Why Cherenkov Emission During Radiotherapy is Not Strongly Dependent on Beam Energy

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INTRODUCTION

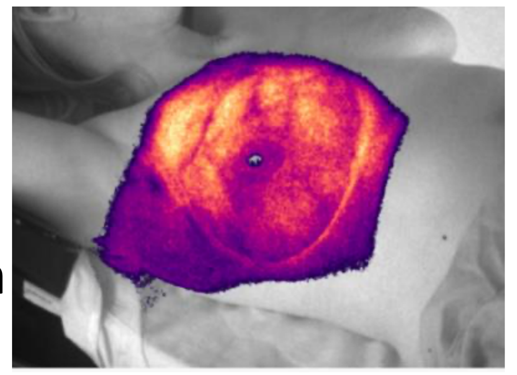


Fig. 1

Cherenkov radiation is the emission of light in a dielectric medium when a charged particle travels faster than the phase velocity of light in that medium. During radiotherapy, Cherenkov light is generated within a patient's tissue, approximately proportional to the delivered dose[1], and is emitted from the patient's surface (Fig. 1). This light can be captured with intensified cameras as a noninvasive method to visualize dose deposition in real time[2,3] (Fig. 2).

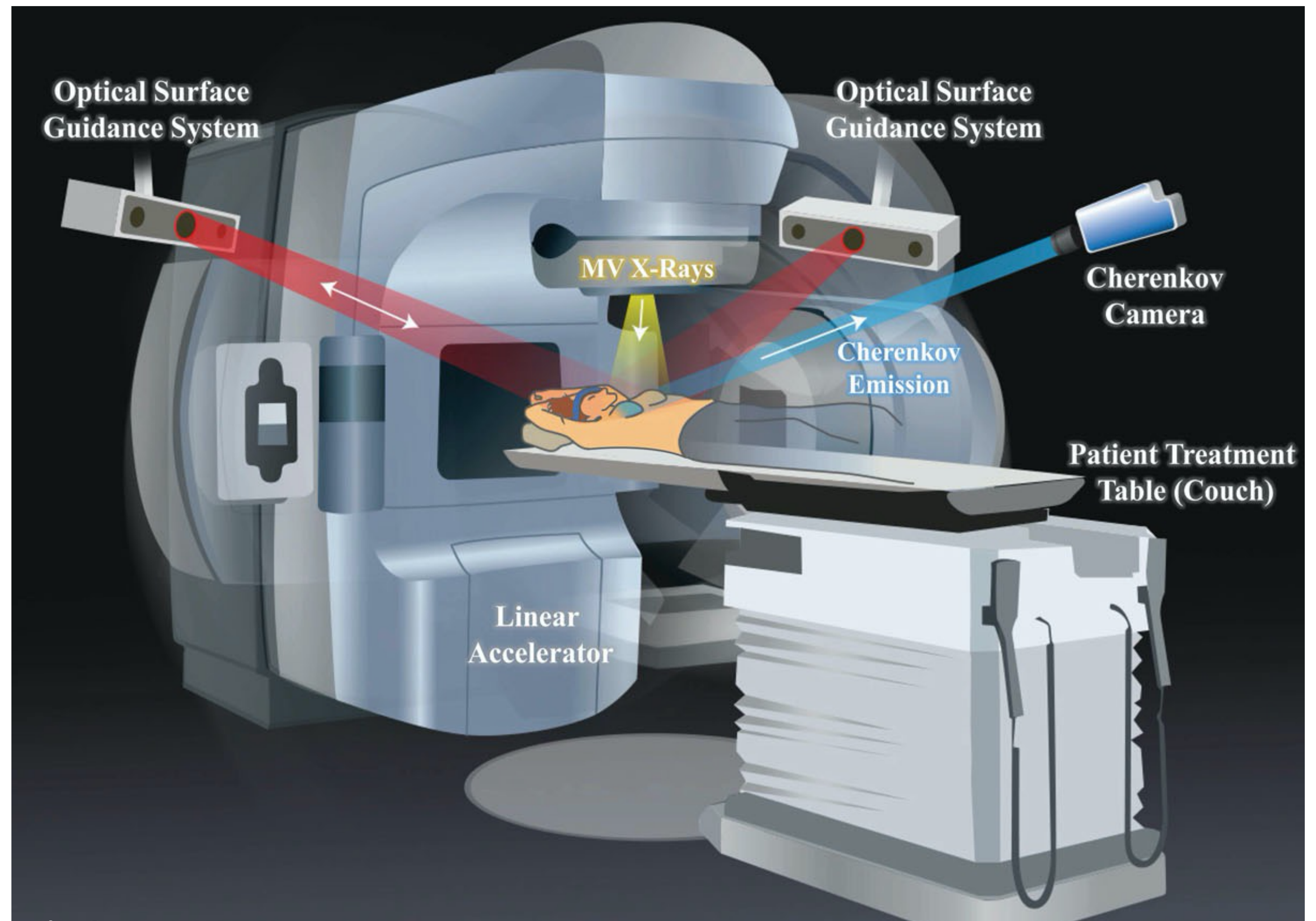
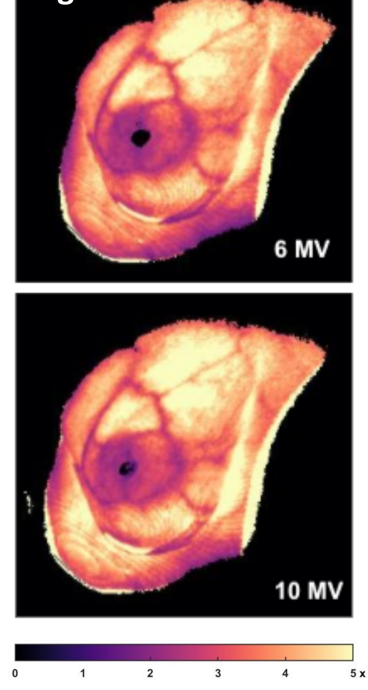


Fig. 2

Though Cherenkov light generation within tissue is strongly dependent on beam energy, it has remained a mystery why the intensity of emitted light appears to be nearly constant when treating at different energies (Fig 3.). In this study, the effects of various beam and tissue properties on the Cherenkov emission were examined in an effort to explain this observed phenomenon.

Fig. 3



AIM

To understand why the Cherenkov signal emitted during radiotherapy is not strongly dependent on treatment beam energy.

THEORY

Following diffusion theory solutions, the emitted Cherenkov signal was derived as a function of the dose build-up slope and tissue optical properties.

R: Emitted Cherenkov signal
φ: Isotropic fluence rate
k_1: surface dose
k_2: build-up slope
D: diffusion coefficient
μ_{eff}: effective attenuation coefficient

$$R_D = -D\,\frac{\partial\varphi(r)}{\partial z}\Big|_{z=0} \qquad (1)$$

$$\varphi(z) = \left(\frac{1}{2D\,\mu_{eff}}\,e^{-\mu_{eff}(z)}\right) * (k_1 + k_2\,z) \qquad (2)$$

METHODS

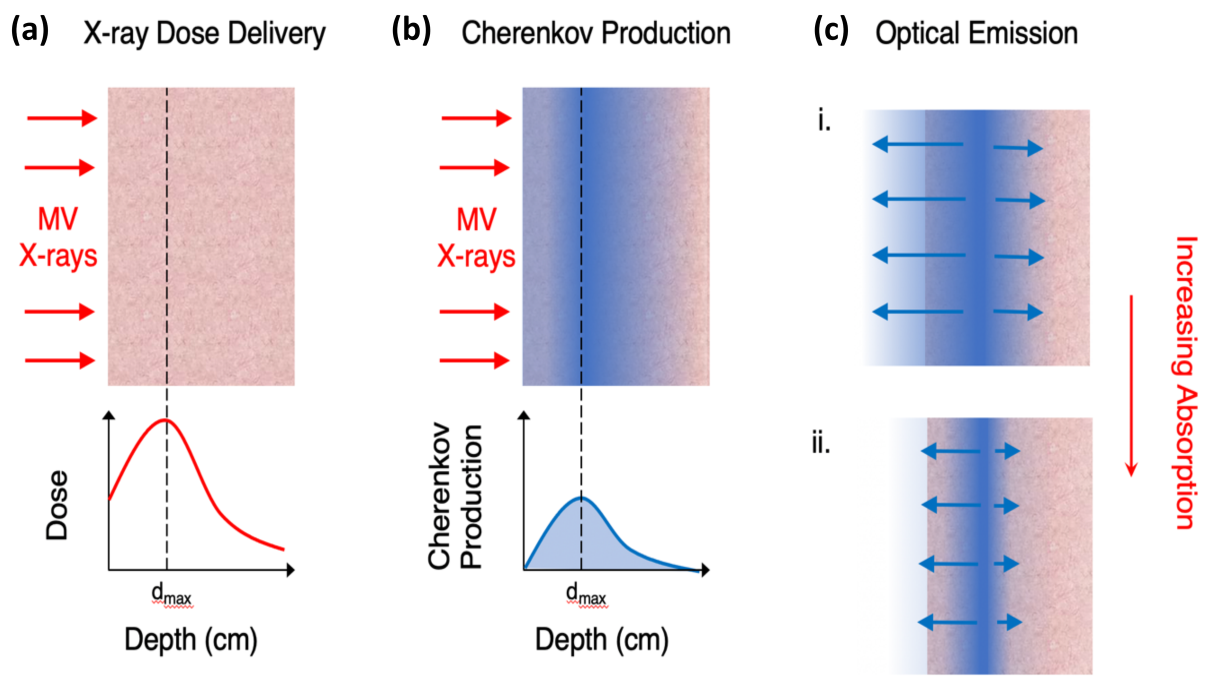


Fig. 4 A linear accelerator irradiates various tissue phantoms of different optical properties with 6, 10, and 18 MV x-rays (a) and dose is deposited as a function of depth, represented qualitatively by the graph. The depth at maximum dose, d_{max}, is also the point of maximum Cherenkov light generation (b). As tissue optical properties vary (c), so does the amount of light that escapes the surface.

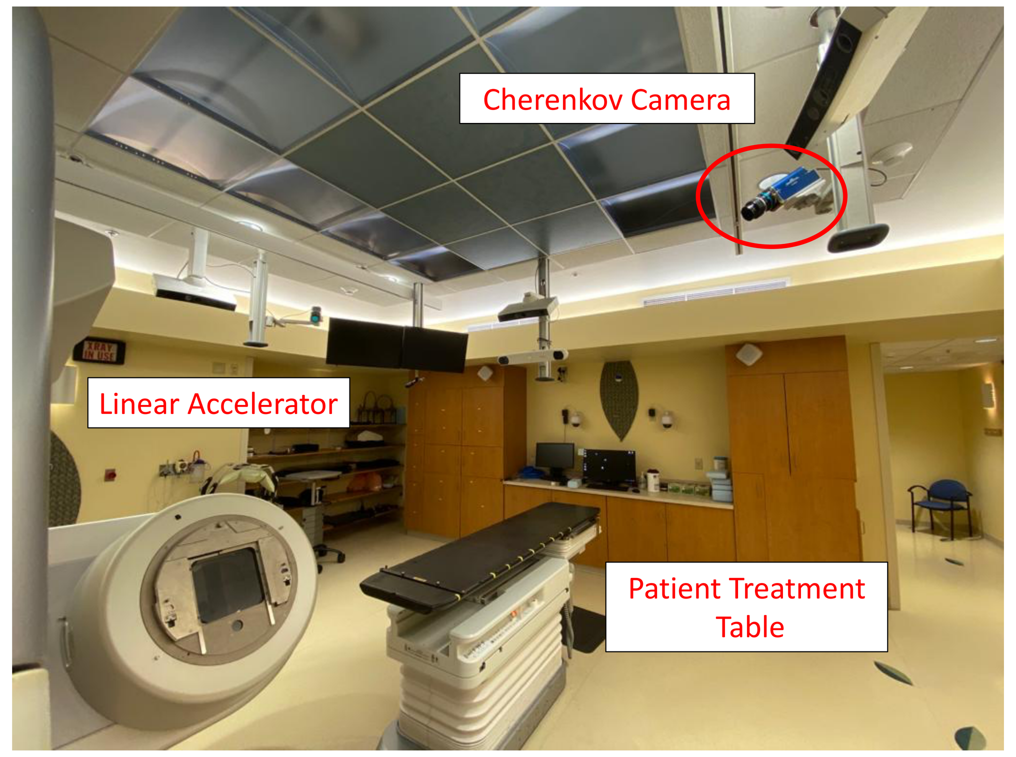


Fig. 5 The Cherenkov emission is captured with an intensified CMOS camera that is fixed in the treatment room for clinical imaging. Each phantom was irradiated top-down for entrance beam surface imaging, as well as from underneath for exit surface imaging. Phantoms were built with the thickness of the depth of d_{max} for each energy.

RESULTS

Consistent with clinical images (Fig. 3), the Cherenkov emission from the phantom's beam entrance surface was independent of energy (a). At the beam exit surface, where there is no dose build-up region, the Cherenkov emission increased as a function of beam energy due to increased light generation[1] (b). Normalizing the entrance Cherenkov emission by approximately the number of Cherenkov photons generated revealed an inverse relationship between beam energy and the slope of the dose deposition build-up within tissue (c). **The two competing effects of increased light generation, yet slower dose build-up with increasing x-ray energy are of nearly the same magnitude, and therefore result in an approximately constant emitted Cherenkov signal from the beam entrance surface** (a).

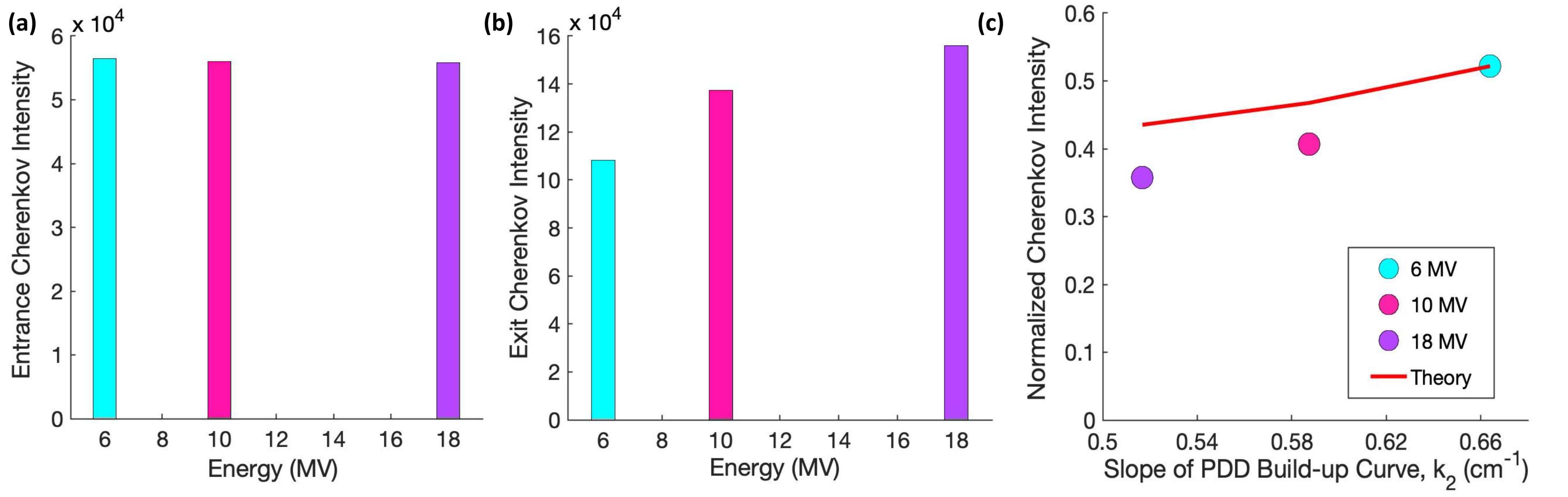


Figure 6. The intensity of Cherenkov emission from the beam entrance surface (a) and the exit surface (b) of a 1% blood / 1% Intralipid® diffuse liquid tissue phantom as a function of x-ray energy. Figure (c) shows the entrance Cherenkov emission intensities normalized by the exit Cherenkov intensities (proportional to the amount of Cherenkov photons produced with increasing x-ray energy) plotted as a function of the dose build-up slope. Figure (c) also shows the theoretical relative emitted Cherenkov light signal following Eqns. (1) and (2), which predict the normalized Cherenkov light that escapes the entrance surface.

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CONCLUSIONS

The results of this study explain why Cherenkov emission during radiotherapy is not strongly dependent on beam energy, despite greater Cherenkov photon generation at higher energies[1]. Quantifying the effects of various beam properties is a progressive step towards verifying surface-dose delivery with Cherenkov light imaging during radiation therapy treatments in real-time.

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Figure List

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Figure 3: Cumulative Cherenkov images taken during whole-breast radiation therapy at DHMC NCCC. All patients provided informed consent in this IRB approved study.

Figure 5. Photo by courtesy of Daniel A. Alexander.

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