Real-time in vivo Cherenkoscopy imaging during external beam radiation therapy

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Abstract. Cherenkov radiation is induced when charged particles travel through dielectric media (such as biological tissue) faster than the speed of light through that medium. Detection of this radiation or excited luminescence during megavoltage external beam radiotherapy (EBRT) can allow emergence of a new approach to superficial dose estimation, functional imaging, and quality assurance for radiation therapy dosimetry. In this letter, the first in vivo Cherenkov images of a real-time Cherenkoscopy during EBRT are presented. The imaging system consisted of a time-gated intensified charge coupled device (ICCD) coupled with a commercial lens. The ICCD was synchronized to the linear accelerator to detect Cherenkov photons only during the 3.25-μs radiation bursts. Images of a tissue phantom under irradiation show that the intensity of Cherenkov emission is directly proportional to radiation dose, and images can be acquired at 4.7 frames/s with SNR > 30. Cherenkoscopy was obtained from the superficial regions of a canine oral tumor during planned, Institutional Animal Care and Use Committee approved, conventional (therapeutically appropriate) EBRT irradiation. Coregistration between photography and Cherenkoscopy validated that Cherenkov photons were detected from the planned treatment region. Real-time images correctly monitored the beam field changes corresponding to the planned dynamic wedge movement, with accurate extent of overall beam field, and expected cold and hot regions.

Keywords: Cherenkov; Cherenkov dosimetry; dose; radiation therapy; linear accelerator; Cherenkoscopy.

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were calculated (mean value over the standard deviation) based on a chosen region (100 pixels × 100 pixels around the center) as indicated by a dotted red box in Fig. 2(a). SNR values were plotted with the corresponding frame rates in Fig. 2(b). To ensure relatively good image quality as well as real-time data acquisition, an accumulation of 50 radiation bursts (fps = 4.7) for each image was chosen as the imaging procedure for the following in vivo imaging. The average pixel value of each image was calculated and plotted with the corresponding delivered dose in Fig. 2(c). Least square linear fitting was applied and the results of the fitting are listed in Fig. 2(c). The good linearity ($R^2 = 1$) between Cherenkov intensity and delivered dose suggests that Cherenkoscopy could be a novel technique for superficial dose estimation. Our previous work focusing on a phantom study validated that, in tissue equivalent phantom, Cherenkov emission could sample superficial dose up to 6 mm and could be taken as surrogate of radiation dose in the sampling region with average discrepancy of 1%. Within the scope of this short note, we focus on validating the fast imaging capabilities of Cherenkoscopy in vivo and correlate this signal to superficial dose qualitatively within the process of EBRT.

As shown in Fig. 3(a), a treatment plan was designed in Eclipse independently to treat a dog with a spontaneous oral tumor without considering the process of Cherenkoscopy. The LINAC was set to irradiate the treatment region with 6 MV photon beam, at a dose rate of 600 MU/min. A total dose of 59 MU (reference dose of 60.5 cGy) was delivered. A dynamic wedge [indicated in Fig. 3(a)] was designed to control the beam dynamically during the treatment, delivering a homogenous dose distribution even in the presence of complex tissue geometry. Detailed information about the treatment field and the dynamic wedge are listed in Table 1. In order to deliver radiation dose to the tumor, high-energy radiation has to incident on the surface externally and results in certain amount of radiation dose to be deposited near the surface. The deposited dose near the surface of the treatment region was predicted by Eclipse and shown in Fig. 3(a). Since phantom studies validated that image quality (SNR > 30) and fast imaging capability (fps = 4.7) are balanced by an accumulation of 50 radiation bursts, Cherenkoscopy was acquired using this acquisition procedure. The tungsten light in the radiotherapy room was turned on to provide a reasonable level of ambient light while imaging. The background image was acquired with the same procedure before the treatment (radiation off), and background subtraction was applied simultaneously during the process of data acquisition. Figure 3(b) shows the photographic view of the...
entrance region from the imaging system. The colorized in vivo Cherenkoscopy [Fig. 2(c)] corresponding to the treatment plan described in Fig. 1 and Table 1 was generated by averaging all the frames of images taken during the treatment and smoothed by a median filter with kernel size of 10 pixels x 10 pixels. In the first image of Fig. 2(c), Cherenkoscopy was coregistered to the photographic view by adding the Cherenkoscopy to the blue channel. It can be validated that the detected Cherenkov emission is from the treatment region. To the extent of overall beam field shape, hot and cold regions, the Cherenkoscopy [Fig. 2(c)] shows similar distribution compared with the predicted surface dose [Fig. 1]. The hot regions in Cherenkoscopy around the teeth disagree with the predicted dose due to the relatively low absorption of Cherenkov photons by the teeth. Figure 3(d) shows frames of coregistered Cherenkoscopy monitored throughout the entire treatment. To remove the noise caused by high-energy photons hitting the ICCD directly, images were processed by median filtering over a stack of images including the two adjacent frames. The hot regions in Cherenkoscopy monitored throughout the entire treatment were coregistered to the photographic view by adding the Cherenkoscopy to the blue channel. This imaging is a novel approach for beam field monitoring and could be extended to radiation dose assessment in real time on the tissue surface during EBRT.

### Acknowledgments

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### References


### Table 1 Parameters of the treatment plan.

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<thead>
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<th>Technique</th>
<th>Machine/energy</th>
<th>Gantry (deg)</th>
<th>Collimator (deg)</th>
<th>Couch (deg)</th>
<th>Wedge</th>
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<td>180.0</td>
<td>180.0</td>
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<td>X2 (cm)</td>
<td>Field Y (cm)</td>
<td>Y1 (cm)</td>
<td>Y2 (cm)</td>
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<td>Y (cm)</td>
<td>Z (cm)</td>
<td>SSD (cm)</td>
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