3D Dosimetry based on a new optical approach for dosimetry gels: Use of the polarisation ratio of the scattering light

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Abstract. Several investigations have been carried out by researchers over past two decades to evaluate and perform the reading of gel dosimeters for the three-dimensional measurement of radiation fields. Imaging of the gels has been successfully accomplished with clinical MRI and via laser-based optical scanning using transmission of the light. We report here the methodology and results of a preliminary study carried out to evaluate the utility of a new and simplified approach to make 3D imaging of gel radiation dosimeters based on the scattering light analysis. For the purpose of this initial investigation, nMAG gel has been studied by our method. All pictures were evaluated through a region-of-interest (ROI) analysis to obtain the average change in image density in each sample as a function of the radiation dose. These measured ROI values were subjected to any fit and given a calibration dose and a spatial resolution. This way, we performed a 3D reconstruction of a dosimeter gel.

1. Introduction
One of the most interesting ways to read dosimeter gels is the optical approach because it is not expensive and is more available in comparison with MRI reading [1, 2]. Many studies have focused on its development by the use of the transmission approach due to the irradiated regions in polymer dosimetric gels becoming visibly opaque with an absorbed dose. By this fact, optical computerized tomography (optical-CT) of polymer gel dosimeters has been considered as an alternative to MRI [3]. Several optical scanner types have been developed [4-8] by relying on the principle of filtered back projection to reconstruct sectional images. Much recent optical-CT work has focused on non-scattering dosimeters [9]. Moreover, latterly, some optical devices were upgraded with dual wavelengths [10], and a new reconstruction algorithm was done but it still continues to use still the same approach, namely filtered backprojection (FBP) and algebraic reconstruction technique (ART).

In the optical CT scanning of 3D dosimeters, the dose distribution recorded in a dosimeter is represented by the 3D optical density map caused by the light attenuation and/or absorption from the radiation induced micro-particles in the dosimeter. Therefore, only the portion of the incoming laser beam that survives the multiple Rayleigh-Mie scattering and/or light absorption in the forward direction should be used for image reconstruction. This is why the IRMA research team and the FNSPE at CTU...
in Prague have previously introduced the new reading method with the scattering light analysis [11, 12]. They showed the feasibility of a non-expensive method based on the scattering light analysis to read polymer and radiochromic gels with an acceptable sensibility and a spatial resolution of 2 mm for 3D dosimetry. These measurements were performed on a small and uniform volume and for absorbed doses from 0 to 2 Gy and from 0 to 15 Gy for polymer and Fricke gel respectively. They validated the correspondence of the Beer Lambert law with the scattering intensity and used this calibration curve to read irradiated gel. Latterly, Kristensson suggests the use of more advanced optical diagnostics based on structured illumination and the use of the scattering light to read the gel [13]. In this work, we have created a new optical bench using scattered light, which specifically uses the polarisation ratio to make a link with the absorbed dose. It could also measure size in Particle sizing and velocity measurement of microspheres as shown in on other domains of research [14].

2. Gel Preparation and Irradiation

The nMAG was based on 2% w/w methacrylic acid (MMA) (∼99% titration, Sigma Aldrich), gelatin (8% w/w) (Type A, 300; Sigma Aldrich) was used as the matrix substance, and tetrakis (hydroxymethyl) phosphonium chloride (THPC, 80%, H2O 20%, Sigma Aldrich) was used as an oxygen scavenger. The remaining constituent was ultra-pure deionized water which was removed gas from nitrogen during 45 min before the preparation (Alpha gaz2, Airliquide TM). The gel preparation was carried out according to the standard practice described by [15]. Then, the gel solution was poured into PMMA containers with 4 optical faces of 5 ml (Fisher TM). In addition, we performed a sample which contained gelatin and the polymer gel in order to have an inhomogeneity sample. Then, it was irradiated, and it was used for the 3D imaging. All gels were thereafter stocked in a fridge during 4 hours, and pushed out 1 h before the irradiations. The samples were placed at 10 cm depth in a 500 cm × 500 cm × 500 cm cubic water tank (MP3-M, PTW) at a source-to-surface distance of 100 cm, and irradiated using a 10 cm × 10 cm and 6 MV photons beam, with the linear accelerator Clinac 2100C (Varian Medical system), set to deliver 400 MU.min⁻¹ from 0 to 5 Gy. Approximately 12 h after the irradiation, the gels were read by our optical bench.

3. Experimental Measurements and 3D Reconstruction

3.1. Readout system

![Figure 1](image1.png)

**Figure 1.** Representation of the optical bench by scattering light.

![Figure 2](image2.png)

**Figure 2.** Visualization of the calibration lane (resolution X200 et X800).

![Figure 3](image3.png)

**Figure 3.** Visualization of the scattered light from an irradiated sample (resolution GX200).

The bench contains a laser He-Ne (633 nm, circularly polarised), manual linear stages for the X,Y,Z axis of the sample, and a polarizing cube (Edmunds Optic TM), 2 mirrors (Edmunds Optic TM), a zoom (with a magnification from 200 to 800) (VH Z150, Keyence TM) and a numeric camera 16 bits (ORCA-Flash4.0 LT, Hamamatsu TM).
A circularly polarized incident light is illuminating the sample, creating the scattered light, which is collected by a convex lens at a specific scattering angle. Then the two components of polarisation are separated into two orthogonal directions by a cube polarizer (perpendicular and parallel polarisation). The gel was chosen so that we assumed to measure single scattering light. Both signals are analysed with a homemade software in Python. For each image, a blank image is done with the same exposition parameter of the acquisition, and deleted from the initial picture. This software analyses the average of the image and calculates the polarisation ratio for all zooms (200, 300, 500, and 800) and ROI for 400 to 25 pixels². 20 µm are represented by 10 pixels at a zoom of X200 (1pixel = 2 µm), and 50 pixels for a zoom of X800 (1pixel = 400 nm) (Fig. 2 and 3).

3.2. Scattering Light Analysis
For the first polarisation, the saturation of the ROI started at 3 Gy, which led to a decrease in the camera exposure time and by consequence, the average of the measured signal. On the second polarisation, the signal was linear with the absorbed dose until the saturation of the camera.

![Figure 4. Scattering intensity for polymer gel.](image)

3.3. Calibration Curve and Spatial Resolution

![Figure 5. Polarisation rate (I1/I2) measured at 90°as a function of the absorbed dose for 633 nm (all zoom).](image)
Figure 6. Polarisation rate \((I_1 - I_2)/(I_1 + I_2)\) measured at \(90^\circ\) as a function of the absorbed dose for 633 nm (all zoom).

We performed the calculation of the polarisation ratio for all zooms and ROIs, and obtained the same results, which means, the same area read by different zooms and ROIs gives the same information (fig 5). Then, we applied a spatial resolution to all ROIs, and showed the resolution spatial (in \(\mu m^2\)) as a function of the absorbed dose (fig 6) with a good sensibility, which depends essentially of the gel characteristics. The latter could be adapted to another dose range by modifying gel reagents.

3.4. Results for 3D reconstruction

We performed 66 acquisitions on the \(Z\) axis (red square), and made a 3D reconstruction of this volume (400 \(\mu m\) x 400 \(\mu m\)), using the calibration done earlier. We performed voluntary a special sample with gelatin and on the center, the dosimetric reagents. The red area is illustrated by the figure 7. Then, this difference is reconstructed in 3D for a small area.

Figure 7. 3D reconstruction of a volume by the scattering method.

4. Conclusion

This preliminary study introduced a new optical bench using the scattering light especially the polarisation ratio. This method is more accurate (\(\mu m\) scale) and more sensitive for low doses than other optical ways, and useful for 3D reconstruction without any algorithmic reconstruction. All data in this work was voluntary not fitted, that could improve results of this approach.

The next steps will consist of testing all kinds of gels, automating the bench, studying all parameters (wavelengths, impact of the volume sample, polarization and depolarization of the scattered light, refractive index, and scattering angulations) and upgrading the zoom and speed of this 3D acquisition. Moreover, we are considering measuring the exact size of microdomains and comparing them with a Mie numerical simulation and finally, to make a link between the absorbed dose and the microdomains’ size. To conclude, this approach for dosimetry gel could become a serious and innovative
way to measure rays without algebraic reconstruction, and for all applications, especially microdosimetry and nanodosimetry.

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6. References
[1] Baldock C et al 2010 Phys. Med. Biol. 55 R1-63
[2] Baldock C 2006 J. Phys.: Conf. Ser. 56 14-22
[3] Bosi S G et al 2008 Phys. Med. Biol. 54 275-83
[4] Gore J C et al 1996 Phys. Med. Biol. 41 2695
[5] Oldham M et al 2001 Med. Phys. 28 1436
[6] Doran S J et al 2001 Phys. Med. Biol. 46 3191
[7] Xu Y et al 2004 Med. Phys. 31 3024-3033
[8] Krstajić N and Doran S J 2006 Phys. Med. Biol. 51 2055-75
[9] Sakhalkar H S and Oldham M 2008 Med. Phys. 35 101
[10] Vandecasteele J and Deene Y D 2013 J. Phys.: Conf. Ser. 444 12053
[11] Alwan R et al 2008 Nucl. Instrum. Meth. B 266 834-40
[12] Svoboda J et al 2009 J. Phys.: Conf. Ser. 164 12026
[13] Kristensson E et al 2015 J. Phys.: Conf. Ser. 573 12010
[14] Huang X Q et al 2012 Opt. Lasers Eng. 50 57-63
[15] Karlsson A et al 2007 Phys. Med. Biol. 52 4697706