Temperature, dose and dose-rate dependency of the optical response for a 3D radiochromic dosimeter

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Abstract

Purpose: text
Methods: text
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Conclusions: text

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Contents

I. Introduction

In the last 30 years, the advances in engineering and software capabilities lead to a rapid progress of radiation therapy (RT), making possible the implementation of three-dimensional (3D) external beam modalities such as Intensity Modulated Radiation Therapy (IMRT), Volumetric Modulated Arc Therapy (VMAT) and Proton Beam Therapy (IMPT)[ed1979]. These techniques offer better local tumor control and minimize dose to the normal surrounding tissue by conforming the dose distribution to the target volume. Consequently, their experimental validation becomes progressively more complex, as small uncertainties in patient positioning and beam delivery can be the difference between achieving target coverage or delivering the dose to healthy tissue or organs at risk instead[Low2011, Liao2020].

3D dosimeters have been a topic of interest for the radiation oncology therapy community for the last decade, as they can provide integrated 3D dose measurements in high spatial resolution, are nearly tissue equivalent and can be cast in a variety of shapes[DeDeene2013, Oldham2]. There are many types of 3D dosimeters, with the two main groups being polymer gels and radiochromic dosimeters, which include Fricke gels, and a variety of dosimeters based on leuco-dyes[Baldock2010, Schreiner2015].

In this study, we investigated a radiochromic silicone-based dosimeter containing leucomalachite green (LMG) and chloroform as an initiator. The chemical process that results in dose-response involves three main reactions; activation of free radical initiators via irradiation, activation of LMG by the free radicals, and conversion of the colourless LMG to malachite green (MG), which is light-absorbing. The formulation chosen was optimized by Høye[Hoye2015], to be dose-rate independent up to 6 Gy/min for photon beams, and it has shown promissing results for topical studies as deformation investigations[Jensen2020a, Kaplan2017], and magnetic resonance imaging guided radiotherapy (MRgRT) verification[Jensen2020].

1D studies with small samples (cuvettes) showed that the signal stability of this radiochromic dosimeter is temperature dependent, and that non-irradiated samples present self-colouring -ie. darken in time, even on the absense of light sources or radiation[Hoye2017a]. A similar behaviour has also been reported for other radiochromic dosimeter formulations, such as PRESAGE [cite P. Skyts 2 papers]. However, like other leuco-dye dosimeters, there can be significant difference in the response between cuvettes and large dosimeters[Schreiner2015], and to the

best of our knowledge the stability of the 3D dose measurements has not been investigated for this composition. Given the prospect of its use for a variety of experiments, it is important to establish a readout protocol, investigating the stability of the samples for different curing times and storage temperatures.

II. Methods

II.A. Dosimeter

Radiochromic silicone-based dosimeters are composed of a silicone elastomer and curing agent (Sylgard 184 Silicone elastomer kit, Dow Corning), leucomalachite green (LMG) powder and chloroform (Sigma-Aldrich). Weight percentages of the two compositions used in this study were shown in table I. The production process is described in detail by Høye[Høye2015]. In brief, LMG was dissolved in chloroform and mixed thoroughly to the silicone elastomer kit. After solidifying, the silicone acts a host material, keeping the LMG fixed in place. Twelve cylindrical dosimeters (50 mm, 50 mm height), six with 5%CA and six with 9% CA, were produced and left to cure in the refrigerator, where the temperature was set to 15°C, until irradiation. The dosimeters are light-sensitive and must be shielded from light at all times, including the production and curing process. Therefore, they were produced in a dark room and subsequently placed in a plastic container, wrapped in several layers of aluminium foil, and stored in the dark. Light exposure was minimized during transportation.

II.B. Irradiation

A photon plan was prepared in Eclipse (version 15.6, Varian Medical Systems, Palo Alto, CA, USA) on a virtual water phantom, consisting of two opposing 10 × 1.6 cm^2 fields with 6 MV beam quality, flattening-filter mode, a source-axis distance of 100 cm, a dose of 372 monitor units (MU)/field and dose rate of 600 MU/min. Dosimeters thermalized at room temperature for 2 hours before irradiation. To achieve charged-particle equilibrium on the dosimeter edges, they were positioned inside of a water tank and elevated from the bottom with a 3D printed stand.

II.C. Optical readout

Optical CT images were taken 2 hours before and after irradiation with the Vista 16 (Modus Medical, London, Canada), using 500 projections over a 360 degrees rotation. The dosimeters were placed in a tank containing a mixture of water, glycerol and blue food colouring, matching their refractive index and colour [18, 19] For practical reasons the liquid's refraction index could not be matched to the dosimeters everyday, as changing the water-to-glycerol ratio introduces air bubbles which take 2-3 days to disappear, so the matching was performed for the dosimeters that cured for 4 days. The data reconstruction of the optical CT slices was performed using the ordered subsets convex algorithm with regularization via total variation (OSC-TV) from the Vista 3-D Reconstruction software (Modus Medical, London, Canada) with 1 mm^3 voxel size[1].

Dosimeters were fixated to the optical CT-scanner by a clamp, covering approximately 1 cm of the edge (the readout setup can be seen in Figure 1), so they had to be scanned twice to image the entire field. To avoid confusion, the scans will be referred to as "top" and "bottom" scans, where the top of the dosimeter is the side that cured in contact with air.

II.D. Storage

After the post-irradiation scans, the dosimeters were separated into three groups, stored at 5, 15 and 20°C, and readout for six consecutive days. The change in the absorption coefficient $\Delta\alpha$ was defined as the difference between pre-and post-irradiation scans, including the follow-up scans.

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[1] All the data sets and relevant code are available in the repository: github.com/liavaldetaro/3Ddosimetry

III. Tables

Table 1: Dosimeter composition in percentages of the total weight [wt%].

table1

Formulation	Curing agent [wt%]	Silicone elastomer [wt%]	LMG [wt%]	Chloroform [wt%]
5% CA	5.10	93.14	0.26	1.50
9% CA	9.00	89.24	0.26	1.50

IV. Figures

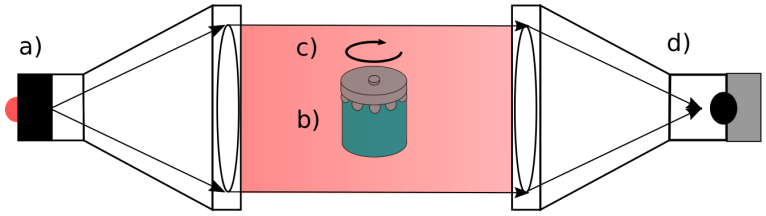

Figure 1: Schematics of the optical CT scanner and dosimeter placement. The light source (a) consists of a small isotropic source (wavelength of 633 nm) and a Fresnel lens. The dosimeter is fixed to the scanner with a clamp (b), which secures one end of the dosimeter, and its rotated 360° in small steps by a stepper motor. A CCD camera (d) images the light transmitted through the dosimeter for every rotation angle.

`fig_example`

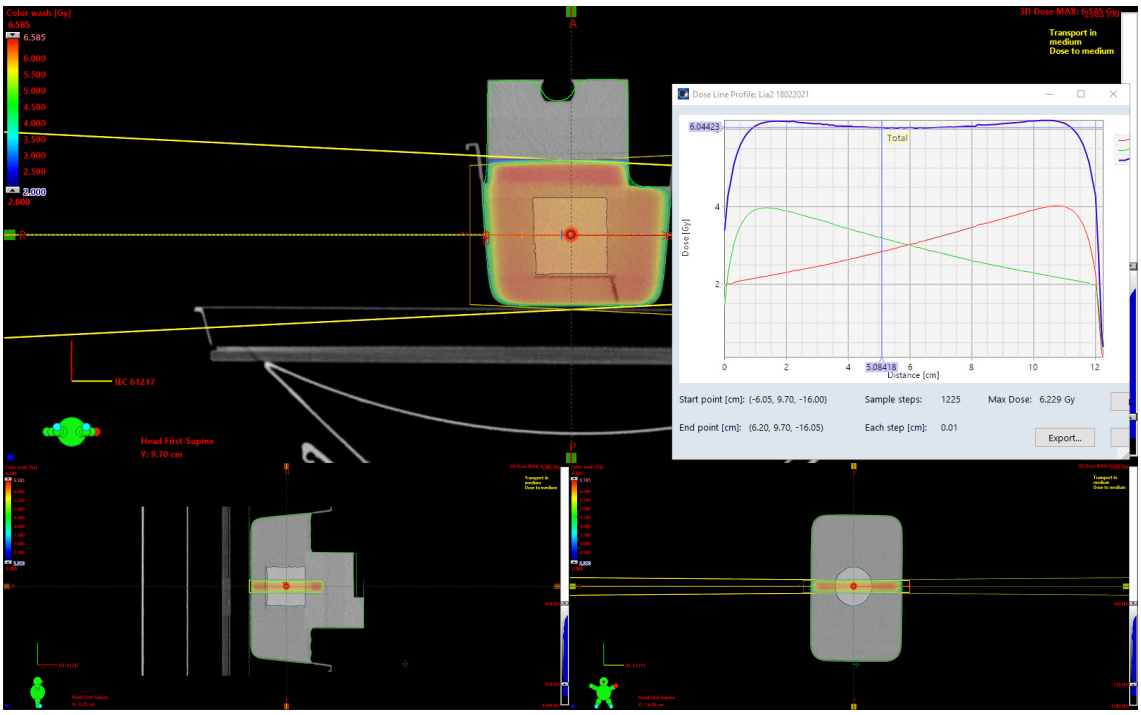

Figure 2: TPS plan `fig_example1`

Appendix

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References