Three Dimensional BANG® Polymer Gel Dosimeters

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Educational objectives:

- Describe the need for high-resolution 3D dosimetry in 3D CRT.
- Explain the physics and chemistry of gel dosimeters in general, and BANG polymer gels in particular.
- List the radiological properties of polymer gel dosimeters.
- Explain how to use gel dosimeters.
- Review the clinical applications (3D CRT; SRS; IMRT; Brachytherapy, including intravascular).

The need for high-resolution 3D dosimetry and QA in CRT

- Rapid progress in 3D CRT techniques has created an urgent need for 3D methods of dosimetry and quality assurance.
- Requirements: fast and accurate measurement of dose distributions integrated over time and throughout the entire volume of a phantom, with at least millimeter resolution.
- Existing conventional dosimetry techniques can be classified as 1D (ion chambers, diodes, TLD's) or 2D (radiochromic film or detector arrays) and therefore do not meet that need.

The physics and chemistry of gel dosimeters in general

- Composition: 1) Gelling agent; 2) Solvent; 3) Active compound; 4) Radiation response modifiers
- Mechanism: 1) Radiolysis of solvents and solutes; 2) Free radicals, ions, unstable and reactive molecules; 3) Chemical reaction; 4) Quantitative readout (e.g. optical, NMR, pH etc.)
- Examples: Gels with radiochromic dyes(Day and Stein, Nature 166, 146, 1950); Fricke (Ferrous Sulfate) gels (Gore et al, Phys. Med. Biol. 29, 1189, 1984)

The physics and chemistry of BANG polymer gels

- Composition: 1) Gelatin; 2) Water; 3) Acrylic monomers; 4) Response modifiers; 5) Oxygen removed
- Mechanism: 1) Radiolysis of water, gelatin and the monomers; 2) Free radicals, in amounts proportional to dose; 3) Free radical chain polymerization, crosslinking and grafting to gelatin; 4) Formation of polymer microparticles, attached to gelatin; 5) Number of microparticles proportional to dose; 6) Permanent 3D image of dose distribution forms in the gel.
- Advantage: no diffusion of polymer in the gel

The physics and chemistry of BANG polymer gels

- Readout: Both the water proton NMR relaxation rates ($R1=1/T1$ and $R2=1/T2$) in the gel and the light attenuation coefficient (due to Rayleigh scattering) increase in proportion to the local concentration of polymer particles in the gel.
- Digitization of the 3D dose distribution cloud in BANG gel is done by MRI or optical CT (OCT) scanning.

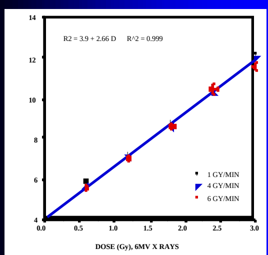
Optical Computed Tomography (OCT)

Our in-house built OCT scanner

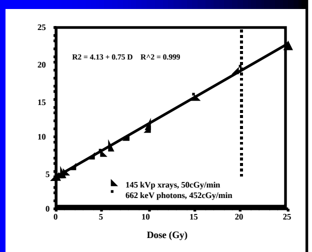
Radiological properties of BANG gels

- Muscle tissue equivalent elemental composition and density
- Adjustable sensitivity and dose range
- Energy independent dose response
- Dose rate independence, up to 450cGy/min, for photons and electrons
- Certain formulations are suitable for HE protons or higher dose rates.
- Accuracy better than 3%

R2 dose response of BANG gels



BANG-3-3Gy



BANG-3-25Gy

How to use BANG gels

- Obtain x-ray CT and/or MRI scans of the BANG gel phantom as required by the RTP system.
- Generate radiation treatment plan for the phantom.
- Mount the BANG gel phantom for irradiation and deliver the planned radiation treatment.
- Irradiate calibration gels to known doses.
- Obtain MRI or OCT scans of the irradiated BANG gels.
- Calculate R2 or optical density per cm (OD/cm) maps.
- Calculate dose maps in the gel.
- Compare gel data with treatment plan

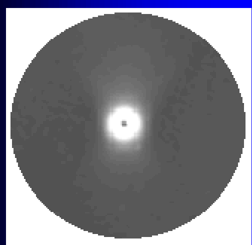
Main advantages of BANG over conventional techniques

- Measurement of the entire 3D dose distribution with high spatial resolution (0.1mm - 2mm pixel)
- Time saving for the physicist and for the radiation treatment facility
- Visible image of the dose distribution cloud in addition to quantitative information

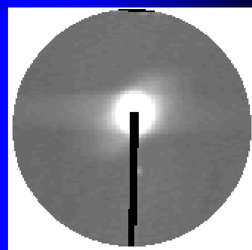
Clinical Applications: Stereotactic Radiosurgery

BANG® gel mounted in Leksell frame.
Dose distribution cloud is visible in the gel.

SRS: single isocenter. MRI-derived axial and sagittal dose maps



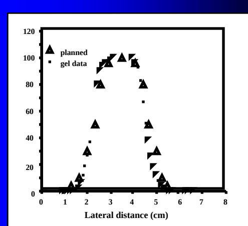
Axial map.



Sagittal map

SRS: single isocenter. MRI data.

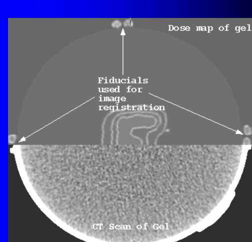
Lateral dose profile across the isocenter. Comparison of BANG® gel data with treatment plan.
(from Maryanski et al, Med. Phys. 23(5), 1996, pp.699-705)



SRS: multiple isocenters

BANG gel CT/MRI fusion.

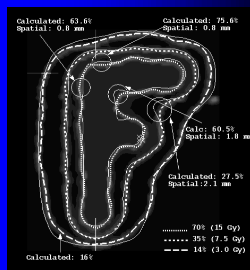
From Meeks et al, Int. J. Rad. Oncol. Biol. Phys. Vol.43, No.5, pp.1135-1141, 1999.



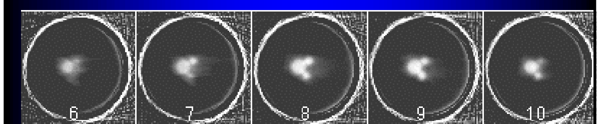
SRS: multiple isocenters

Comparison of treatment plan with BANG gel data.

From Meeks et al, Int. J. Rad. Oncol. Biol. Phys. Vol.43, No.5, pp.1135-1141, 1999.



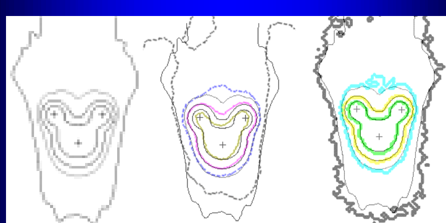
SRS: Optical CT imaging



Five axial dose maps from multi-planar OCT scan

From Knisely et al., in: Kondziolka D. (ed): Radiosurgery 1997, Vol. 2. pp.251-260. Radiosurgery. Basel-Karger, 1998.

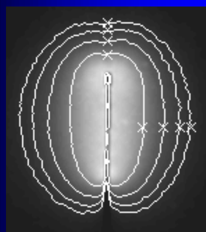
SRS: Optical CT imaging



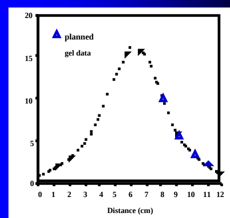
plan | Plan vs. OCT | Plan vs. MRI

From Knisely et al., in: Kondziolka D. (ed): Radiosurgery 1997, Vol. 2. pp.251-260. Radiosurgery. Basel-Karger, 1998.

Brachytherapy



Sagittal dose map:
multiple-dwell protocol



Transverse dose profile:
plan vs. gel comparison

(from Maryanski et al, Med. Phys. 23(5), 1996, pp 699-705)

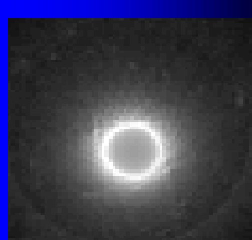
Intravascular Brachytherapy: Dosimetry requirements

- Steep dose gradients
- High spatial resolution (0.1mm) required
- The need for full 3D characterization
- Routine QA measurement should be fast

Intravascular Brachytherapy Using OCT Microimaging

OCT reconstructed
transverse dose map:
Ir-192 seed.

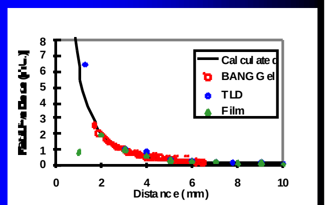
From Maryanski et al, Med. Phys. 25(7), A107, 1998



Intravascular Brachytherapy Using OCT Microimaging

Dose falloff: Ir-192 seed.

From Maryanski et al, Med. Phys. 25(7), A107, 1998



IMRT

- Oldham et al, Phys. Med. Biol. 43(5) pp. 1113-1132, 1998
- Low et al, Med. Phys. 26(8), August 1999, *in press*

Summary

- 3D gel dosimeters are needed for QA of 3D CRT
- Using BANG gels the entire treatment plan verification can be performed using a single phantom, with high spatial resolution, after minimum irradiation time.
- Phantoms of various shapes can be made for specific applications
- BANG gels can be imaged using MRI or OCT