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Enhancing the Cherenkov light image quality using fluorescent dye for radiation therapy

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ABSTRACT

Background: Cherenkov light imaging is a promising tool in various clinical applications, including in vivo dosimetry and radiation field setup verification. Due to strong light attenuation, however, the technique requires no light-attenuating material to be placed on the patient's skin, thereby prohibiting the wearing of any clothing. To overcome this drawback, we hypothesized that cloth containing fluorescent chemicals (or dyes) could compensate for the loss of photon attenuation by emitting additional photons.
Purpose: To study the feasibility of enhancing the Cherenkov light image of a high-energy photon beam by an opaque cloth containing fluorescent dye.
Methods and Materials: A 25 cm x 25 cm x 25 cm water bath was placed on the treatment couch of the Varian True Beam linear accelerator. A 10 MV FFF photon beam with an 8 cm x 5 cm field size was used to irradiate the phantom at a 90-degree gantry angle. A scientific COMS camera (PCO.Panda 4.2) was positioned 100 cm from the water bath to capture an image of the photon beam from the lateral direction. A digital color camera (Canon EOS 6D) positioned 80 cm from the water bath, was also used to capture photos of the photon beam. The shutter durations were 0.1 and 1 seconds for the PCO and Canon cameras, respectively. Multiple images were taken in a dark room. To hide the water bath, a thin cotton sheet was hung on the wall facing the camera. A cotton sheet with varying amounts of fluorescein dye was used to study the effects of fluorescence on the photographic images of the radiation beam produced by Cherenkov light. Additional measurements were performed to evaluate the impact of fluorescence on fluorescein levels in cotton and the type of dyes, by simulating Cherenkov light imaging experiments using a flashlight torch with white light and RGB color options as a visible-light source.
Results: The high-energy photon beam was visible on the photos without the cotton sheet. However, by placing it, the beam shape became unrecognizable in the pictures. By adding an optimal amount of fluorescein dye to the cotton sheet, the beam became visible again on the photographic image. The analysis of color images confirmed that the image intensity enhancement was due to the fluorescent dye, which converted shorter-wavelength Cherenkov photons to longer wavelengths in the green or red ranges.
Conclusions: We demonstrated that Cherenkov light can be used for imaging and dosimetry even when a patient wears opaque clothing.

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BACKGROUND

- Cherenkov light imaging is a promising tool in various clinical applications, including in vivo dosimetry and radiation field setup verification.
- Due to strong light attenuation, however, the technique requires no light-attenuating material to be placed on the patient's skin, thereby prohibiting the wearing of any clothing.
- To overcome this drawback, we hypothesized that cloth containing fluorescent chemicals (or dyes) could compensate for the loss of photon attenuation by emitting additional photons.

PURPOSE

- To study the feasibility of enhancing the Cherenkov light image of a high-energy photon beam by an opaque material containing fluorescent dye.

METHODS AND MATERIALS

- A 25 cm x 25 cm x 25 cm water bath was used for two experiments. To mask the water bath, a 0.5 mm thick cotton sheet was hung on the wall facing the camera.
- First, measurements were performed to evaluate the impact of fluorescence on fluorescein levels in cotton and the type of dyes, by simulating Cherenkov light imaging experiments using a flashlight torch with white light and RGB color options as a visible-light source.
- A digital color camera (Canon EOS 6D) positioned 80 cm from the water bath, was used to capture photos of the photon beam.
- A cotton sheet with varying amounts of fluorescein dye was used to study the effects of fluorescence on the photographic images of the radiation beam produced by Cherenkov light.
- Second, a 10 MV FFF photon beam with an 8 cm x 5 cm field size was used to irradiate the phantom at a 90-degree gantry angle.
- A scientific COMS camera (PCO.Panda 4.2) was positioned 100 cm from the water bath to capture an image of the photon beam from the lateral direction.
- The shutter durations were 0.1 and 1 seconds for the PCO and Canon cameras, respectively. Multiple images were taken in a dark room.

RESULTS

Experiment 1

- The photon intensity profiles were taken along the light source direction (Figure 3). The light intensity was the lowest when there was no cloth in the water bath (i.e. Plain Glass).
- With a plain cotton cloth placed in the water bath, the intensity increased up to 52%. Whereas without a dye, the intensity profile was flat along the light beam (Figure 3).
- The green, blue, and orange painted on the cotton cloth resulted in a significant increase in light attenuation.
- The fluorescein dye concentration of 0.15 g showed least attenuation hence an elevated line profile, indicating the fluorescent effect.
- Whereas a higher fluorescein dye concentration, as seen in figure 2c, demonstrated an increased light attenuation, negating the positive impact of fluorescence.

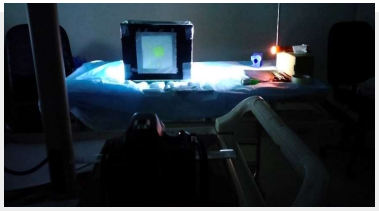

Figure 1: Experimental setup for validating the fluorescent effects of various color paints and dye concentrations. The flashlight source simulated the Cherenkov-triggered visible light emission from 10 MV FFF X-rays.

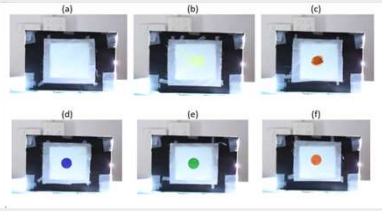

Figure 2. Illustration of various paints on the white cotton fabric: (a) plain cotton, (b) 0.12 g fluorescein dye, (c) orange fluorescein dye, (d) blue paint, (e) green paint, (f) orange paint.

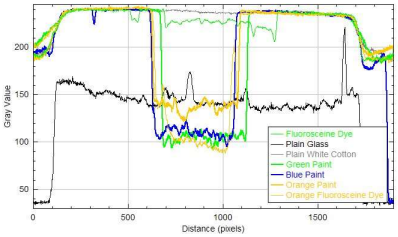

Figure 3: The photon intensity profiles along the light source direction.

Experiment 2

- The high-energy photon beam was visible on the photos without the cotton sheet. However, by placing it, the beam shape became unrecognizable in the pictures.
- By adding an optimal amount of fluorescein dye to the cotton sheet, the beam became visible again on the photographic image.
- The analysis of color images confirmed that the image intensity enhancement was due to the fluorescent dye, which converted shorter-wavelength Cherenkov photons to longer wavelengths in the green or red ranges.

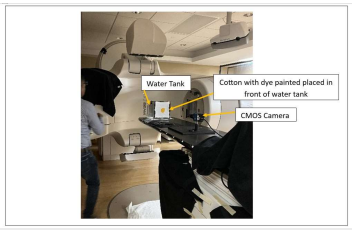

Figure 4: Experimental setup for capturing a Cherenkov light image with fluorescein dye in a cotton cloth

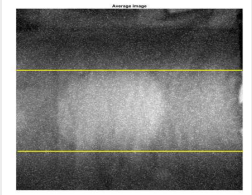

Figure 5: Cherenkov light image with fluorescein dye in cotton cloth (Canon EOS 3D). The image is split into three color channels. The enhanced area in the green image indicates an increase in photons emitted by the fluorescein dye.

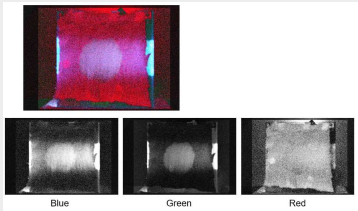

Figure 6: Cherenkov light image with fluorescein dye in cotton cloth captured by a sCMOS camera. The yellow horizontal lines indicate the edges of the photon beam.

CONCLUSIONS

We demonstrated that Cherenkov light can be used for imaging and dosimetry even when a patient wears opaque clothing.