3D Dosimetry (in Radiation Therapy)

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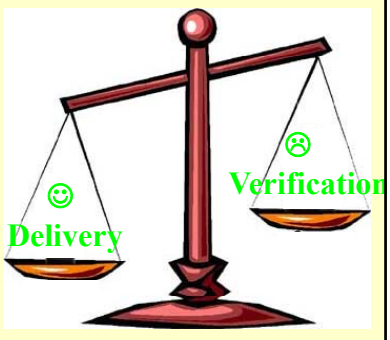
Rationale for 3D ?

- Increased treatment complexity
- Known problems of implementation
  - E.g. RPC credentialing results
- 3D dosimetry system can help …
  - Whole system test,
  - Error follow up
  - Small fields, srs, brachy ..
  - Goal – 3%, 1mm^3, cheap and quick !



No conflicts of interest !

What 3D dosimetry systems are available ?

- Polymer gels
- Radiochromic gels
  - Fricke-xylenol-orange
- Radiochromic plastics
  - Presage

MRI readout

X-ray-CT readout

Optical-CT readout

Liquid scintillators
Transit dosimetry
Semi-3D systems
E.g. diode arrays

6th IC3DDose meeting (www.IC3DDose.org)

Academic Sponsors:
AAPM
SEAAPM
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Duke University Medical Center

Scientific Organizing Committee:
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Kevin Jordan (Canada),
Martin Lepage (Canada),
Thomas Maris (Greece),
Mark Oldham (USA - Chair),
Evangelos Pappas (Greece),
John Schreiner (Canada)

Polymer Gels

- The first 3D dosimeters
  - Water, gelatin, BIS, acrylamide
- Succession of improved formulations
  - Less toxic (acrylamide substitutes)
  - Less oxygen sensitivity (MAGIC)
- Mature, well understood ..
  - Non-resuable ..
  - MRI - expensive but useful
  - Optical-CT - scatter ?
  - X-ray-CT – noise ?

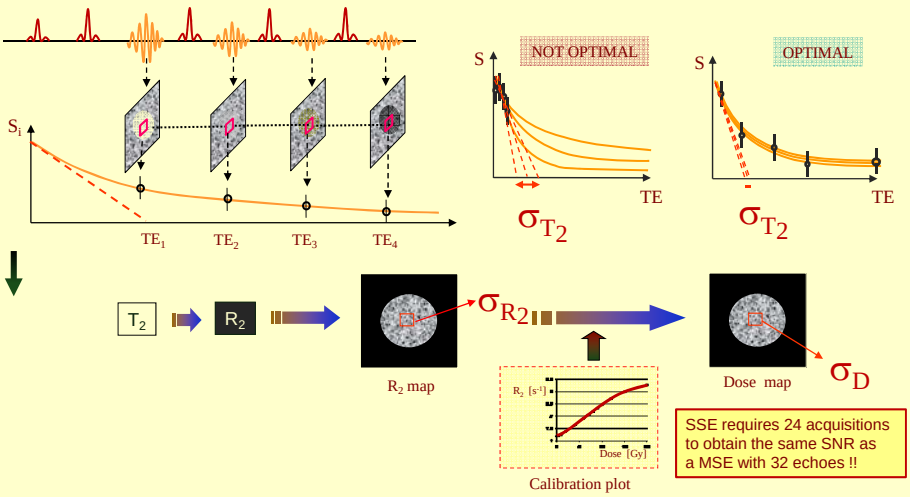
Schreiner et al., IC3DDose 2010

Wuu et al., IC3DDose2010

Component	PAGAT	MAGIC	MAGAT	NIPAM	VIPAR	Formula
	(weight percent)					
Water	88.9	82.8	85.9	90.9	80.5	H_2O
Gelatin	5	8	8	5	7.5	*
Bis	3	-	-	2	4	$C_7H_{10}N_2O_2$
Acrylamide	3	-	-	-	-	C_3H_5NO
Methacrylic acid	-	9	6	-	-	$C_4H_6O_2$
N-isopropyl acrylamide	-	-	-	2	-	$C_6H_{11}NO$
N-vinyl pyrrolidone	-	-	-	-	8	C_6H_9NO
Ascorbic acid	-	0.035	-	-	0.0007	$C_6H_8O_6$
Hydroquinone	-	0.02	-	-	-	$C_6H_4(OH)_2$
Copper sulphate	-	0.002	-	-	0.0008	$CuSO_4.5H_2O$
	(mM)					
THP[1]	-	-	2	-	-	$[(CH_2OH)_4P]_2SO_4$
THPC[2]	5			6.67		$C_4H_{12}ClO_4P$

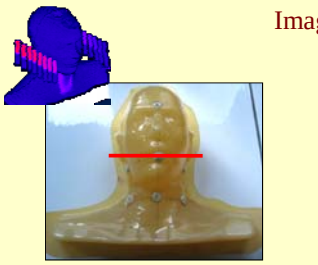
Baldock et al. 55 (5) Phys Med Biol. 2010

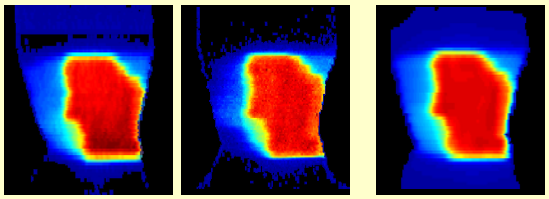
Optimizing the multiple spin echo sequence



SSE requires 24 acquisitions to obtain the same SNR as a MSE with 32 echoes !!

Image artifacts: *Temperature drift*

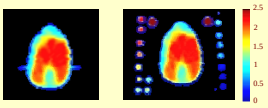




GEL DOSIMETER: CORONAL reconstructed from TRANSVERSE slices

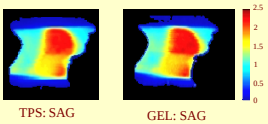
GEL DOSIMETER: CORONAL (scanned)

TPS: Pinnacle



TPS: TRA

GEL: TRA



TPS: SAG

GEL: SAG

Optical Tomography (optical-CT)

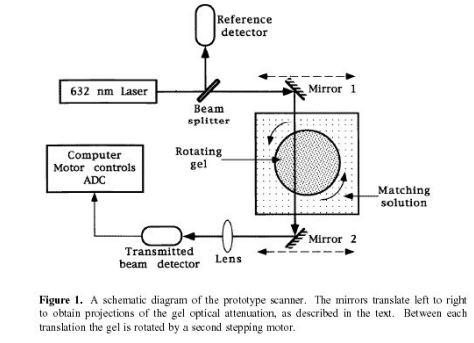
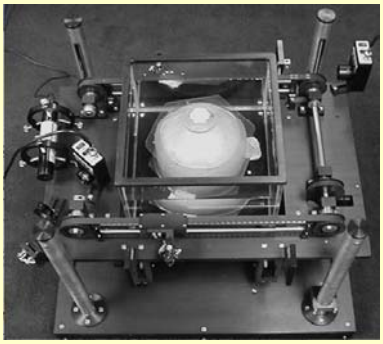


Figure 1. A schematic diagram of the prototype scanner. The mirrors translate left to right to obtain projections of the gel optical attenuation, as described in the text. Between each translation the gel is rotated by a second stepping motor.

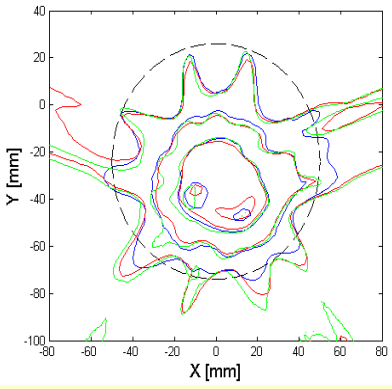


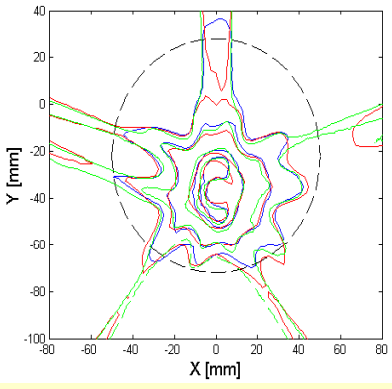
MGS OCTOPUS Scanner
MGS Research

- Single scanning laser
  - Accurate, less sensitive to scattered light
  - Slow requiring many hours for high-resolution 3D

Comparison of Transverse Dose Distributions (40, 60, 100, 115%)

Red: Plan Blue: Gel Green: Film

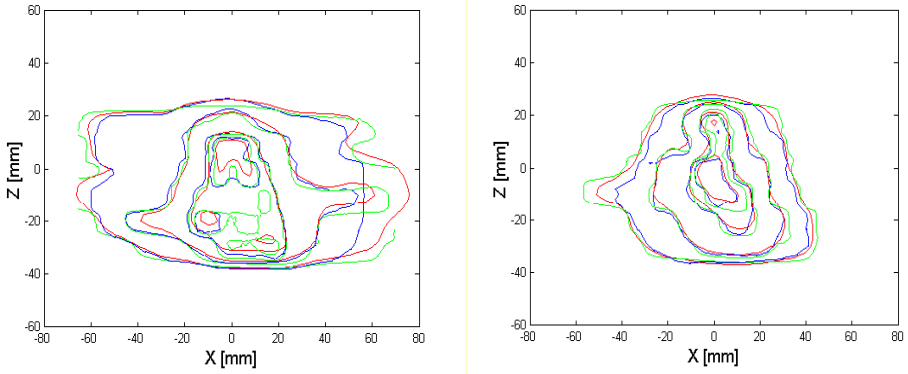




Wuu et al, IC3DDose2010

Comparison of Coronal Dose Distributions

Red: Plan Blue: Gel Green: Film



Wuu et al, IC3DDose2010

X-ray-CT

IMAGE AVERAGING & BG SUB

- IMAGE AVERAGING IMPROVES SNR
- BACKGROUND SUBTRACTION IMPROVES ARTEFACT REDUCTION

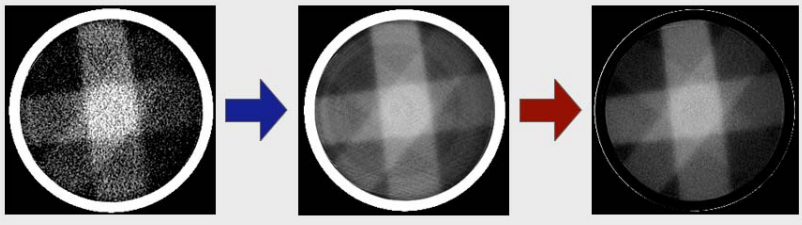
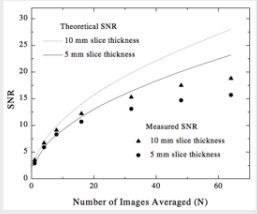


IMAGE AVERAGING

BACKGROUND SUBTRACTION



Jirasek, Hilts et al, IC3DDose2010

Radiochromic gels
Fricke (xylenol orange)

$$Fe^{2+} + OH\bullet \rightarrow Fe^{3+} + OH^-$$
$$Fe^{2+} + HO_2\bullet \rightarrow Fe^{3+} + HO_2^-$$
$$HO_2^- + H_3O^+ \rightarrow H_2O_2 + H_2O, \text{ and}$$
$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH\bullet + OH^-$$

- Radiochromic (dark)
  - Optical contrast is absorbing
  - Broad-beam fast scanning
- Non-toxic, no oxygen sensitivity, easy to make, energy independent
- Diffusion, temperature (0.1deg), light scatter, auto-oxidation

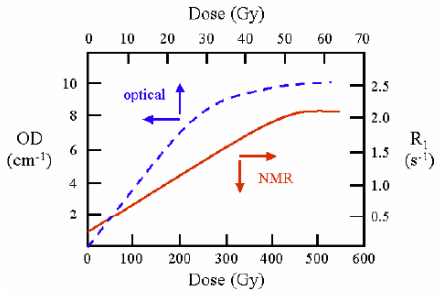
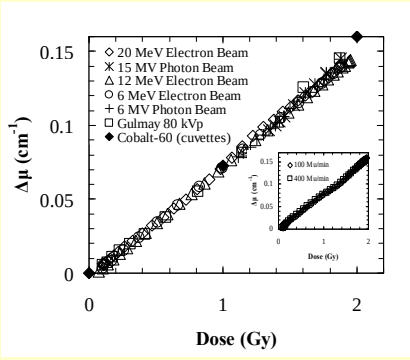
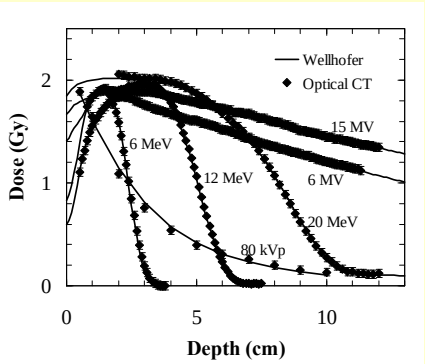


Figure 2. The dose dependent change in the optical density (in dashed blue) of a Ferrous sulphate xylenol orange dosimeter irradiated in the range from 0 to 70 Gy. The measurements were at 585 nm (from Bero [28]). The radiation induced change in the spin-lattice relaxation rate measured at 25 MHz (in solid red) of an aqueous Fricke solution irradiated from 0 to 600 Gy (from Podgorsak [27]).

Dose-to-Attenuation Calibration

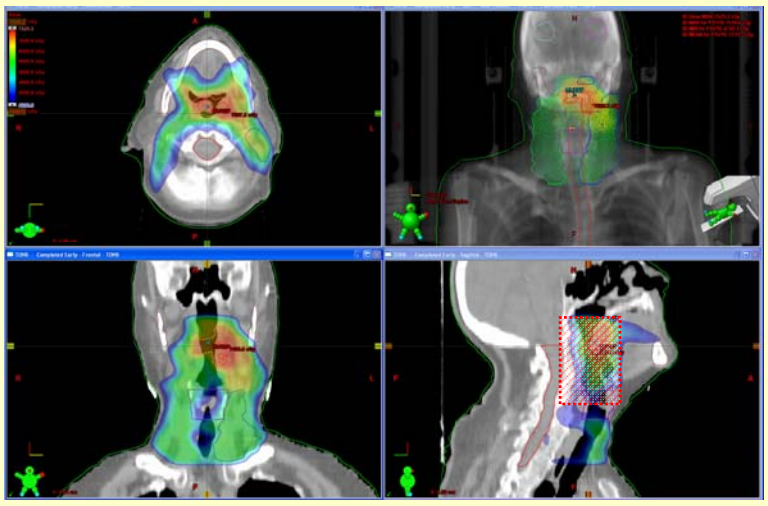




- Inter-jar reproducibility for a standard-sized 1 L FXG gel dosimeter
- Energy independence

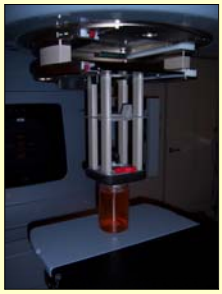
Olding and Schreiner, IC3DDose 2010

Head-and-Neck IMRT Treatment Plan



Olding and Schreiner, IC3DDose 2010

Wax Rando with FXG gel dosimeter insert



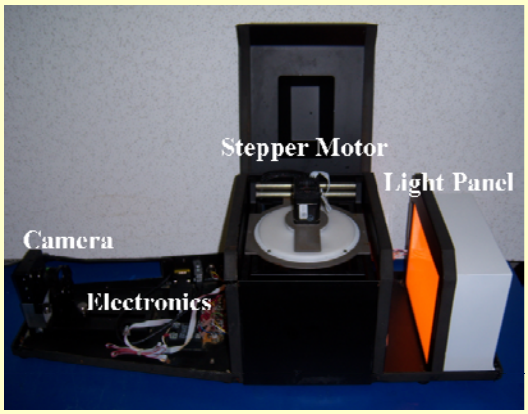
Electron Beam Calibration

IMRT Delivery

Calibration & Measurement Jars

Olding and Schreiner, IC3DDose 2010

VISTA™ Scanner*

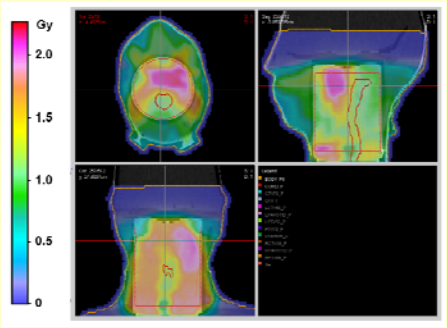


Using the 590 nm amber LED diffuse light source

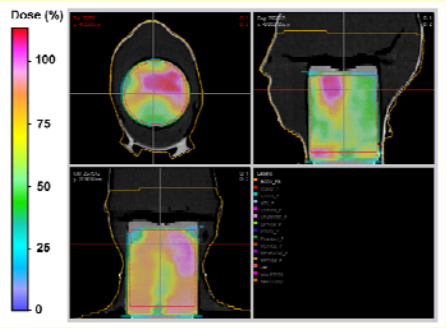
Projection data acquired with a 1024x768 pixel, 12-bit CCD camera using a 2/3” diameter, 12 mm focal length lens

*Modus Medical Devices Inc, London, ON, Canada

Dosimetric Evaluation*



Eclipse Plan

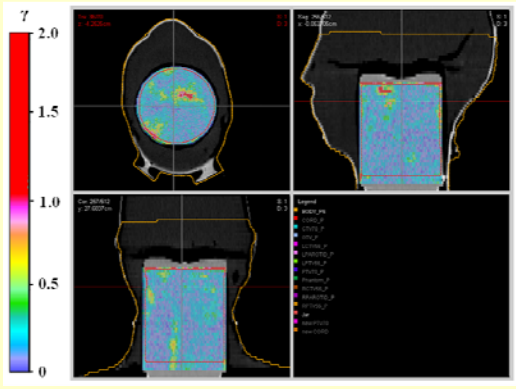


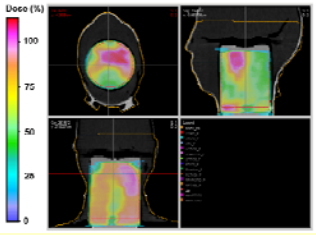
Gel Measurement

Olding and Schreiner, IC3DDose 2010

*in the CERR environment in MATLAB

IMRT Delivery Evaluation

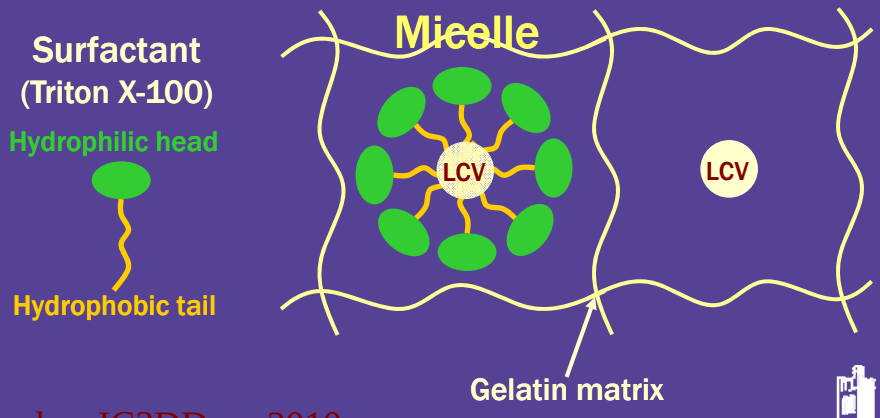




3%, 3mm gamma test

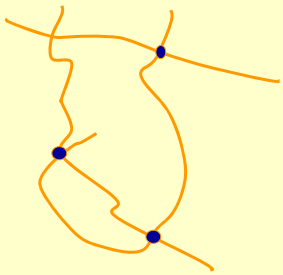
Micelle gels

- Leuco crystal violet is water insoluble
- Can be dissolved using surfactants

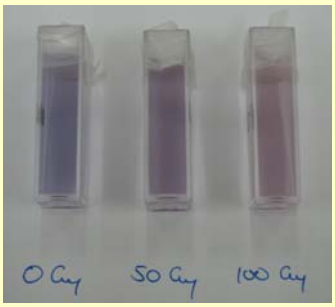


Jordan, IC3DDose 2010

Genipin gel:



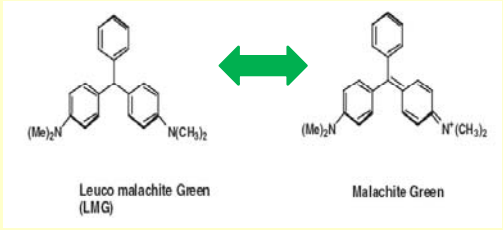
- Extract of gardenia fruit
- Cross-links gelatin to form a non-toxic, blue gel
- Gel bleaches color on irradiation
- Applications: tissue engineering, wound healing, replacement for gelatin in food



Davis and Baldock et al, IC3DDose 2010

Radiochromic Plastic:

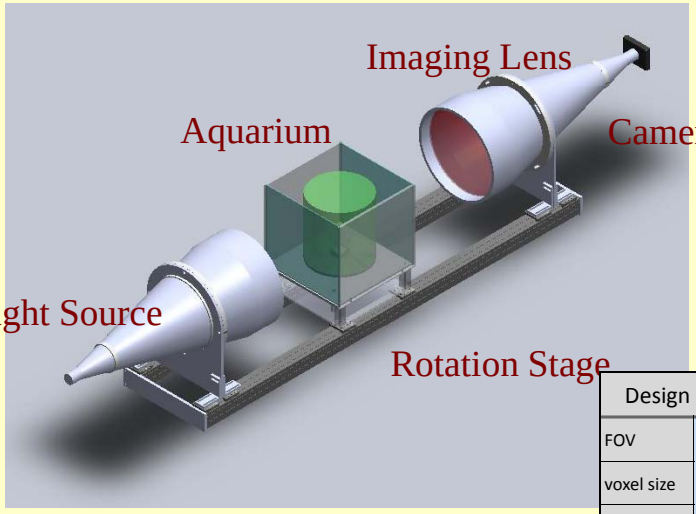
- Presage/optical-CT
  - Sensitive, linear, CT~80-160
  - Flexible, OK in lab
  - Light absorbing contrast
  - Reversible (re-useable)



λ_{max} = 633 nm

5 Beam Tx

DLOS system:
Duke Large Field-of-View Optical-CT Scanner

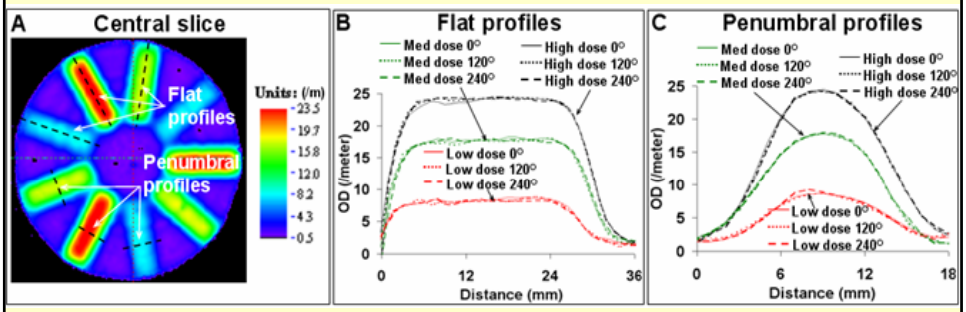


Design Specifications		
FOV	24	cm
voxel size	0.175	mm
scan time	10	minutes

Thomas, Oldham et al, IC3DDose2010

Intra-dosimeter uniformity

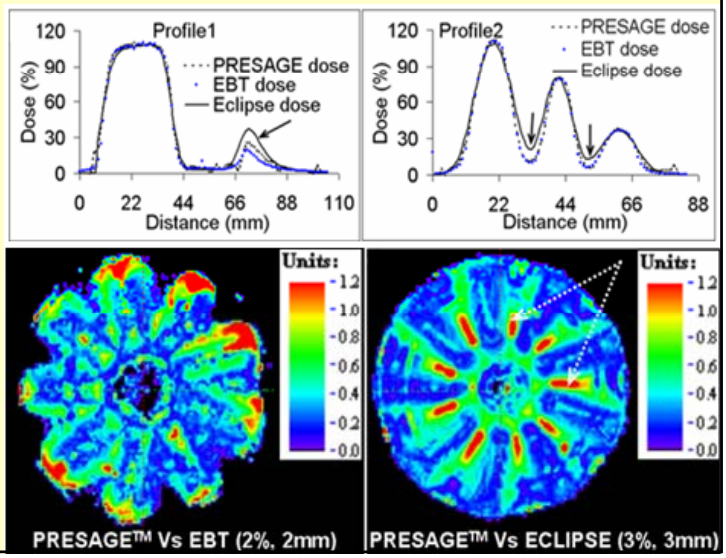
- 98% gamma pass rate (2%,1mm)



Sakhalkar, Ibbott, Oldham et al. Med Phys, 2009

Accuracy of dose readout

- PRESAGE agrees with EBT - 98% pass rate 2%,2mm
- EBT and PRESAGE show Eclipse modeling errors in penumbral regions

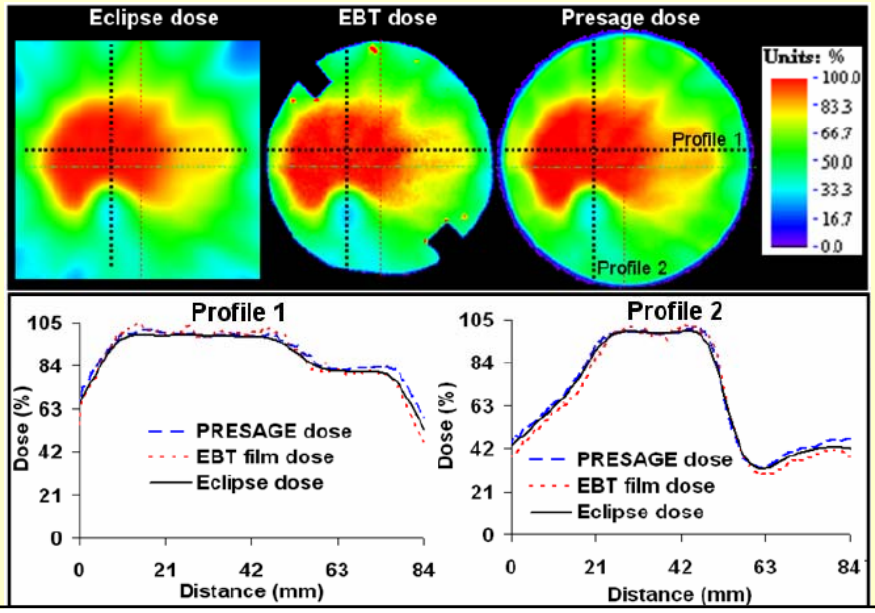


Sakhalkar, Ibbott, Oldham et al. Med Phys, 2009

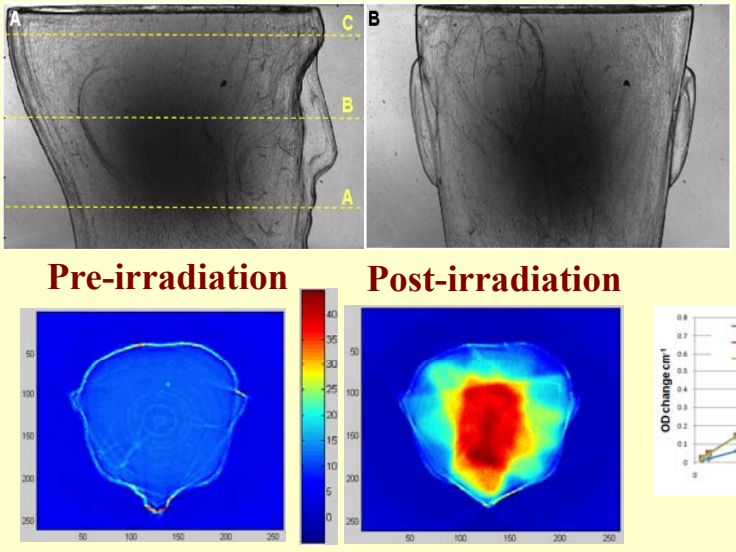
- To cut a long story …!
  - Low noise (2%)
  - Intra-dosimeter uniformity (~2%,1mm)
  - Temporal stability (> 90 hrs)
  - Inter-dosimeter reproducibility (within 2%,2mm)
  - Accuracy 98% (3%,2mm)

- PRESAGE/optical-CT may be OK for 3D credentialing
  - Shipping robustness ?

Comparison dosimetry in RPC phantom



Recent developments ?



OCTOPUS™ 5X, 0.9 mm³.

Conclusions

- For the *specialised* clinic:
  - The technology of 3D dosimetry has **arrived**.
  - Accurate, robust, hi-res 3D dosimetry achievable ..
    - Dosimeters: -PAGs, Radiochromic gels/plastics
    - Scanners: - MRI, laser, telecentric, conebeam ?
- For the *non-specialised* clinic:
  - 3D techniques available soon ?
  - Faster scanners, cheaper re-useable dosimeters
- Much ongoing research ……
- Commercialization !

Advanced Tx requires advanced verification !!