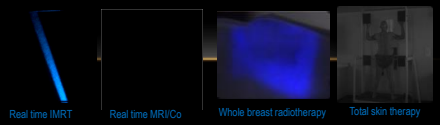
CHERENKOV IMAGING IN RADIOTHERAPY: 2D, 3D, REALTIME 3D,…



Brian W. Pogue PhD
Engineering, Physics, Surgery,
Dartmouth College

Disclosure

Brian Pogue is founder and President of DoseOptics LLC, developing the a commercially viable Cherenkov imaging system for radiotherapy.

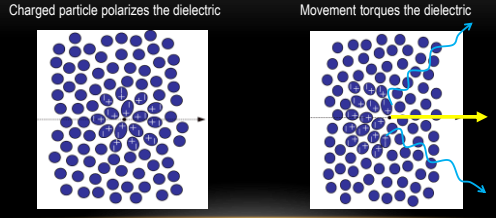
The company is NIBIB SBIR funded.

Cherenkov Imaging

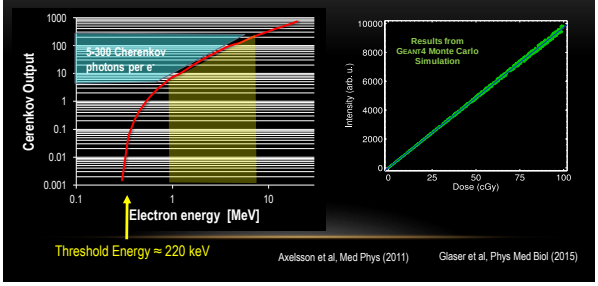
Water tank - 2D real time (Varian & ViewRay)
- 3D tomography
- 3D real time

Patient imaging – 2D Total Skin
- 2D + CT Breast

Cherenkov light emission

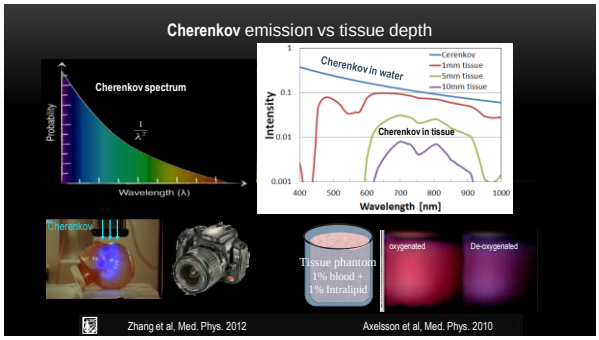


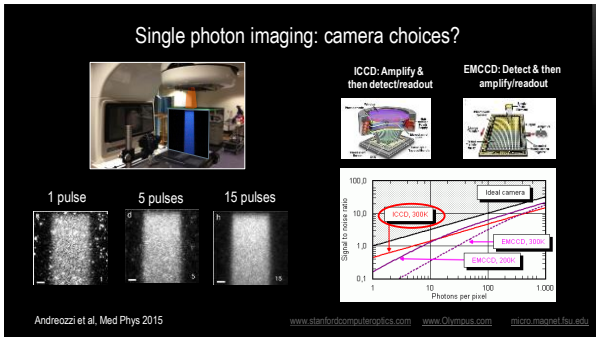
High energy electrons produce Cherenkov light during dose deposition

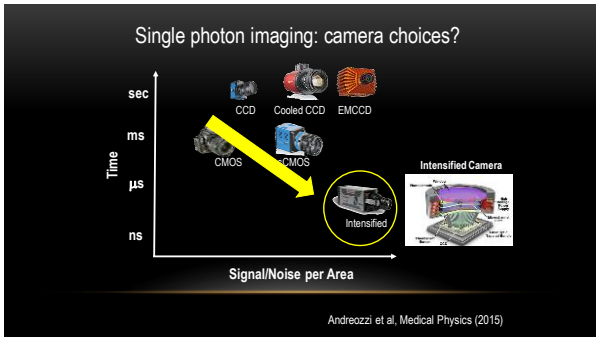


Axelsson et al, Med Phys (2011)

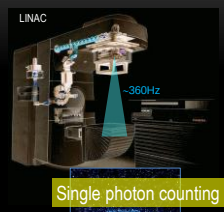
Glaser et al, Phys Med Biol (2015)

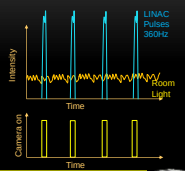

Cherenkov emission vs tissue depth
Cherenkov spectrum
Probability
Wavelength (λ)
Cherenkov in water
Cherenkov in tissue
Intensity
Wavelength [nm]
Cerenkov
1mm tissue
5mm tissue
10mm tissue
Cherenkov
Tissue phantom
1% blood +
1% Intralipid
oxygenated
De-oxygenated
Zhang et al, Med. Phys. 2012
Axelsson et al, Med. Phys. 2010


Single photon imaging: camera choices?
ICCD: Amplify &
then detect/readout
EMCCD: Detect & then
amplify/readout
1 pulse
5 pulses
15 pulses
Ideal camera
ICCD, 300K
EMCCD, 300K
EMCCD, 200K
Signal to noise ratio
Photons per pixel
Andreozzi et al, Med Phys 2015
www.stanfordcomputeroptics.com
www.Olympus.com
micro.magnet.fsu.edu


Single photon imaging: camera choices?
Time
sec
ms
µs
ns
CCD
Cooled CCD
EMCCD
CMOS
sCMOS
Intensified
Intensified Camera
Signal/Noise per Area
Andreozzi et al, Medical Physics (2015)

Imaging LINAC pulses with time-gated ICCD





Single photon counting with the room lights on!

- Intensifier gain (10,000X)
- Time gated - 3us LINAC pulses
- Wavelength filtering
- Spatial median filter
- Temporal median filter
- Background subtraction online

Beam images rejecting room light

Glaser et al, Opt. Lett, 2012

Real-time 2D

Cherenkov Beam Imaging

Adam Glaser PhD

Glaser et al, Med. Phys. (2014)

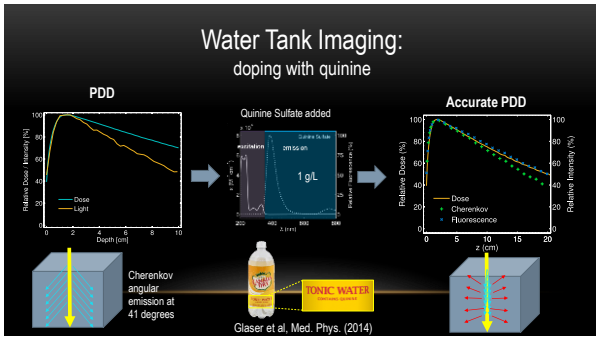
Real-time 2D+ or 3D Radiotherapy Beam Imaging

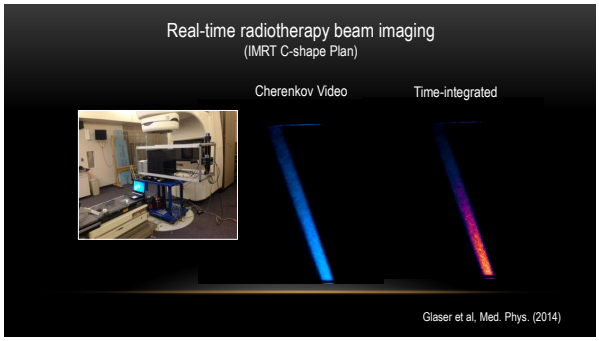
2D + time imaging

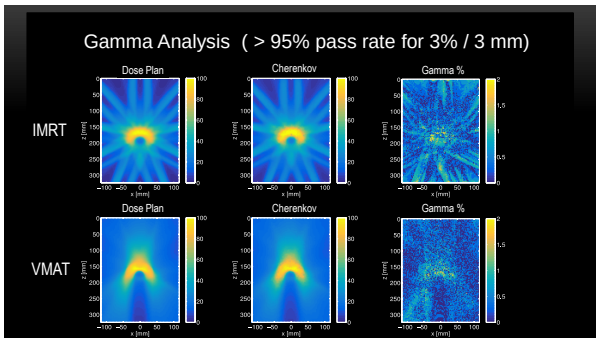
3D static imaging

Adam Glaser PhD

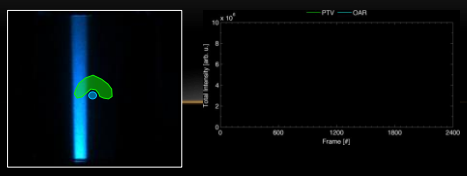
Glaser et al, Med. Phys. (2014)


Water Tank Imaging:
doping with quinine
PDD
Quinine Sulfate added
Accurate PDD
Dose
Light
1 g/L
Dose
Cherenkov
Fluorescence
Cherenkov angular emission at 41 degrees
TONIC WATER
Glaser et al, Med. Phys. (2014)


Real-time radiotherapy beam imaging
(IMRT C-shape Plan)
Cherenkov Video
Time-integrated
Glaser et al, Med. Phys. (2014)


Gamma Analysis (> 95% pass rate for 3% / 3 mm)
Dose Plan
Cherenkov
Gamma %
IMRT
VMAT

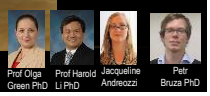
Temporal Analysis of VMAT



Planning Target Volume (PTV)
Organ at risk (OAR)

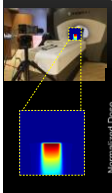
MRI-radiation therapy: ViewRay (Washington Univ.)
2D Dosimetry imaging in high B-fields!

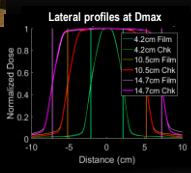
Andreozzi et al, AAPM 2016, TU-AB-BRA-12

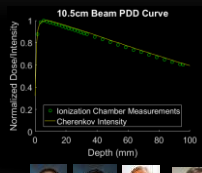


Prof Olga Green PhD | Prof Harold Li PhD | Jacqueline Andreozzi | Petr Bruza PhD

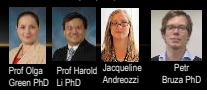
MRI-radiation therapy: ViewRay (Washington Univ.)
2D Dosimetry imaging in high B-fields!





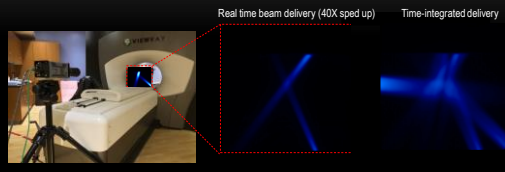


Andreozzi et al, AAPM 2016, TU-AB-BRA-12



Prof Olga Green PhD | Prof Harold Li PhD | Jacqueline Andreozzi | Petr Bruza PhD

MRI-radiation therapy: ViewRay (Washington Univ.)
2D Dosimetry imaging in high B-fields!



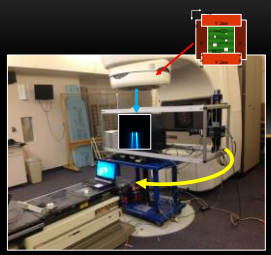
Andreozzi et al, AAPM 2016, TU-AB-BRA-12

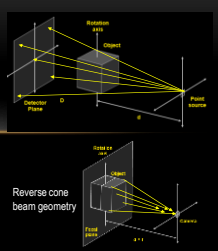
Prof Olga Green PhD | Prof Harold Li PhD | Jacqueline Andreozzi | Petr Bruza PhD

3-D CHERENKOV IMAGING?

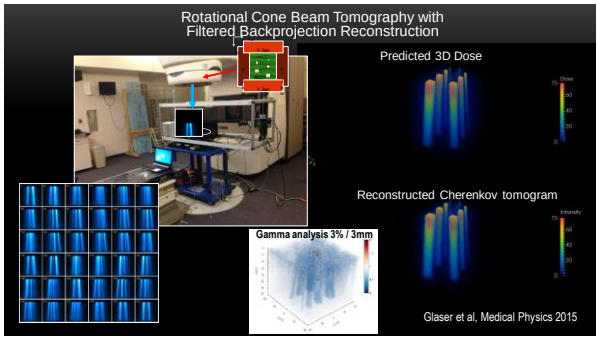
1. Rotational tomography
2. Combined EPID/Cherenkov tomography

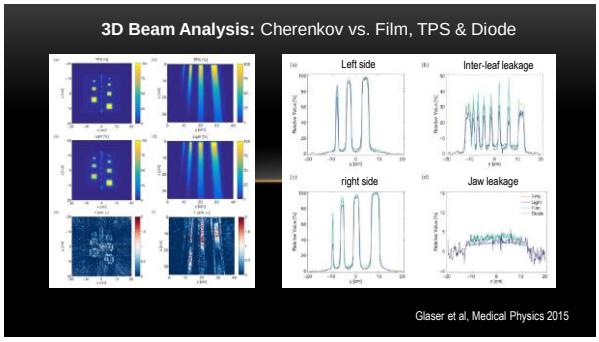
Cherenkov Image Filtered Backprojection Reconstruction

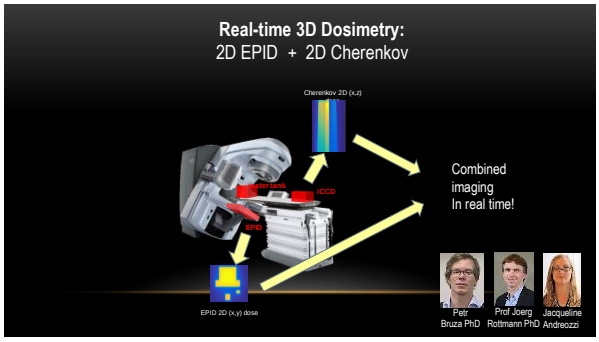


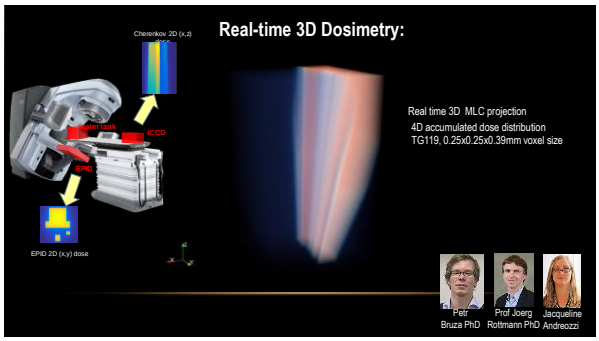


Glaser et al, Medical Physics 2015

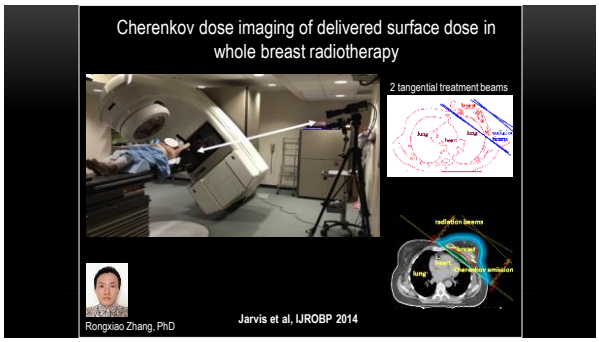

Rotational Cone Beam Tomography with
Filtered Backprojection Reconstruction
Predicted 3D Dose
Reconstructed Cherenkov tomogram
Gamma analysis 3% / 3mm
Glaser et al, Medical Physics 2015


3D Beam Analysis: Cherenkov vs. Film, TPS & Diode
Left side
Inter-leaf leakage
right side
Jaw leakage
Glaser et al, Medical Physics 2015


Real-time 3D Dosimetry:
2D EPID + 2D Cherenkov
Cherenkov 2D (x,z)
Combined
imaging
In real time!
ICCD
EPID
EPID 2D (x,y) dose
Petr
Bruza PhD
Prof Joerg
Rottmann PhD
Jacqueline
Andreozzi


Real-time 3D Dosimetry:
Cherenkov 2D (x,z)
water tank
ICCD
EPID
EPID 2D (x,y) dose
Real time 3D MLC projection
4D accumulated dose distribution
TG119, 0.25x0.25x0.39mm voxel size
Petr Bruza PhD
Prof Joerg Rottmann PhD
Jacqueline Andreozzi

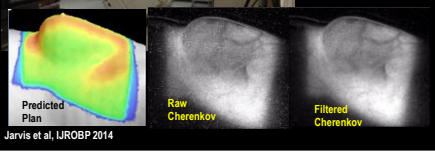

Human Imaging with Cherenkov


Cherenkov dose imaging of delivered surface dose in whole breast radiotherapy
2 tangential treatment beams
lung
heart
radiation beams
Cherenkov emission
Rongxiao Zhang, PhD
Jarvis et al, IJROBP 2014

Cherenkov dose imaging of delivered surface dose in whole breast radiotherapy

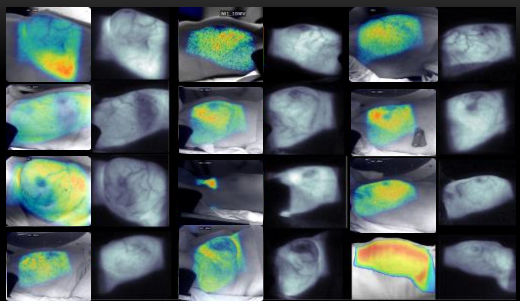
2 tangential treatment beams

First real-time radiation dose ever visualized!

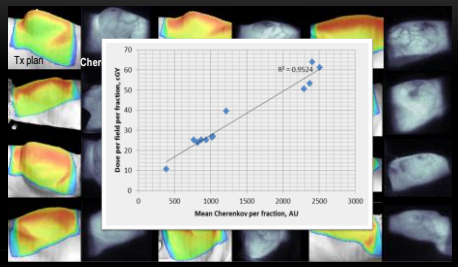


Jarvis et al, IJROBP 2014

Real time Cherenkov videos: 12 patient pilot trial



Treatment planned doses vs. Cherenkov images

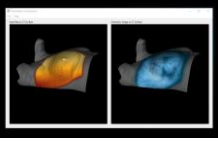


Zhang et al, Phys. Med. Biol. 2015

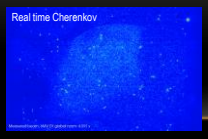
DOSEOPTICS
Visualize radiation therapy

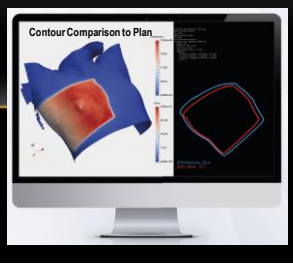
www.doseoptics.com

- Specialized radiation dose imaging camera
- High resolution CMOS – video rate readout
- Onboard FPGA processing
- Output direct Cherenkov images overlaid on video white light images
- Imaging at the right price point…



Ongoing Clinical Trial

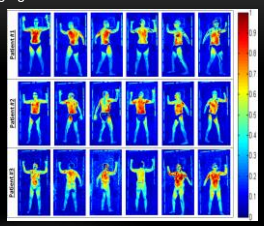




Total Skin Irradiation Imaging

Old treatment angles

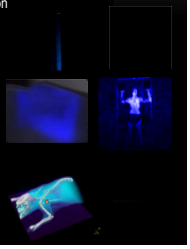
New treatment angles



Andreozzi et al, Medical Physics (2016)
1st prize, Young Investigator Award, AAPM, July 2015

SUMMARY

1. Cherenkov is readily imaged, with background/noise suppression
2. Water tank dosimetry → real time 2D, & static 3D
   → real time 3D with EPID
3. Human dose delivery imaging → trials ongoing
   → whole breast, total skin
4. Commercial translation → DoseOptics LLC
5. Molecular imaging → high resolution luminescence imaging



CENTER FOR IMAGING MEDICINE

Alumni


Johan Axelsson, Ph.D.


Adam Glaser, Ph.D.


Rongxiao Zhang, PhD


Head Phantom PhD

Radiation Oncology


David Gladstone, Sc.D.


Lesley Jarvis, MD PhD


Colleen Fox, Ph.D.

Thayer School of Engineering


Petr Bruza, PhD.


Jacqueline Andreozzi


Sara Saunders

DoseOptics LLC


Venkat Krishnaswamy VP Technology PhD


Bill Ware, CEO MS


Tianshun Miao, Software MS

Harvard / BWH Rad. Oncol.


Joerg Rottmann PhD

Washington U. Rad. Oncol.


Olga Green PhD


Harold Li PhD

DOSEOPTICS
Visualize radiation therapy

Correction factors for Cherenkov/Dose: Monte Carlo Study

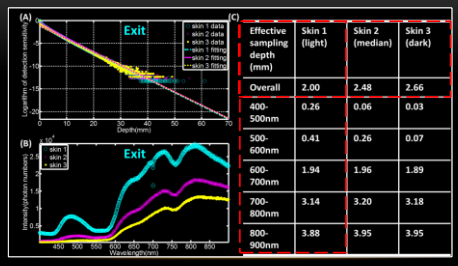
Factor Examined	Range of calibration factors (Dose (Gray) per emitted Cherenkov photon$\times 10^{-5}$)		Relative standard deviation (%) (std. dev./mean)		Sampling depth (mm)	
	Entrance	Exit	Entrance	Exit	Entrance	Exit
Skin color range light to dark	3.5 ~ 8.6	1.6 ~ 4.1	42*	45*	5.7 ~ 6.2	2.1 ~ 2.7
Nominal photon energy (MV) 4-15 MV	4.3 ~ 2.5	1.9 ~ 1.1	21*	22*	5.4 ~ 6.0	2.1 ~ 2.0
Curved surface 0-180° (10cm diam.)	3.4 ~ 2.2	2.2 ~ 1.6	18*	14*	5.0 ~ 3.1	3.1 ~ 2.4
Field size 6.5 to 20 cm square	3.8 ~ 3.4	1.4 ~ 1.7	4.0	5.0*	6.3 ~ 5.1	2.0 ~ 2.1
Thickness 2.5 – 20 cm	3.5 ~ 3.6	1.6 ~ 1.5	0.73	2.3	5.7 ~ 5.7	2.1 ~ 2.1
Curvature 2.5 – 20cm diam.	3.0 ~ 2.9	1.9 ~ 1.8	1.4	1.2	4.0 ~ 4.3	2.4 ~ 2.6
SSD 80-120 cm	3.5 ~ 3.6	1.5 ~ 1.6	0.21	1.1	5.7 ~ 5.7	2.1 ~ 2.1

R. Zhang et al, J. Biophotonics (in press)

Reflectance based correction for tissue optics

R. Zhang et al, J. Biophotonics (in press)

Sampling depth: Monte Carlo Studies



(C)

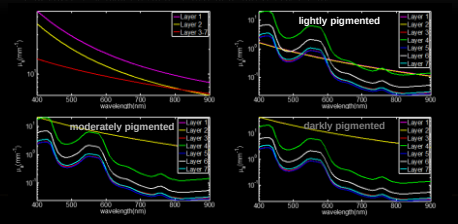
Effective sampling depth (mm)	Skin 1 (light)	Skin 2 (median)	Skin 3 (dark)
Overall	2.00	2.48	2.66
400-500nm	0.26	0.06	0.03
500-600nm	0.41	0.26	0.07
600-700nm	1.94	1.96	1.89
700-800nm	3.14	3.20	3.18
800-900nm	3.88	3.95	3.95

R. Zhang et al, PMB, 2012. R. Zhang et al, Med Phys, 2013.

Skin optical properties

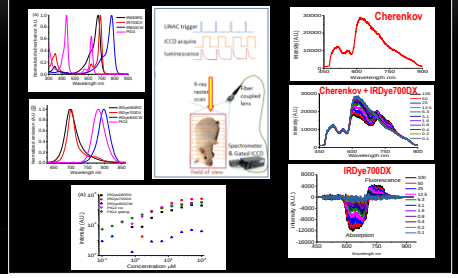
Layer1	Layer2	Layer3	Layer4	Layer5	Layer6	Layer7
Stratum corneum	Living epidermis	papillary dermis	upper blood net dermis	reticular dermis	deep blood net dermis	subcutaneous fat
20μm	80μm	150μm	80μm	1500μm	100μm	6000μm

**Thickness values are known to fluctuate +/- 30% between individuals or between locations on the same individual.*

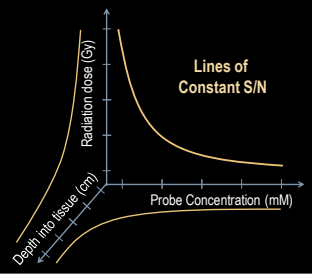


I. V. Meglinski and S. J. Matcher, "Quantitative assessment of skin layers absorption and skin reflectance spectra simulation in the visible and near-infrared spectral regions," Physiological measurement 23, 741-753 (2002).

CELSI with Fluorophores – spectrally resolved

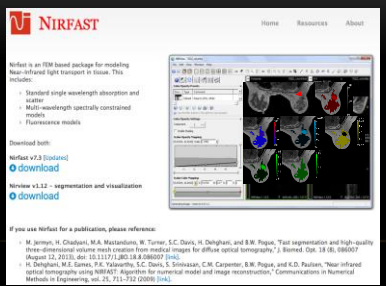


Factors affecting Cherenkov Luminescence imaging sensitivity



HTTP://WWW.NIRFAST.ORG

DIFFUSE TOMOGRAPHY SOFTWARE FOR MEDICAL IMAGING



Simultaneous 3 mouse imaging