Cherenkov imaging of total skin electron irradiation (TSEI)

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Abstract. Total Skin Electron Irradiation (TSEI) utilizes high-energy electrons to treat skin cancers, mostly mycosis fungoides. The otherwise invisible radiation beam can be visualized using the optical Cherenkov light emitted from interaction between incident electron beams and tissue during radiation therapy. Using a gated camera system with built-in intensifier, the Cherenkov emission can be used to evaluate the dose uniformity on the surface of the patient in real-time. Each patient was also monitored on the skin surface using in-vivo diode or OSLD dosimeters.

1. Introduction
Total Skin Electron Irradiation (TSEI) utilizes high-energy electrons, usually 6 MeV, to treat skin cancer of the entire body. At University of Pennsylvania, we utilize a Stanford Technique [1] to deliver the TSEI at a source-to-surface distance of 500 cm from a Varian Truebeam accelerator with a dose rate of 2500 MU/min in HDSE mode (Fig. 1a). It is usually required that the dose uniformity to the entire body surface to be less than 10%. For the optimized gantry angles (90°±16°), we found that the variation of percentage dose of the dual field, normalized to incident on face electron beam (gantry angle (90°), is well within 5% (Fig. 1b). The small bump at 103 cm is due to the electron backscattering from a lead backscatter sheet used to boost scalp dose [2].

We used a gated camera provided by Dartmouth College to measure the Cherenkov emission generated by the TSEI [3]. The Cherenkov light signal is generated when the speed of high-energy electrons in the medium is higher than the speed of light in the medium [4]. Experiments have shown that, for beams with the same energy, there is a linear relationship between the Cherenkov signal intensity and dose deposited on the surface of the phantom with uniform optical property [3].

2. Methods and Materials
Based on prior experience from Dartmouth for Cherenkov imaging of TSEI [5], we have started a clinical trial for TSET [6]. The setup of Cherenkov imaging is shown in Fig 2, where the Cherenkov imaging camera mounted on a tripod is at about 400 cm from the TSE stand. Patient anatomic positions are obtained via a 3D scanner.
Figure 1. (a) Schematics of TSEI using a Stanford technique with a dual electron fields with gantry tilted up and down 16 degrees. (b) The profile of dual electron beams. The y-axis is the percentage value assuming normalized to a single on-face electron beam as 100%. The x-axis is the distance at the Stand in cm.

Figure 2. Experimental setup for the Cherenkov imaging of TSEI. The patient is placed in the TSE box at 500 cm away from isocenter. The Cherenkov imaging camera is placed on a tripod at about 400 cm from the patient. A 3D scanner is used to imaging the anatomic position of the patient in 3D.

2.1. Cherenkov signal dependence on tissue optical properties

There is a difference between dose IVD dose profile and Cherenkov intensity map. A perspective correction factor can be identified as:

\[ CF \theta = \frac{D(x,y)}{D_{\text{max}}}/\frac{Ch(x,y)}{Ch_{\text{max}}}, \]

Where \( Ch(x,y) \) is the Cherenkov intensity and \( D(x,y) \) is the measured dose value at off-axis location \((x, y)\) on a plane of TSE phantom (e.g., a PVC panel) at SSD = 500 cm. Figure 3 shows the correction factors in the vertical direction [6]. There is no need for correction in the horizontal direction (data shown elsewhere) [6]. The correction factor is substantially larger for the dual field than for the single...
field in the vertical direction. Thus, a Cherenkov correction factor is applied to the acquired patient data in that direction.

Figure 3. (a) Cherenkov raw image for dual field in 1200x1600 pixel map. The isocenter of the radiation field is located at pixel location (600, 500). The distance between pixels is 0.1647 cm projected at SSD = 500 cm. The “x” marked the diode locations, which is spaced at 20 cm apart on the PVC board. The red line is where the Cherenkov intensity is taken for comparison. (b) Comparison of Cherenkov and Diode dose profiles for dual fields composed of gantry angles 74° and 106° and a single field of gantry angle 90°. The vertical offset is in cm on the PVC panel. (c) The correction factor is determined using Eq. (1) in the same coordinates as Fig. 3b for single and dual fields, respectively.

2.2. Cherenkov signal dependence on incident angles

The Cherenkov intensity is linear to the delivered dose from a 6 MeV electron beam at depth of 6 mm. However, when tissues with different optical properties are used, the slope of this linear dependence will change because of the absorption and scattering of the Cherenkov photons by the tissue. Figure 4 shows the relationship between Cherenkov intensity and dose on the central axis on the PVC board for
different tissue-simulating solid phantoms, with optical properties $(\mu_a, \mu_s') = (0.130, 11.2), (0.156, 1.9), (0.0425, 14.1), \text{ and } (0.4, 5.5) \text{ cm}^{-1}$. It seems to be proportional to the value of diffuse reflectance at 630 nm [6].

**Figure 4.** (a) Cherenkov intensity vs. dose with three different optical properties $(\mu_a, \mu_s')$. (b) Slope of Cherenkov response vs. value of diffuse reflectance at 630 nm of the tissue simulating phantoms.

### 2.3. Conversion of Cherenkov signal to dose

The conversion of Cherenkov signal to dose follows two steps: First, the perspective correction factor is applied in the vertical direction; Second, the corrected Cherenkov intensity is normalized to the value at the umbilicus point, where the dose is measured using a diode. The corrected Cherenkov intensity is then converted to dose.

### 3. Results

Figure 5 showed the Cherenkov converted dose for a patient for all 6 postures during TSET.

### 4. Discussions

The conversion of Cherenkov intensity to dose for the upper row of Fig. 5 is done by renormalizing the corrected Cherenkov intensity to umbilicus point, where the dose is measured. For the bottom row in Fig. 5, the diode reading at umbilicus point cannot be used because the body blocked it. We made the conversion by multiplying the same Dose-to-Cherenkov ratio for the corresponding day for the patient. This way, the conversion can be made without worrying about the effect of tissue optical properties.

Figure 5 shows that the dose on the legs is lower than the dose in other parts of the body even though the optimal angles (74 and 106) gives uniform profile in the phantom conditions (see Fig. 1b and Fig. 2a). The reasons for the low dose are unknown but we can speculate two possible reasons: (1) Dose conversion error due to approximation made to the perspective correction factor. The perspective correction factor (Eq. (1)) should be a two-dimensional correction covering $(x, y)$ on the patient plan, however, we have approximated this as a one-dimensional correction factor (Fig. 3b). In addition, for oblique fields (LAO, LPO, RAO, RPO) the plan where the correction should be obtained is tilted by 30 degree relative to the PVC board used in Fig. 3a, that may also introduce errors in the conversion. In addition, our current conversion factor did not take into account of the camera response distortion. (2) The dose is lower near the floor due to floor scattering as pointed out by a recent study, where the dose near the floor is lower on a solid-water material compared to that on the PVC material [7]. Thus on the patient, the dose distribution may indeed be lower near the feet. A selection of asymmetrical gantry angles for TSET may provide an appreciable more uniform dose distribution [7]. Further studies using a human shaped phantom coupled with in-vivo dosimetry on the patient feet should help us understand the cause of the lower dose.
We have studied 10 patients so far, the ratio of dose reading on Chest point is compared to that at umbilicus. They agree to within 5% and is presented elsewhere [6].

![Figure 5](image)

Figure 5. Cherenkov converted dose distribution for the 6 positions of a TSET patient in Day 1 and Day 2 for a total of 200 cGy/2-day cycles. X and Y (cm) is at patient location (SSD=500 cm).

5. Conclusions
We conclude that Cherenkov imaging provide a mean to study the distribution of surface dose for patient undergoing TSET.

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7. References
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