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RESEARCH

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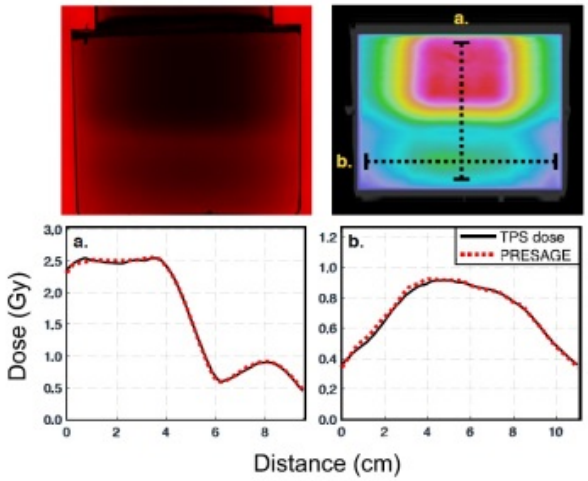
3D dosimetry protocol is compatible with MR-guided radiotherapy

MR-guided radiation therapy holds promise of increased treatment precision. However, the presence of a permanent, high-strength magnetic field within such systems introduces additional uncertainty and complexity to the challenging tasks of commissioning and treatment verification. With this challenge in mind, a US research collaboration has developed a high-resolution 3D remote dosimetry protocol for MR-guided radiotherapy (*Med. Phys.* doi: 10.1016/j.ijrobp.2017.10.020 (http://onlinelibrary.wiley.com/doi/10.1002/mp.12565/full)).

The researchers, from Duke University (https://www.duke.edu/), University of North Carolina at Chapel Hill (http://www.unc.edu/) and Washington University School of Medicine in St Louis (https://radonc.wustl.edu/), developed the protocol based on PRESAGE - a radiochromic plastic dosimeter that changes colour when exposed to high-energy photons. The 3D distribution of this colour change, which is linearly related to the dose, is then read out using an optical-CT system.



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PRESAGE/optical-CT dosimetry (http://images.iop.org/objects/med/news/12/12/43/pic1.jpg)

"The 'remote dosimetry' capability means that dosimeters are planned and treated at a field institution, which has an MRI-Linac, for example, and then shipped back to a base institution for readout and analysis," explained lead author Mark Oldham (http://radonc.duke.edu/research-education/research-labs/radiation-physics/oldham-lab) from Duke University Medical Center. "The exciting thing about this remote dosimetry approach is not just that it is compatible with MRI, but that it opens up the availability of this technique to any institution that may not have optical-CT dosimeter readout capability."

In this work, the team developed and applied the protocol to investigate the accuracy of intensity-modulated radiotherapy (IMRT) delivery in the presence of a strong magnetic field, assuming a time delay between irradiation and readout of within 48 hr. In a companion paper, they demonstrate the protocol in action on IMRT plans delivered by ViewRay's cobalt-based MR-guided radiotherapy system, MRIdian (*Int. J. Radiat. Oncol. Biol. Phys.* **97** 1095 (http://www.redjournal.org/article/S0360-3016%2817%2930286-9/fulltext)).

Protocol development

While most conventional dosimeters do not work in high magnetic fields, PRESAGE is a chemical dosimeter with no electrical components and is thus unaffected by the presence of a magnetic field. PRESAGE dosimeters also enable true high-resolution 3D dosimetry, an essential tool for verification of complex 3D dose distributions. For this study, John Adamovics (Heuris Inc) developed a novel PRESAGE formulation with new leuco-dyes that deliver high post-irradiation stability.

The researchers first evaluated the dose-response of the new PRESAGE material in a small-volume study in 4 ml cuvettes. They irradiated the cuvettes using either a Co-60 source in a 0.35 T field or a standard 6 MV linac, to doses of 0, 5, 10 and 15 Gy. The changes in optical density (ΔOD) of the PRESAGE showed that, in the presence of this magnetic field, the dosimeter responded linearly to Co-60 irradiation at 48 hr post irradiation. Irradiations with the MR-guided system were within 1% sensitivity of the 6 MV linac irradiation.

To accommodate the required time delay between treatment and readout, the team needed to verify the temporal and spatial stability of PRESAGE dosimeters. To do this, they irradiated three large-volume 2 kg cylindrical dosimeters with four-field plans and tracked the dose readouts for two days post-irradiation.

They observed a linear response one hour after irradiation. However, the dosimeters then gradually darkened with time (by less than 5% per day). They also noted a small radial dependence (less than 3% of the maximum dose) in dosimeter sensitivity as time increased. To address these relatively small systematic changes, which were consistent between dosimeters, Oldham and colleagues determined temporal (C_T) and spatial (C_R) correction factors.

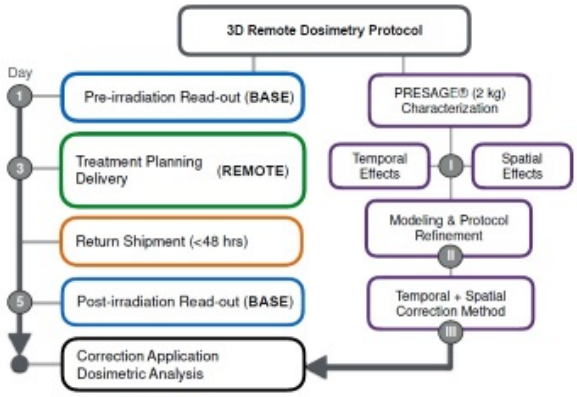
The team then used C_T and C_R to develop a remote dosimetry protocol in which the raw ΔOD reconstructions imaged at a post-irradiation time (*x* hr) are corrected back to a standardized readout time (set at 1 hr for clinical convenience), where the linear dose-response of PRESAGE is known.

The new PRESAGE formulation provided greatly increased stability over previous PRESAGE dosimeters, enabling the dosimeters to be shipped and stored at room temperature throughout the protocol. "This is a change from prior work, where dosimeters were shipped cooled, and greatly increases convenience," the authors wrote.

TG-119 testing

In the companion study reported in the *Red Journal*, the research team used their refined remote dosimetry protocol to perform an IMRT evaluation study. For this, they used the MRIdian's Monte Carlo-based treatment planning system (TPS) to create TG-119 (AAPM Task Group report 119) plans.

"TG-119 intensity-modulated plans are representative of treatments deliveries typically encountered in a clinical setting, and therefore provide a comprehensive set of test cases during IMRT commissioning," explained Harold Li, the lead Washington University researcher for this study.



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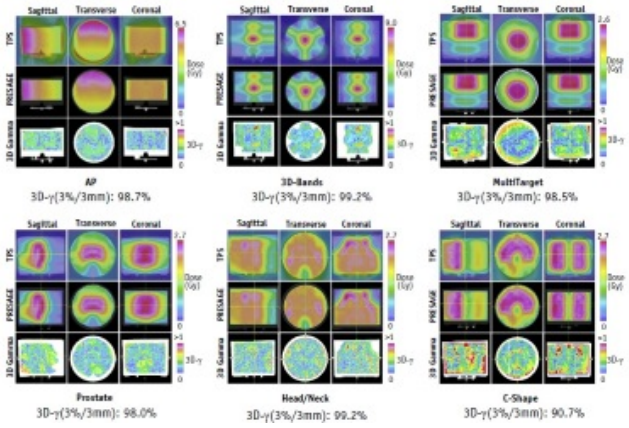
Timeline for the remote dosimetry protocol (http://images.iop.org/objects/med/news/12/12/43/pic2.jpg)

The researchers performed baseline optical-CT scans at Duke's 3D Dosimetry Lab, then shipped the dosimeters to the remote clinic (Washington University in St Louis) for treatment planning and delivery. At all stages, dosimeters were stored at room temperature in opaque bags. After treatment delivery, the dosimeters were returned to Duke for ΔOD readout at 48 hr post-irradiation.

First, the team performed preliminary tests, delivering two open-field plans (AP and 3D-bands) to 1 kg cylindrical PRESAGE dosimeters. These tests, used to check for linear dose response and spatial uniformity throughout the detector, demonstrated good agreement between the TPS and the measured dose.

They then created four clinical IMRT plans according to the TG-119 standards (multitarget, prostate, head/neck and C-shape) for delivery to the larger 2 kg PRESAGE dosimeters. Comparing the measured doses with the TPS using 3D-γ analysis (3%/3 mm global, 10% threshold) revealed passing rates of 98.5%, 98.0%, 99.2% and 90.7%, for multitarget, prostate, head/neck and C-shape plans, respectively.



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PRESAGE/optical-CT versus TPS for all test plans (http://images.iop.org/objects/med/news/12/12/43/pic3.jpg)

The researchers note that, for both the simple and complex treatments, the 3D-γ passing rates increased from the uncorrected to the corrected (including CT and CR) PRESAGE reconstructions.

"This work has established the basic viability of the technique, and we were very pleased how well the results came out, with low noise and high accuracy, once the corrections had been determined," Oldham told *medicalphysicsweb*. "Future work will tackle more advanced challenges in MRI dosimetry, for example, characterizing dosimetry artefacts in cavities and higher-Z inserts. We also need to further characterize any variations in the corrections between different PRESAGE formulations and batches."

About the author

Tami Freeman is Editor of *medicalphysicsweb*.