the system that works best for your application/work flow
 - As need is demonstrated, commercialization of experimental systems will evolve

However!

- *In vivo* dosimetry is no substitute for:
 - Comprehensive QA program
 - Adequate training
 - Safety culture
- But!**
- *In vivo* dosimetry provides information not traditionally available to the clinical team
 - We need to address the issue “what will we do if we see an error/deviation”
 - If you don’t measure how good/bad you are, how can you attest to the quality of treatment you are giving??

Natalka Suchowerska



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- Prof Anatoly Rosenfeld
- Ryan Smith
- A/Prof Rick Franich

For their slides, resources, and many comments that I've incorporated into this presentation



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