Optical evaluation of Fricke xylenol orange gel by light scattered at 90 degrees

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Abstract. This communication presents optical method for evaluation of Fricke xylenol gel (FXG) using light scattered at 90 degrees to initial direction. Although Fricke gel is predominantly absorbing, gelatine matrix scatters enough light which could be collected and related to dose delivered to gel. Initials experiments were oriented to determination applicability of this approach.

1. Introduction
This research is focused to development of an optical method based on measuring of a light primary scattered on gelatine and then attenuated by absorption. The basic is to established relations between scattered light intensity and doses. Moreover used apparatuses are very simple and thanks to utilization of the rectangular containers instead of cylindrical this technique avoids problems related to reflections.

2. Materials and Methods
The experimental setup consists of laser, piezoelectric apparatus providing light thin light sheet, focusing lens and support with sample. Scattered light is collected by a 12 bits CCD camera (fig 1). As a dosimeter a Fricke xylenol orange gel [1] was used for all experiments. Once the raw image is de-noised and smoothed analyse [2] begin. Target is to find attenuation coefficient either for whole cell or for small region of pixels. Next step consists in comparison of attenuation at different point of a one sample. Last one lies in measuring on heterogeneous sample and reconstruction of attenuation distribution.
2.1. Spectrometric cells
In this first experiment a set of 7 irradiated spectrometric cells (0, 1, 2, 4, 6, 9 and 12 Gy) was subsequently illuminated by laser sheet passing through the centre of a cell (fig. 2). Theses wavelengths were used 476, 488, 514 and 633 nm. For reduction of noise every image was taken as an average of 320 frames. After that, images were processed using Matlab software. Then the intensity of images was examined in order to verify exponential decrease $I = I_0e^{-ax}$ and its parameter $a$ where $I$ is observed image’s intensity $I_0$ is initial intensity and $x$ is distance in pixels. The objective of this measurement was to determine the response of our systems.

2.2. Uniform phantom
Glass 5x5x8 cm glass container filled with nonirradiated gel was placed on the support so laser sheet passed through just behind wall closer to camera, then container stepped by 1 mm toward the camera until laser reached remoter wall. In this way 50 images were acquired which allowed to complete a 3D data set. Aim of this measurement was examination of decreases of images’ intensity in both directions – parallel and perpendicular to propagation of a laser sheet. For this purpose attenuation in parallel direction was directly estimated from the images and also attenuation in smaller region (100x100 pixels) was calculated and compared. In case of perpendicular direction corresponding data in different images were plotted in graph and fitted.

2.3. Phantom with artificial cavities
For this phantom same glass container as in previous experiment were used. Three artificial cavities, two circular with diameter of 1 and 1,3 cm and one rectangular 1x3,5 cm were filled with FXG coloured by addition of known amount of Fe$^{3+}$ (0,4 and 0,6 mM). By now only homogenous samples were measured so the experiment was used to test capability to distinguish difference among coloured gels and reconstruction of the attenuation distribution. To assign appropriate value of $a$ in layer between two consecutive positions of the laser sheet (514 nm), it is necessary to make correction for precedent layers. Initially the $a$ for small regions (50x50 pixels) in first image (closest to CCD camera) is calculated. Next image intensity of the second layer is modified in order to compensate a lost of signal due to passage of the first layer. Then modified image is used to find $a$ for the second image. In this way $a$ for all laser sheet position is determined.

3. Results and Discussion

3.1. Spectrometric cells
Images’ intensities for all cells were plotted in graph (fig. 3). Parameter $a$ was found to be in range from $3.266.10^{-5}$ pixel$^{-1}$ for nonirradiated gel to $7.59.10^{-5}$ pixel$^{-1}$ for gel irradiated to 12 Gy as shown in next graph (fig. 4). Note that $a$ is an experimental value and an exact relation between the $a$ and the coefficient of extinction has to be established yet. However $a$ seems to be related to dose and thus it could be used for dose measurement.

![Figure 3. Intensity of images for irradiated gel. Red laser (633 nm) passes through cells from the left to the right.](image3)

![Figure 4. Parameter $a$ as a function of the dose measured at 633 nm.](image4)

3.2. Uniform phantom
Parameter $a$ for planes parallel to the laser sheet was measured to be $2.302\pm0.367.10^{4}$ pixel$^{-1}$. For perpendiculars planes intensity of different images with same x coordinates were used (Fig. 5) and $a$ was found to be $2.592\pm0.576.10^{4}$ pixel$^{-1}$. Additionally $a$ was calculated for smalls region of the image.
(100x100 pixel) and the result is $2,359\pm 0,995 \cdot 10^{-4}$ pixel$^{-1}$. All three values are in agreement although the standards deviations are important.

Figure 5. This image illustrates signal’s diminution in gel measured for 5x5 cm phantom. The laser sheet (514 nm) is propagated along x axis. The entering surface is that with coordinates [0, y] while CCD camera is placed next to surface [x, 50].

3.3. Phantom with artificial cavities
The result of the last experiment is presented at the following image (Fig. 6). One pixel in original image corresponds to ~ 0,05 mm, however spatial resolution in reconstructed image is about 5 times worse as larger region (50x50 pixel) had to be used because of noise. Coefficient $a$ was calculated $2,417\pm 0,305 \cdot 10^{-4}$ pixel$^{-1}$ for clear gel, $3,406\pm 0,571 \cdot 10^{-4}$ pixel$^{-1}$ (cavity 2), $5,079\pm 0,468 \cdot 10^{-4}$ pixel$^{-1}$ (cavity 1) and $5,127\pm 0,275 \cdot 10^{-4}$ pixel$^{-1}$ (cavity 3). These values agree with previous experiment.

Figure 6. Phantom with cavities – a) Composed image of acquired data, each column represents one position of the laser sheet which was moved with 1 mm step across the container. Areas 1, 2 and 3 correspond to coloured gel (1 and 3 - 0,6 mM while 2 - 0,4 mM of Fe$^{3+}$). b) Estimated coefficient $a$. 
4. Conclusion
This method seems to be usable for 3D dosimetry. Next step consists of amelioration of images processing, spatial resolution and using more appropriated wavelength corresponding to the absorption maximum of irradiated gel and thus increase sensibility.

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