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58TH ANNUAL MEETING & EXHIBITION | WASHINGTON, DC

Three Dimensional Dosimetry

Session Program: Therapy Education
Session Organizer: L. John Schreiner

Speakers: LJ Schreiner[1], S Ceberg[2], T Juang[3], G Ibbott[4]

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[2] Lund University, Lund, Sweden
[3] Stanford Cancer Center, Stanford, CA
[4] UT MD Anderson Cancer Center, Houston, TX

August 1, 2016

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Learning objectives

1: 3D Dosimetry in the Clinic: Background and Motivation

- Understand recent developments enabling clinically practical 3D dosimetry,
- Appreciate 3D dosimetry workflow and dosimetry procedures, and
- Observe select examples from the clinic.

2: 3D Dosimetry in the Clinic: Motion interplay effects in dynamic radiotherapy

3: 3D Dosimetry in the Clinic and Research: Special techniques

4: 3D Dosimetry in end-to-end dosimetry QA

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Disclosure

Over the years I have had the pleasure of working with various companies to test and develop ideas.

- **Most recently, Modus QA**
  - Testing readout systems and dosimeters under development, sharing software ideas…
  - No personal gain, but valuable in-kind research support.

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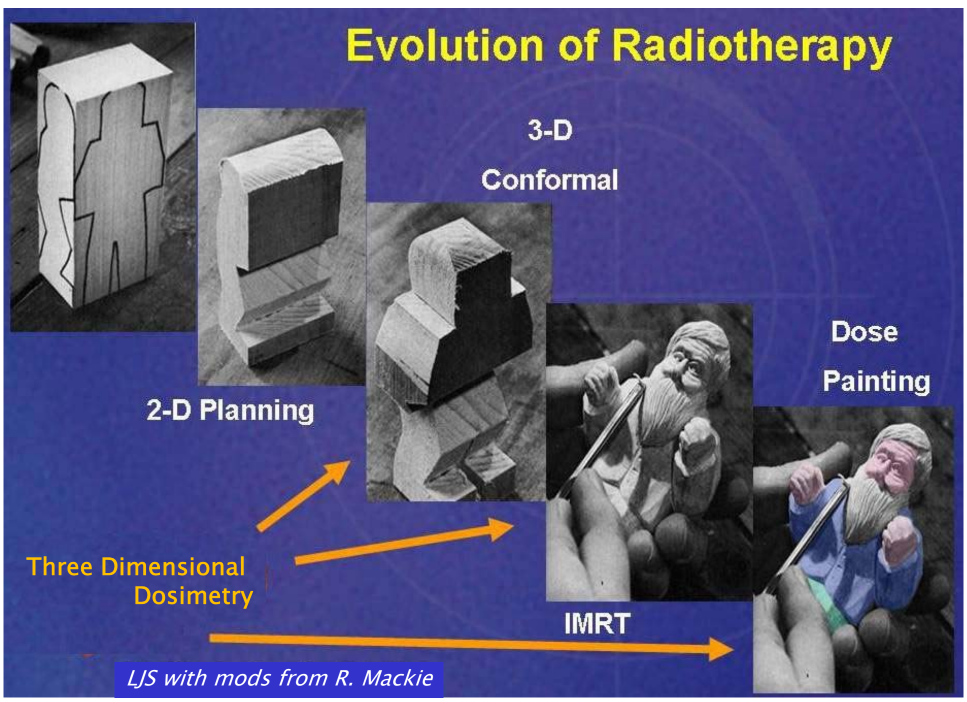


3D volumetric dosimeters

- **Chemical dosimeters that undergo radiation changes that can be probed by some physical technique**

Gel dosimeters

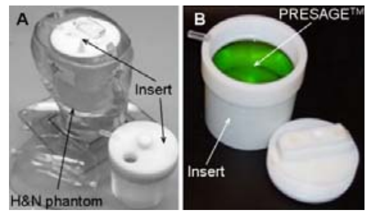
CCSEO

NIPAM

FXG

LCV micelle

PRESAGE
Radiochromic plastic



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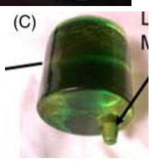

Mark Oldham Duke
Geoff Ibbott MDAnd

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~~3D volumetric dosimeters~~

- Chemical dosimeters that undergo radiation changes

- We are NOT considering:
  - Liquid Scintillators
  - Exit/transit dosimetry – EPIDS
  - Semi-3D systems – diode/ion chamber arrays

  These are important systems that have their place, but are not in the scope of this session.

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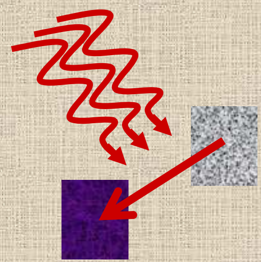
What typically comprises a volumetric 3D dosimeter?

hν



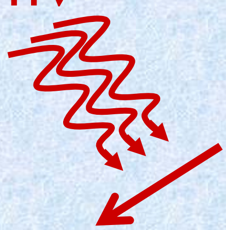
Some matrix through which some stuff is dispersed

(Stuff ≡ dose reporter molecules)

Small amount stuff that changes under irradiation

e.g., Fricke gel dosimeter

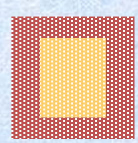
hν



Fe^{2+}

Fe^{3+}

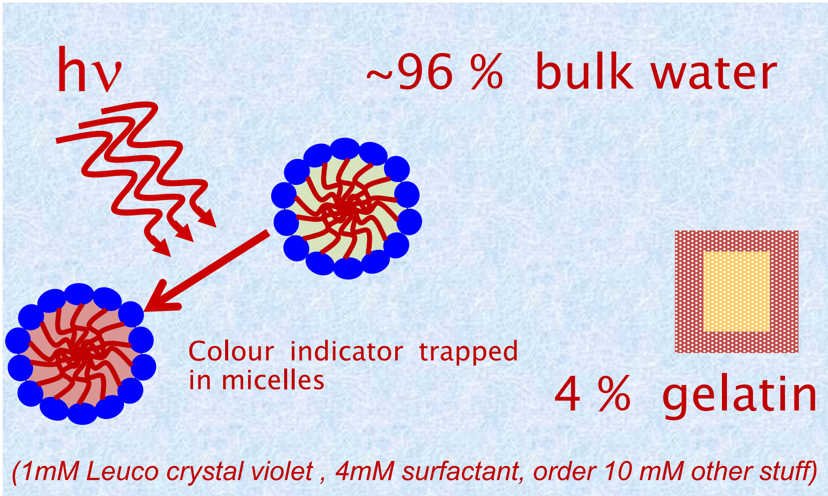
89 % bulk water



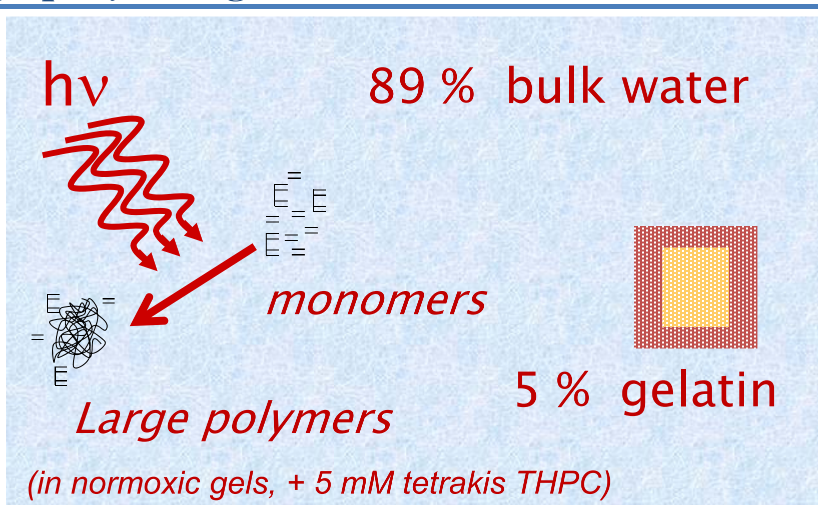
5 % gelatin

(in FX gels, + 0.05 mM xylenol orange)

e.g., radiochromic Leucodye micelle dosimeter

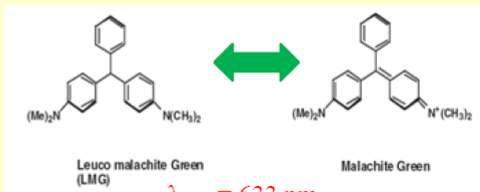


e.g., polymer gel dosimeter



Radiochromic Plastic: Presage

- a radiochromic Leucodye dispersed in polyurethane matrix
- Tissue equivalent
- Economical



λ_{max} = 633 nm

5 Beam Tx

(From Oldham AAPM 2011)

Typical 3D Dosimeters

records and retains spatial dose deposition information

3D!

high spatial resolution

manufactured in liquid form

anatomical equivalence

can be manufactures in anatomically equivalent phantoms

absorbs dose similarly to water/tissue

not necessary to correct for different absorption properties

tissue equivalent

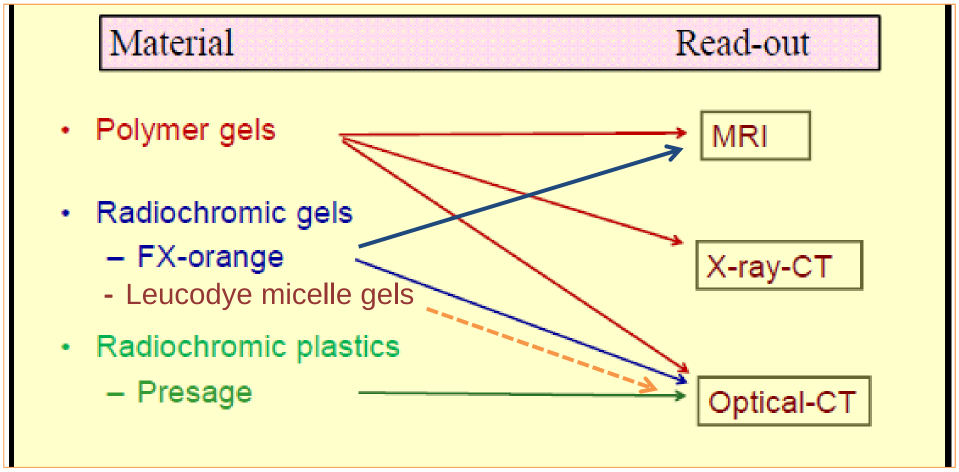
can experiment with other types of equivalence (e.g. lung)

dose integrating

can record dose over entire delivery (e.g. IMRT)

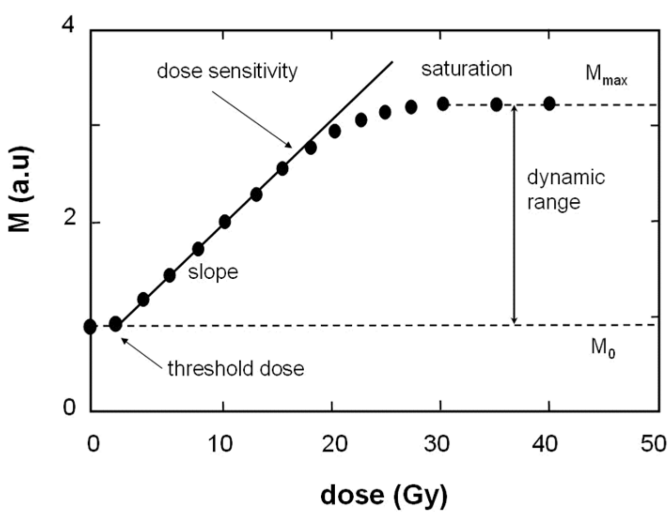
(c/o Andrew Jirasek, UBC Kelowna)

Dosimeter - 3D Readout



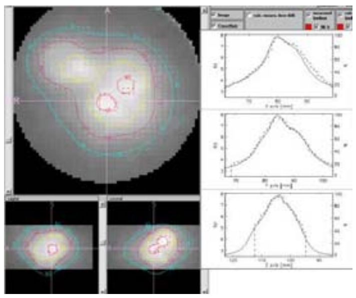
(adapted from M Oldham, Duke)

Model dose response

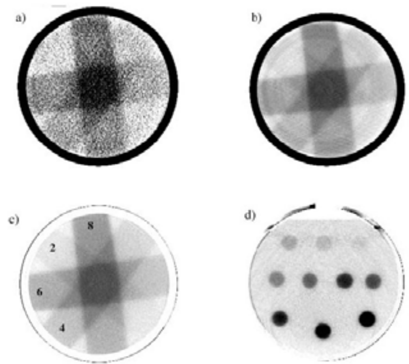


Not all dosimeters show a threshold or a saturation dose.

Examples of Readout

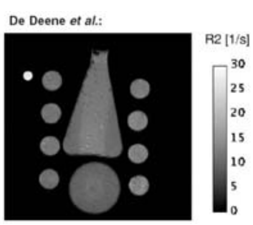


MRI: Schieb 2001



X-ray CT: Hilts *et al.* 2000

CALIBRATION



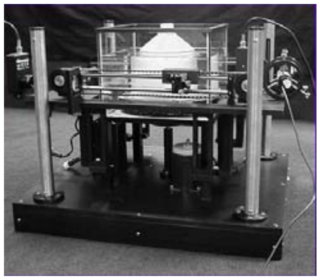
vials

Internal

Our Preference

Independent volumes from same batch of dosimeter

Optical CT



MGS Research

Modus QA

Based on change of optical attenuation coefficients in irradiated dosimeter

- *Fricke and Radiochromic dosimeters*
  - Absorption changes

Precision and accuracy of 3D systems

In our hands using gel dosimeters we have been able to achieve:

- Relative doses (precision)
  - 2 to 3% easily, <1 or 2% with work
- Delivered dose (absolute dose) (accuracy)
  - 3 to 5% easily, 1–2% with work

o

3D Dosimetry (old problems/solutions)

Not yet broadly clinically adopted

- Imaging for readout not always readily available
  → (MRI to optical CT or x-ray CT as available)
- Gel preparation (toxicity, oxygen contamination …)
  → (some systems easily prepared, commercial vendors)
- May have better tools for applications to be tested
  → (use the right tool for the right job)
- Data analysis laborious and lengthy
  → (open source Slicer-RT module)

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3D Dosimetry (old problems/solutions)

Commercial service providers for various systems and dosimeters:

- GeVero, Poland (www.polygevero.com)
- Heuris Pharma, USA (www.presage3d.com)
- MGS Research Inc., USA (www.mgsresearch.com)
- Modus QA, Canada (www.modusqa.com)
- RT Safe, Greece (www.rt-safe.com)

Apologies if this list is dated.

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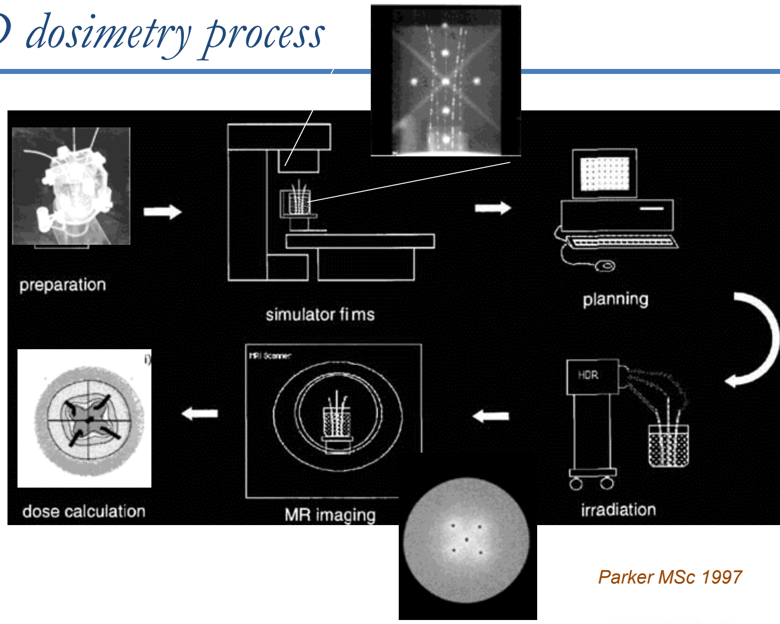
3D dosimetry process



Parker MSc 1997

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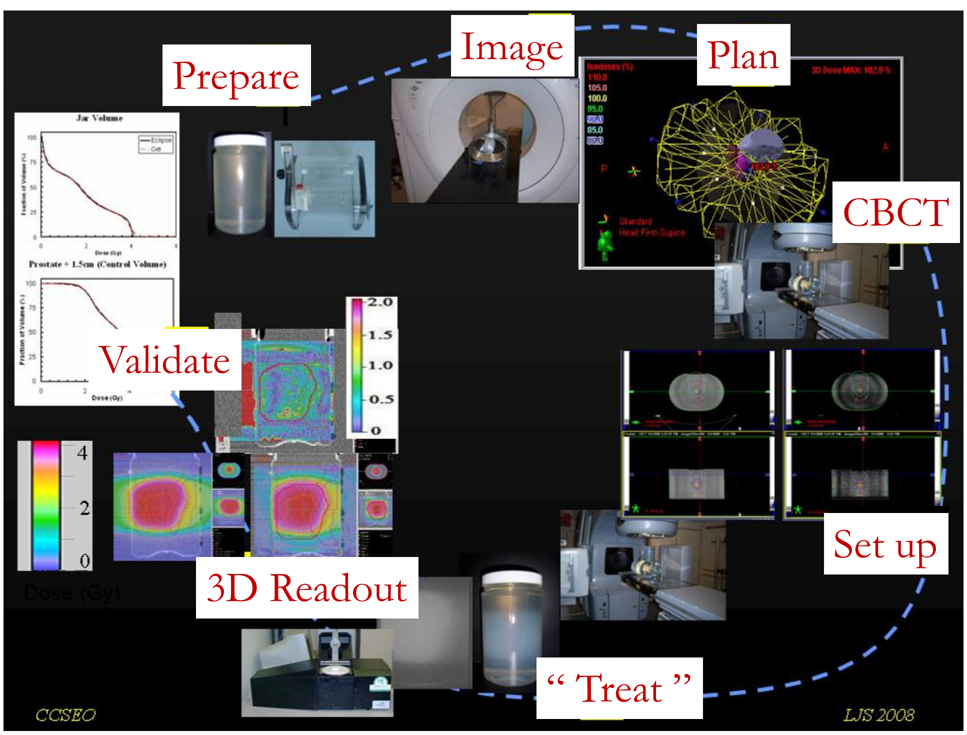
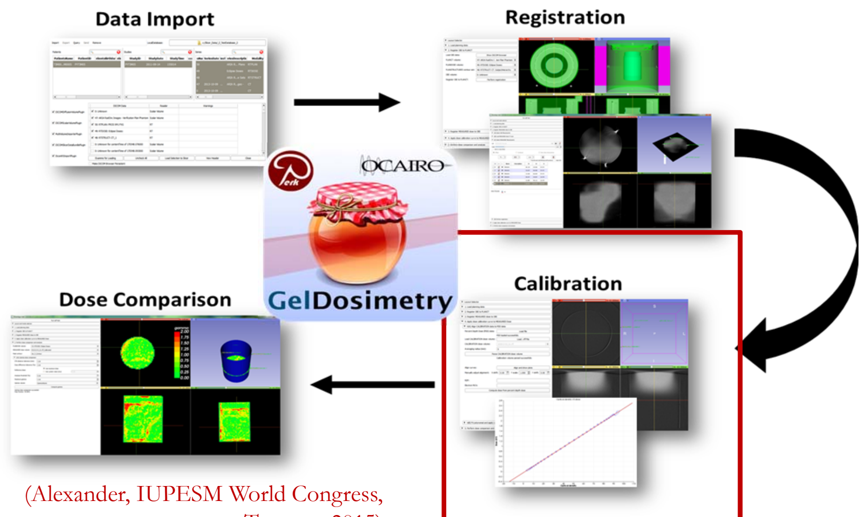


Data analysis

We work in SLICER-RT open source environment

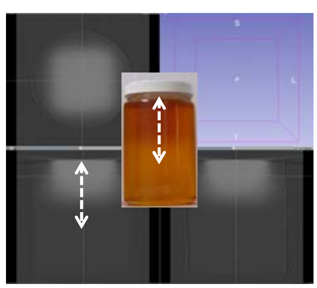


(Alexander, IUPESM World Congress, Toronto, 2015)

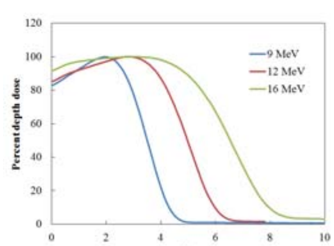
Gel dosimeter batch calibration

- Percent depth-dose (PDD) method was used to calibrate (i.e. calculate optical dose sensitivity) our gel dosimeters
- Electron beam irradiations to the surface of a Fricke xylenol orange gel dosimeter were performed for a range of energies (9, 12, 16 MeV)
- Gel response has previously been shown to be independent of photon or electron energy

6 x 6 cm^2 applicator



12 MeV electron beam irradiation



Consistency

- Calibration procedure was performed by a single user five times for each gel, and dose sensitivities were averaged

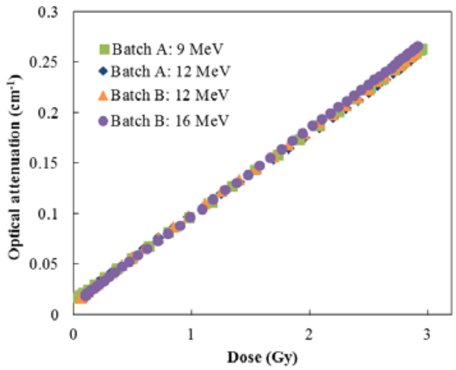


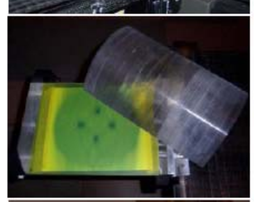
Table 1 Mean sensitivities for electron beam gel dosimeter irradiations

Gel Batch	Electron Beam Energy (MeV)	Mean Sensitivity (cm^{-1} Gy^{-1}) ± Relative Standard Deviation
A	9	0.0840 ± 0.1%
A	12	0.0830 ± 0.1%
B	12	0.0849 ± 0.1%
B	16	0.0872 ± 0.1%

Validation of VMAT FSRT calculated doses using a multi-configurational phantom

- Ion chamber:
  - Capintec PR-05P (volume=0.07 cm^3)
    - Point dose measurements at isocenter
- EBT3 Gafchromic film
  - Coronal mid-plane orientation
  - Analyzed with CCSEO radiochromic film imaging system
- Fricke xylenol orange gel
  - Vista optical CT scanner*
  - Analyzed with Gel Dosimetry Analysis Application in 3D Slicer

(Lalonde, IUPESM World Congress, Toronto, 2015)

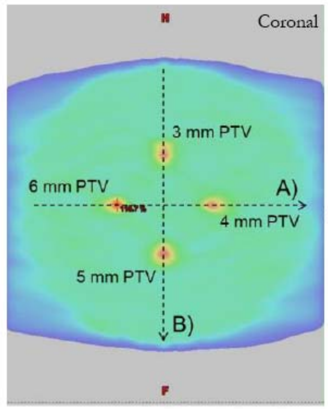


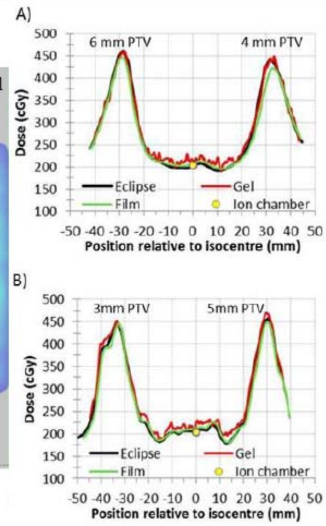
Technique Validation CCSEO (prior to first treatment)

- **4 PTV_{40} plans**
- Dose profiles
  - Eclipse
  - Film
  - Gel

Peak PTV doses agree with calculated doses within:

- 3% for gel
- 5% for film





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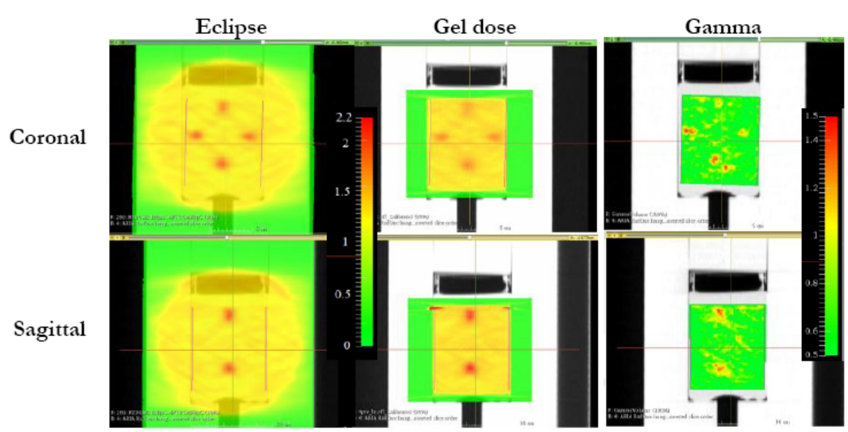
Technique Validation CCSEO (prior to first treatment)

- Gel Results: 4PTV plan (3 to 6 mm diam.):
  - **Gamma agreement (3%/3 mm) = 95.8%**



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Conclusions

- ❖ **Full 3D dosimeters have attractive features desirable for modern dose delivery validation**
- ❖ **Many of the problems that have kept 3D dosimetry out of the clinic have been corrected**
- ❖ **My colleagues will now illustrate this further**

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Resources for future reading

2 reviews lightly cited:

Oldham M 2014
in: Advances in Medical Physics
Godfrey D et al (ed)
(Medical Physics Publishing, Madison WI)

CHAPTER 5

Methods and Techniques for Comprehensive 3D Dosimetry

Mark Oldham, Ph.D.
Professor, Department of Radiation Oncology
Duke University Medical Center
Durham, NC

Schreiner LJ and Olding T 2009 Gel dosimetry
in: Clinical Dosimetry Measurements in Radiotherapy

(AAPM Medical Physics Monograph No. 34)
Rogers D and Cygler J (ed.),
(Medical Physics Publishing, Madison WI)

Chapter 30
Gel Dosimetry

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Resources for future reading (2)

6 Volumes of the open journal J. Phys: Conf. Series

IOPscience Journals Books Login

Journal of Physics: Conference Series

Volume 573 2015	8th International Conference on 3D Radiation Dosimetry (IC3DDose) 4–7 September 2014, Ystad, Sweden
Volume 444 2013	7th International Conference on 3D Radiation Dosimetry (IC3DDose) 4–8 December 2012, Sydney, Australia
Volume 250 2010	IC3DDose: The 6th International Conference on 3D Radiation Dosimetry 22–26 August, 2010, South Carolina, USA

Volume 164 2008 · Volume 56 2006 · Volume 3 2004 — DosGel (International Conferences on Radiotherapy Gel Dosimetry

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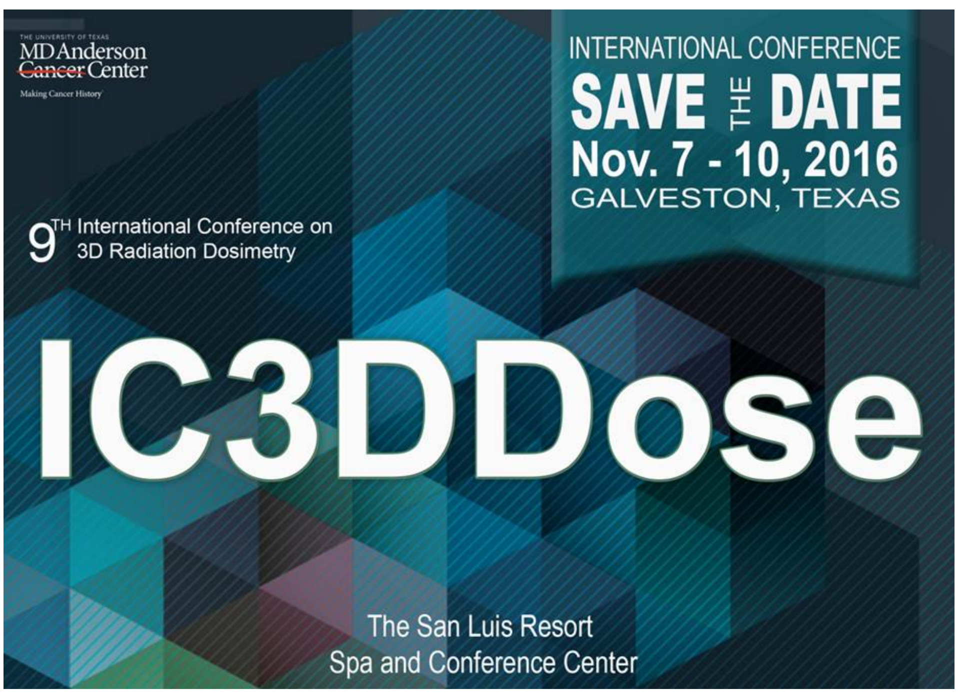

Questions: time is short today, feel free to contact us

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