Optical laser scanning of a leucodye micelle gel: preliminary results of a 3D dose verification of an IMRT treatment for a brain tumor

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Abstract. In the present study an in-house developed leucodye micelle gel was used in combination with an in-house developed optical laser scanner for the 3D dose verification of an IMRT treatment of a pituitary adenoma. In an initial prospective study, a gel measured depth dose distribution of a square 6 MV photon beam was compared with an ion chamber measurement. In a second experiment, the gel and scanner were used to verify a clinical dose distribution on a recently installed linear accelerator. The calibration procedure is identified as the major source of dose deviations.

1. Introduction

To make a quantitative comparison between MRI and optical read-out techniques, a head phantom (figure 1) was constructed with a cylindrical cavity (10 cm in diameter) for the placement of a 3D gel dosimeter. In this exploratory study the optical read-out technique using an in-house developed micelle gel [1] was evaluated. Sources of error in the dose maps dose are identified and will be used in a final optimization.

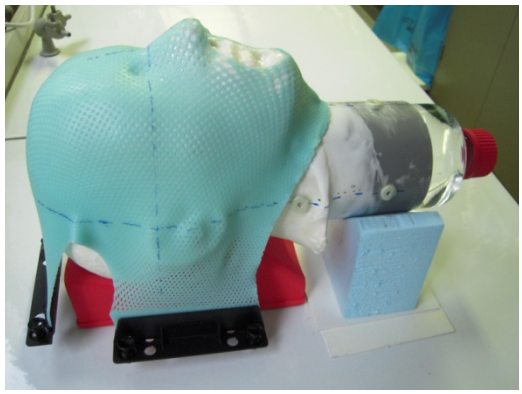

Figure 1: An in-house built head phantom with cylindrical cavity for the insertion of a 3D dosimeter.

2. Materials and methods

2.1. Gel fabrication

A leucodye micelle gel was fabricated consisting of 6% gelatin, 80 mM chloroform ($CHCl_3$), 50 mM sodium dodecyl sulphate (SDS), 5 mM trichloroacetic acid (CCl_3COOH) and 0.37 mM leucomalachite green (LMG) all dissolved in deionised water. Gelatin is dissolved in 60% (w/w) of the total water volume at room temperature and is left to swell for 10 minutes. Thereafter the gelatin-water solution is heated to 45°C. The remaining 32% of total water volume is used to dissolve SDS, CCl_3COOH, $CHCl_3$ and LMG. The solution is stirred for 30 minutes until all LMG is dissolved. After cooling down the

gelatin-water solution to approximately 40°C, the two solutions are added together and stirred for 30 minutes in a dark room. Finally, the gel is poured into cylindrical Teflon recipients with a diameter of 9.6 cm and a height of 20 cm.

2.2. Depth dose measurement

A micelle gel dosimeter was irradiated with a 4 cm x 4 cm 6 MV photon beam to a total dose of 43.7 Gy at the dose maximum (SSD 90 cm) using a clinical linear accelerator (Elekta Synergy). The dose distribution in the micelle gel dosimeter was read-out using an in house built optical CT laser scanner: the OPTOSCAN (figure 2, [2]).

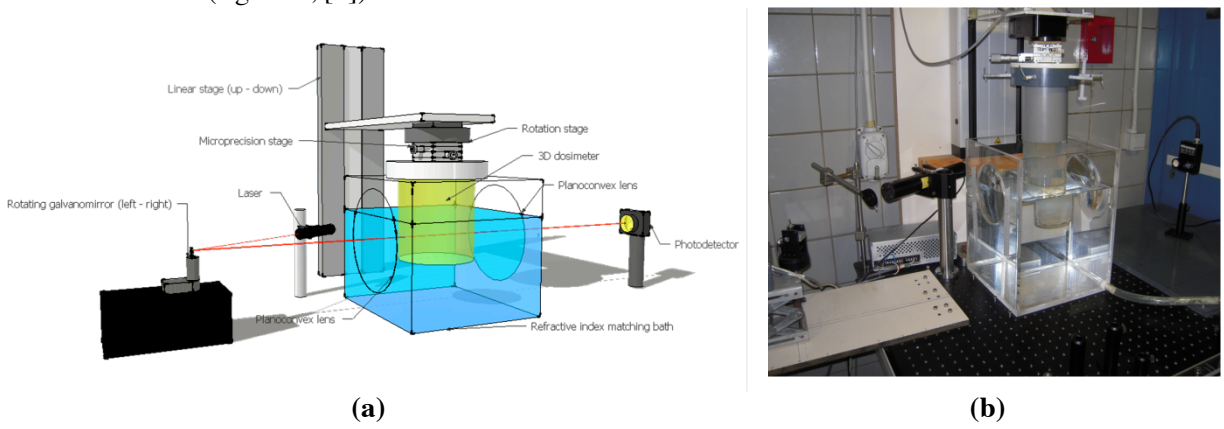

Figure 2: Schematic overview of the in-house built optical CT laser scanner (a) and a photograph (b).

180 projections of 120 mm were recorded per slice with a phantom rotation increment of 2°. 600 spatial increments were acquired per projection yielding a profile resolution of 0.2 mm. All sinograms were averaged to a resolution of 1 mm. Twenty-three slices were acquired over a total range of 115 mm (each separated by 5 mm). The total scan time amounted to 90 minutes. The refractive index matching solution consisted of approximately 9% propylene glycol in water. In-house developed Matlab code was used to control the optical scanner and construct optical density images. All optical density images were calibrated to dose images via a linear dose response relationship determined using the optical density values of the region of dose maximum and zero dose. A first scan of the phantom was acquired 19 hours post-irradiation. A second scan was acquired 21 hours post-irradiation. The first 12 hours post irradiation the phantom was stored in a refrigerator at 4°C. Afterwards, the gel was kept at 23°C.

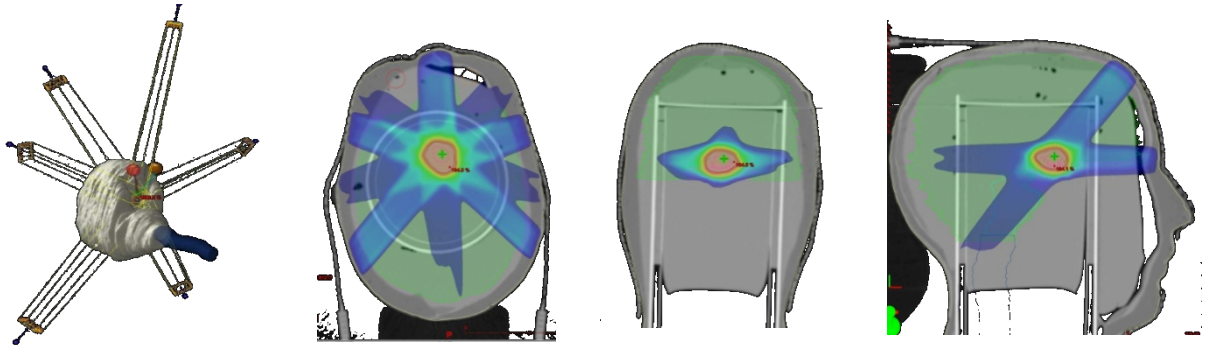

Figure 3: An overview of the important anatomy relative to the 6 beams used for the IMRT treatment in (a). In b, c and d a transverse, coronal and sagittal slice through the irradiation isocentre are shown.

2.3. Clinical experiment

A 3D dose verification of an IMRT treatment for a brain tumour was performed with a leucodye micelle gel and the OPTOSCAN. A head phantom was casted from epoxy resin and filled with 6% gelatin gel. Inside this head phantom, a cylindrical cavity was made for the 3D dosimeter phantom. A helical CT scan was acquired of the head phantom filled with a 3D micelle gel dosimeter. Using these CT images an IMRT plan for a pituitary adenoma was planned in Eclipse (Varian) in collaboration with the radiation oncologist (figure 3). A CTV, PTV, and critical organs such as cerebrum, optic chiasm, eye lenses, optical nerves and brainstem were identified (figure 3a). A sliding window IMRT treatment was optimized for six beam angles of which 5 angles were coplanar. A total dose of 15.8 Gy was planned at the isocentre calculated by the AAA_8908 algorithm (figure 3b, 3c and 3d).

The irradiation was performed on a Varian Clinac 2300IX (figure 4). Prior to the treatment delivery, a cone beam CT was acquired to match the phantom position to the treatment planning CT. The phantom was irradiated with 3 fractions resulting in a dose of 47.4 Gy to the isocentre.

A stack of 30 slices (2 mm slice distance) of the irradiated micelle gel dosimeter was optically acquired using the same imaging parameters as in the first experiment. The total scan time amounted to 119 minutes. The optical density maps were calibrated to dose maps relative to the isocentre dose predicted by the TPS. An ion chamber measurement is planned in the near future to independently verify the delivered dose at the isocentre.

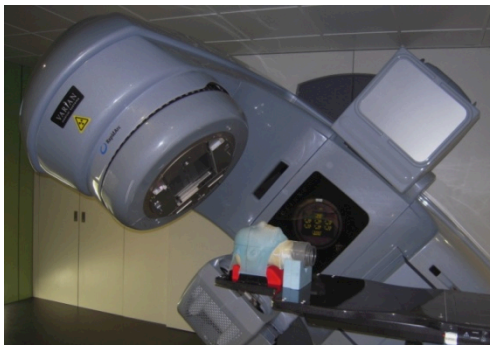

Figure 4: Irradiation treatment of the gel dosimeter head phantom

3. Results and discussion

3.1. *Depth dose measurement*

Both gel measurements show excellent agreement with the ion chamber recorded dose values (figure 5). Remarkably no clear signs of diffusion of the leucodye molecules can be observed post-irradiation (figure 5a). A minor change has been made in the fabrication protocol. Instead of mixing the leucodye with pure chloroform both products are separately added to the water - SDS - CCl_3COOH solution. A precise measurement of the diffusion coefficient will be performed in the near future.

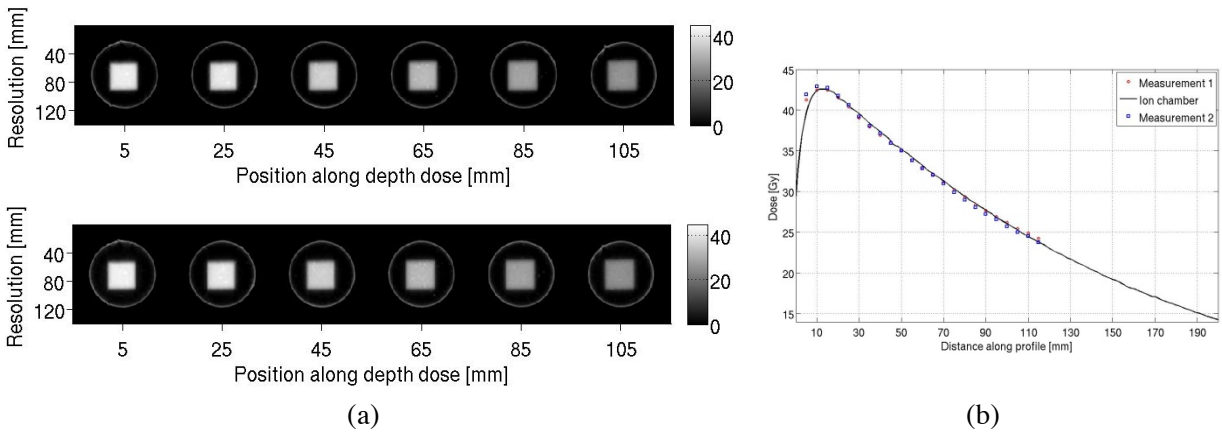

Figure 5: In (a) 6 out of 23 measured dose maps are shown of the fist measurement 19 minutes post-irradiation (top) and the second measurement 21 hours post-irradiation (bottom). The mean of the measured dose in a circular ROI in the centre of the square field with radius 0.7 cm is plotted against an ion chamber dose measurement in (b).

3.2 Clinical experiments

An edge artefact caused by a small mismatch of the refractive index matching solution results in a large dose deviation in an annular region of 0.5 cm from the edge of the phantom. This region was omitted from our results. In figure 6a and 6b, the TPS calculated and gel measured dose distribution near the isocentre can be seen respectively. In figure 6c a percentage difference map is shown were maximum dose underestimations in the order of 6% are found. In figure 6d a 3D gamma evaluation using the 3%/3mm criterion is shown displaying the failing pixels.

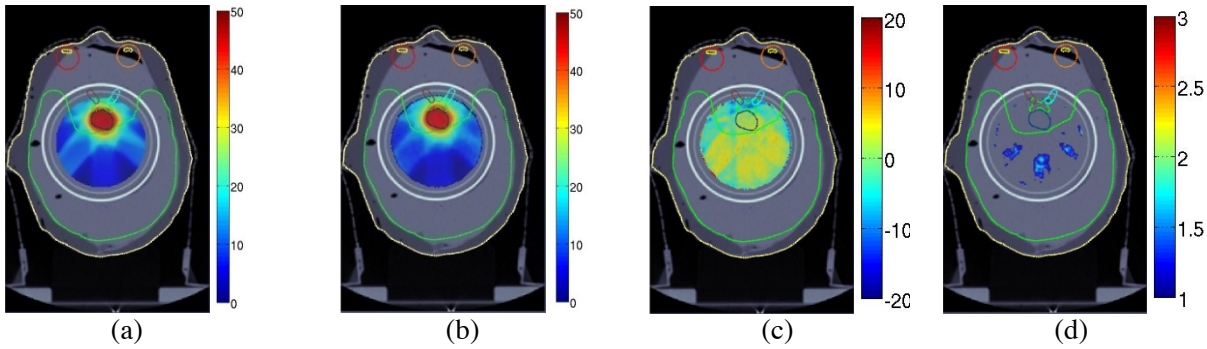

Figure 6: The dose distribution of the TPS (a), the gel measurement (b), the difference map between the TPS and gel (expressed in percent) (c) and a gamma map (3%/3mm, d) are shown as an overlay figure on the CT images at the level of the isocentre. Anatomical structures are shown: cerebrum, eyes, eye lenses, optical nerves, optic chiasm, PTV and CTV.

Additionally, in a coronal and sagittal direction a good qualitative agreement was found (figure 7). However, on average 5% of the pixels in the scanned volume (300ml) deviate by more than 7% in absolute dose from the TPS. In the total scanned volume 9% of the pixels fail the 3%/3mm criteria, while only 2.8% of the pixels fail the 5%/3mm criteria. The majority of these pixels are located in the low dose regions.

These errors are presumed to be attributed to the linear calibration process. Furthermore, temperature during readout and post-irradiation stability need to be further investigated.

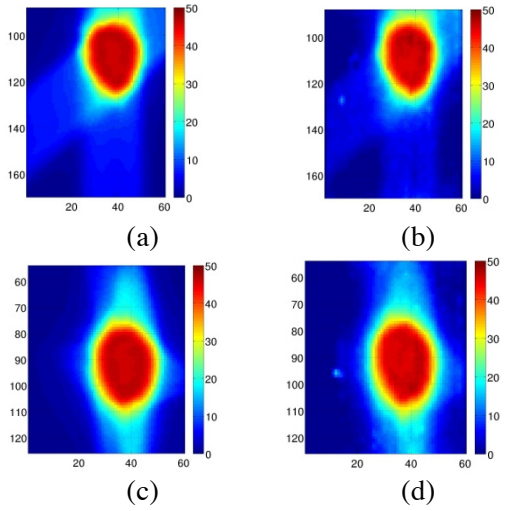

Figure 7: A comparison between a TPS calculated (a,c) and gel measured (b,d) slice along sagittal (a,b) and coronal (c,d) direction through the isocentre.

4. Conclusions

The accuracy of our system amounts to approximately 7%. However, the origins of dose deviations are being investigated. Accurate measurements within 5% in a total 3D volume are expected to be feasible.

5. Acknowledgements

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6. References

[1] Vandecasteele J *et al* 2011 *Phys. Med. Biol.* **56** 627
[2] Vandecasteele J and De Deene Y 2009 *J. Phys.: Conf. Ser.* **164** 012024