3D POLYMER GEL DOSIMETRY FOR QUALITY ASSURANCE IN RADIATION THERAPY

Sofie Ceberg, Diana Adlienè and Sören Mattsson

Medical Radiation Physics, Lund University/Skåne University Hospital, Sweden and Department of Physics, Kaunas University of Technology, Lithuania
Humans are 3D, tumours are 3D
Radiation therapy is given in 3D
Dynamic radiation therapy → 4D
Problems with latest radiation therapy techniques:
Narrow margins, large dose gradients and small fields.
Therefore gel dosimetry!

- Absorbed dose in 3D with high spatial resolution
- The detector volume forms both phantom and detector
- Gels are soft tissue equivalent
- Density and atomic number can be modified

Now 3D printed phantoms
Some excerpts from the gel history

1927 Fricke och Morse irradiated iron-ion solutions: $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$

1984 Gore et al. quantifies radiation induced changes in Fricke solutions by MR

1988 Appleby mixes in gel to obtain 3D dose information

1990s Realises that the problem with diffusing iron ions is significant
Some excerpts from the gel story

1993  Maryanski performs his first MR-studies of polymer gels. Resulting in BANANA, BANG, PAG...New problems: need for oxygen-free environment, toxic

2001  Fong et al. introduce a polymer gel with antioxidant

2007  New non-toxic polymer gel

Monomer (Akrylamid)  Polymer (Akrylamid polymer)
Different readout methods

Measurable changes in how the gel absorbs and scatters ultrasound, light, X- and gamma-rays

Polymerization alters the MRI relaxation times of the water protons in the gel dose meter.
Dose response MR

Dosrate-dependent
Each gel requires calibration
Clinical applications

The dose-planning system does not take dose-smearing into account.

Deficiencies in the dose-planning system, especially for lung tissue.

The dose-planning system does not take dose-smearing into account.
Clinical applications

Development of tumour related 3D polymerized dose gel shapes for brachytherapy

Demonstration of complex dose distribution obtained from HDR brachytherapy source positions in two catheters and of corresponding polymerized dose gel shape after irradiation
Clinical applications

Absorbed dose verification in 3 D

- Dose distributions in brachytherapy
- Dosimetry at respiratory gated breast cancer treatment
- Dosimetry at sequential beam irradiation
- IMRT dose verification
- VMAT (RapidArc) treatment dose verification
- TomoTherapy dose verification
- Evaluation of breathing interplay effects during VMAT and TomoTherapy of thoracic tumors
- Evaluation of motion induced thread effect during TomoTherapy
- ....
- ....
Interplay effects depends on...

Patient specific:
- Breathing amplitude
- Period time
- Initial breathing phase

Machine specific:
- Dose rate
- Plan modulation complexity
- Gantry rotation period/pitch/beam width
Studies of interplay effects in modulated volumetric radiotherapy of thoracic tumors

3D Dosimetry in the clinic: Motion interplay effects in dynamic radiotherapy

- Observe full dosimetry under dynamic radiotherapy during respiratory motion
- Understand how the measurement of high resolution dose data in an irradiated volume can help understand interplay effects during TomoTherapy or VMAT
Overlay of 3D target isodose surfaces

Red volumes: stationary polymer gel during VMAT
Green volumes: polymer gel in motion during VMAT

Lung VMAT measurements

Prostate VMAT measurements

An obvious target dose reduction due to motion

Fig. 3a. The histogram presents the distribution of voxel-by-voxel deviations between the gel measurements within the volumes enclosed by the 90% isodose surface for the lung VMAT plan delivery. The total dosimetric effect of the motion (data from [29]).

Fig. 3b. The histograms present the distribution of voxel-by-voxel deviations between the gel measurements within the volumes enclosed by the 90% isodose surface for the lung VMAT plan delivery. The histogram shows the dosimetric effect of the interplay effect only (data from [29]).

Shows the combination of dose-smearing and potential interplay effects
In these clinically relevant example

- The total dosimetric effect due to breathing motion and dynamic MLC motion during VMAT and Tomo delivery resulted in an average of about 4% target dose reduction.

- For repeated stationary measurement, i.e. without interplay effects but including all other measurements uncertainties (e.g. set-up), the differences had a narrow distribution with a standard deviation between 0.5 and 0.9%.

- Thus, the larger standard deviations of 1.4%-2.3% (1SD) were interpreted as interplay effects.
Thank you for listening!

soren.mattsson@med.lu.se