Superficial Dosimetry and Optical Imaging

Timothy C. Zhu

Department of Radiation Oncology, School of Medicine, University of Pennsylvania, Philadelphia, PA 19104, USA

Perelman School of Medicine University of Pennsylvania

Thayer School of Engineering at Dartmouth

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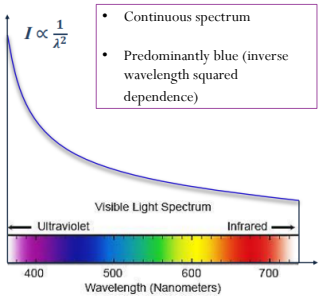
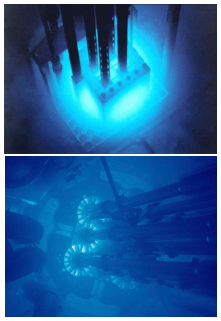
Cherenkov Emission

$I \propto \frac{1}{\lambda^2}$

- Continuous spectrum
- Predominantly blue (inverse wavelength squared dependence)





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Cherenkov Imaging

- Cherenkov light is emitted when speed of charged particle is exceeding speed of light in the medium
  - Visualizing the radiation beam directly on the surface of the patient
  - Can be used for quantifing surface dose

Phys. Med. Biol. 58: 5477, 2013, Med. Phys. 43: 993, 2016

DoseOptics, Hanover

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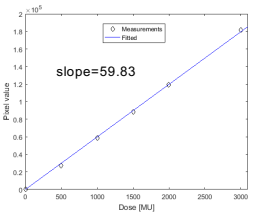
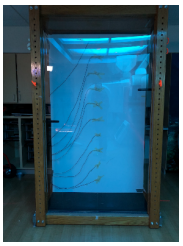
Cherenkov vs. MU dependence

- The Cherenkov imaging intensity is proportional to the delivered dose
  - Gantry 90, collimator at 0, field size 36 cm x 36 cm
  - PVC board at 5 m, and camera is placed on side of the treatment head





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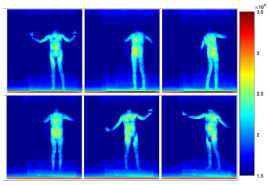
Introduction

- Cherenkov emission from tissue surface during total skin electron beam therapy (TSET) can be used to visualize radiation dose deposition on patient.



Cumulative Cherenkov signal intensity of a patient during TSET. Adapted from [1]

- **However, linearity between dose and Cherenkov signal can be affected by tissue optical properties, perspective corrections, and inverse square law.**

[1] Xie, Y., et. al. *proc. SPIE 47*, 201-211, (2020)

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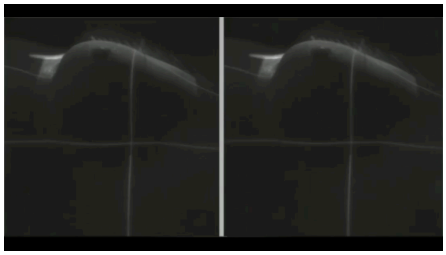
Breast Cherenkov imaging

Entrance Cherenkov Exit Cherenkov



Courtesy Brian Pogue

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Relationship between Surface Dose and Cherenkov intensity

$$Dose(cGy) = a(E, \boldsymbol{r}, \hat{s}, R_d, SDD) \cdot Cherenkov$$
$$= a'(E) \cdot b'(R_d) \cdot c'(\boldsymbol{r}, \hat{s}) \cdot \left(\frac{CDD_0}{CDD}\right)^2 \cdot Cherenkov$$

- a is Cherenkov-to-dose conversion factor and is a function of radiation energy (E), pixel position ($\boldsymbol{r}$), radiation incident direction ($\hat{s}$), tissue optical properties (R_d), and source-to-surface distance (SDD).
- $a'(E)$ Cherenkov-to-dose conversion factor for E and reference tissue optical properties at the central-axis for normal incidence.
- $b'(R_d)$ **tissue optical properties correction factor**
- $c'(\boldsymbol{r}, \hat{s})$ **perspective correction factor**
- $(CDD_0/CDD)^2$ **inverse square factor**, CDD is the camera-to-detector distance, CDD_0 is the camera-to-detector distance at central-axis.

Xie, Y., et. al. *Med Phys 47*, 201-211, (2020)

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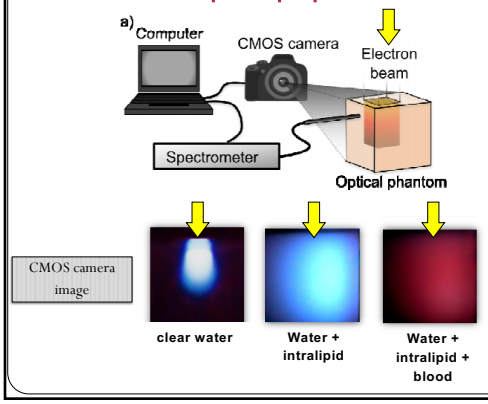
Effect of tissue optical properties



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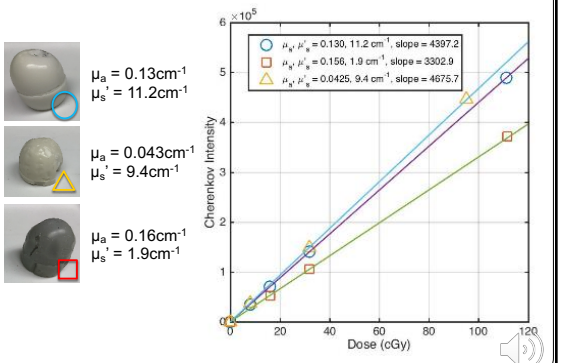
Tissue optical properties dependence



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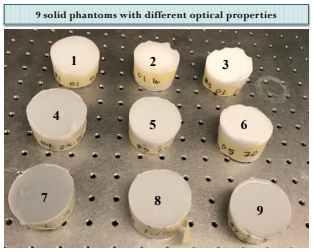
Tissue optical properties dependence

9 solid phantoms with different optical properties



Phantom optical properties at 665 nm

Index	μ_a	μ_s'	a'	R_d
1	0.127	3.89	0.969	0.427
2	0.085	9.67	0.991	0.623
3	0.102	16.42	0.994	0.667
4	0.250	4.23	0.944	0.330
5	0.225	6.57	0.967	0.418
6	0.251	13.18	0.981	0.511
7	0.504	3.92	0.886	0.215
8	0.434	7.01	0.942	0.323
9	0.424	11.60	0.965	0.408

$$a' = \mu_s'/(\mu_a + \mu_s')$$
$$R_d = 0.4843a' \cdot (1 + e^{-4.428\sqrt{1-a'}}) \cdot e^{-2.65\sqrt{1-a'}}$$

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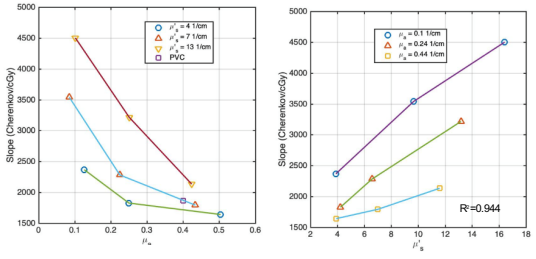
Cherenkov Slope vs. μ_a and μ_s'



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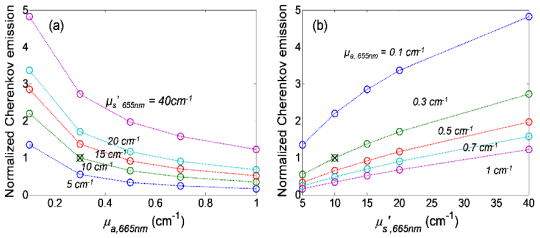
Cherenkov intensity vs μ_a & μ_s' (MC)



- Cherenkov intensity decreases with μa
- Cherenkov intensity increases with μs'

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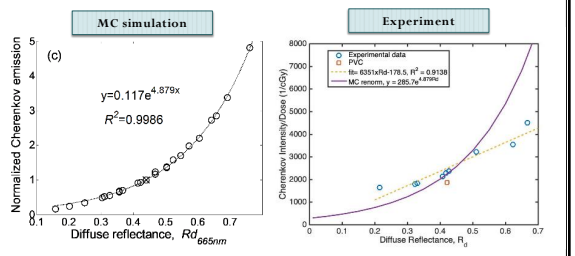
Normalized Cherenkov intensity vs R_d



- Cherenkov intensity can be expressed in one-dimensional analytical function of diffuse reflectance, Rd.

$a' = \mu_s'/(\mu_a + \mu_s')$

$R_d = 0.4843a' \cdot (1 + e^{-4.428\sqrt{1-a'}}) \cdot e^{-2.65\sqrt{1-a'}}$

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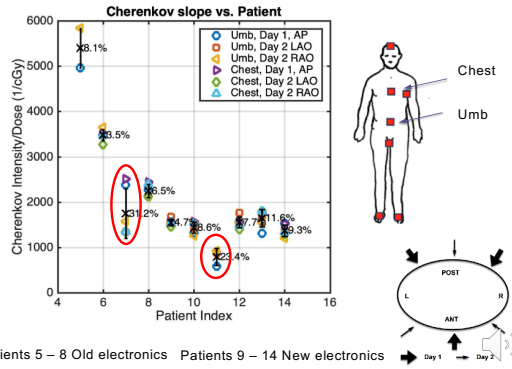
Cherenkov vs. Dose – in TSE patients



Patients 5 – 8 Old electronics Patients 9 – 14 New electronics

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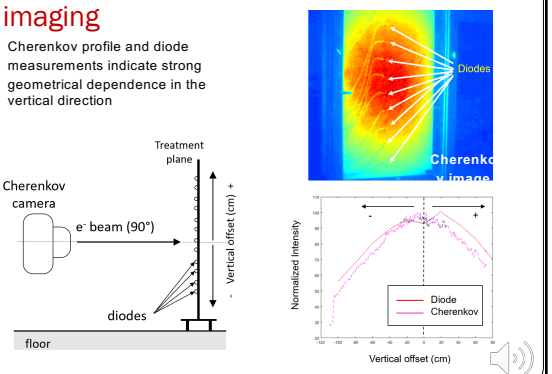
Perspective correction for Cherenkov imaging

Cherenkov profile and diode measurements indicate strong geometrical dependence in the vertical direction



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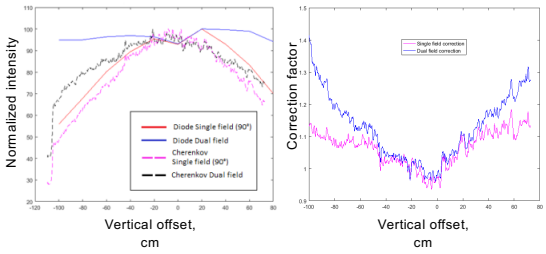
Perspective Correction corrector

- Homogenous dose (diode) along vertical direction after dual field technique
- Additional correction for Cherenkov is needed



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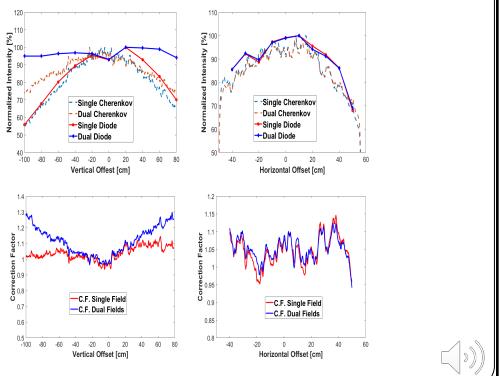
Cherenkov Imaging – Phantom Study



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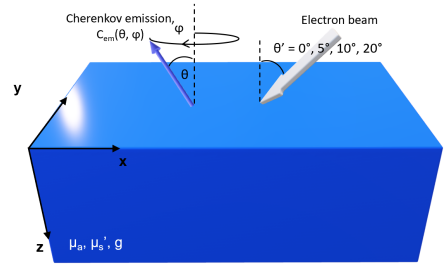
MC simulation of Cherenkov emission produced by tilted electron beam



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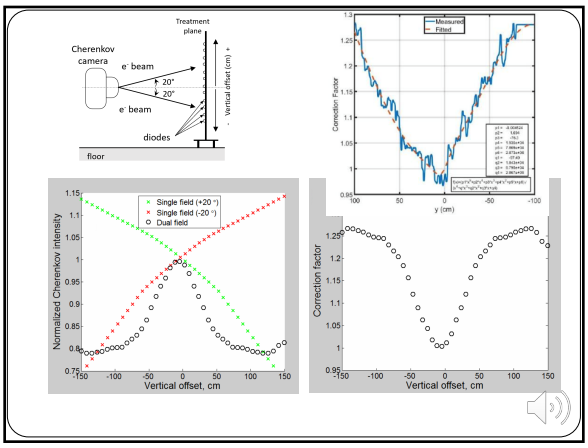

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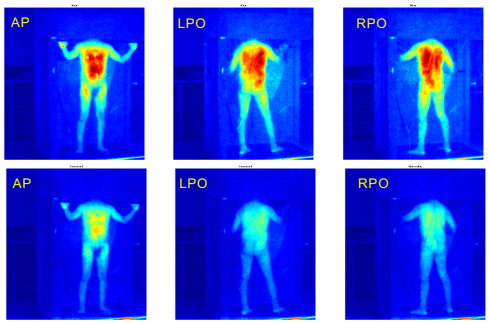
Raw (upper row) vs Corrected (lower row)



200 cGy/cycle

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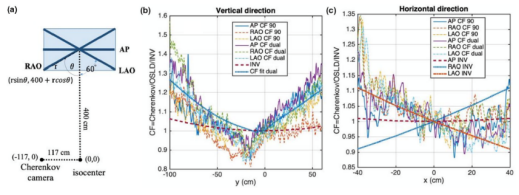
Inverse-square correction factor



$$\left(\frac{CDD_0}{CDD}\right)^2$$

- *CDD* is the camera-to-detector distance.
- *CDD0* is the camera-to-detector distance at central-axis.

Xie, Y., et. al. *Med Phys 47*, 201-211, (2020)

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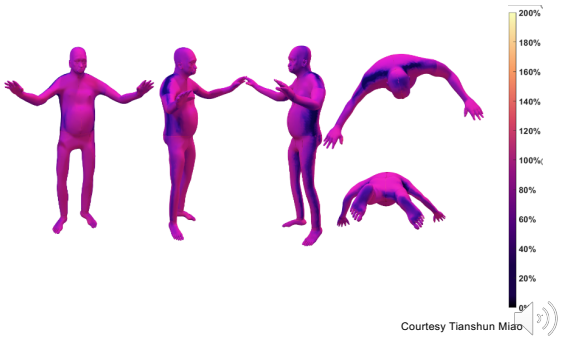
Cumulative surface dose



Courtesy Tianshun Miao

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Conclusions

- Cherenkov intensity is proportional to radiation surface dose.
- Three correction factors are necessary to convert Cherenkov intensity to radiation surface dose: tissue optical properties correction factor, perspective correction factor, and inverse square law correction factor.
- Clinically, it is possible to evaluate the cumulative surface dose on TSE patients using Cherenkov imaging.

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