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Simulation of Diffuse Optical Tomography using COMSOL Multiphysics®

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Motivation

- Diagnostic procedures essential for proper diagnosis of medical conditions
  - X-rays, CT-Scan, MRI etc.
  - Employ harmful electromagnetic radiations
- Safe alternative: optical tomography techniques
  - Employ infrared light
  - Biological tissues – turbid media
    - Scattering mean free path = 0.1 mm
    - Absorption mean free path = 10 – 100 mm

Diffuse Photon Density Waves (DPDW)

- Frequency domain optical tomography technique based on diffusive propagation of light
- Employs intensity modulated light sources
- Determine the optical properties of tissues
- Important for many biomedical applications.
  - Observe and analyze cutaneous and subcutaneous tissue damage
  - Diagnosis and treatment of pressure ulcers, skin and tissue injuries, wounds and burns.
- Our simulation produced results that are two orders of magnitude faster than the equivalent Monte Carlo method of light transport in tissues.

Light inside biological tissues

- Biological tissues
  - Absorption Coefficient μ_a
  - Scattering Coefficient μ_s
  - Anisotropy Factor g
- Radiative transfer equation (RTE)
  - Diffusion equation (DE)
- Monte Carlo method

Radiative transfer equation

- Radiative transfer equation (RTE)

$$\frac{1}{\nu}\frac{\partial L(\vec{r},\hat{s},t)}{\partial t} = -\hat{s}\cdot\nabla L(\vec{r},\hat{s},t) - \mu_t L(\vec{r},\hat{s},t) + \mu_s \int_{4\pi} L(\vec{r},\grave{s},t)\, p(\hat{s},\grave{s}) d\grave{s} + S(\vec{r},\hat{s},t)$$

- Light radiance
  - *Light power per unit area travelling in the $\hat{s}$ direction at position $\vec{r}$ and time t*

$$L(\vec{r},\hat{s},t) = \frac{1}{4\pi}\varphi(\vec{r},t) + \frac{3}{4\pi}J(\vec{r},t)\cdot\hat{s}$$

Radiative transfer equation

- Photon fluence rate
  - *Total power per unit area moving radially outward from the infinitesimal volume element at position $\vec{r}$ and time t*

$$\varphi(\vec{r},t) \equiv \int_{4\pi} L(\vec{r},\hat{s},t)\, ds$$

- Photon flux
  - *Power per unit area travelling in the $\hat{s}$ direction at position $\vec{r}$ and time t*

$$J(\vec{r},t) \equiv \int_{4\pi} L(\vec{r},\hat{s},t)\hat{s}\, ds$$

Diffusion equation

- Diffusion equation

$$-\nabla \cdot \left(\mathrm{D}(\vec{r})\nabla\varphi(\vec{r},t)\right) + \nu\mu_a(\vec{r})\,\varphi(\vec{r},t) + \frac{\partial\varphi(\vec{r},t)}{\partial t} = \nu\mathrm{S}(\vec{r},t)$$

- Photon diffusion coefficient

$$\mathrm{D}(\vec{r}) \equiv \frac{\nu}{3\left(\mu_s'(\vec{r}) + \mu_a(\vec{r})\right)}$$

- Diffusion equation for DPDW (Helmholtz equation)

$$-\nabla \cdot \left(\mathrm{D}(\vec{r})\nabla U(\vec{r})\right) + \left(\mu_a(\vec{r}) - \frac{i\omega}{\nu}\right) U(\vec{r}) = \mathrm{S}_{ac}(\vec{r}).$$

Simulation Model

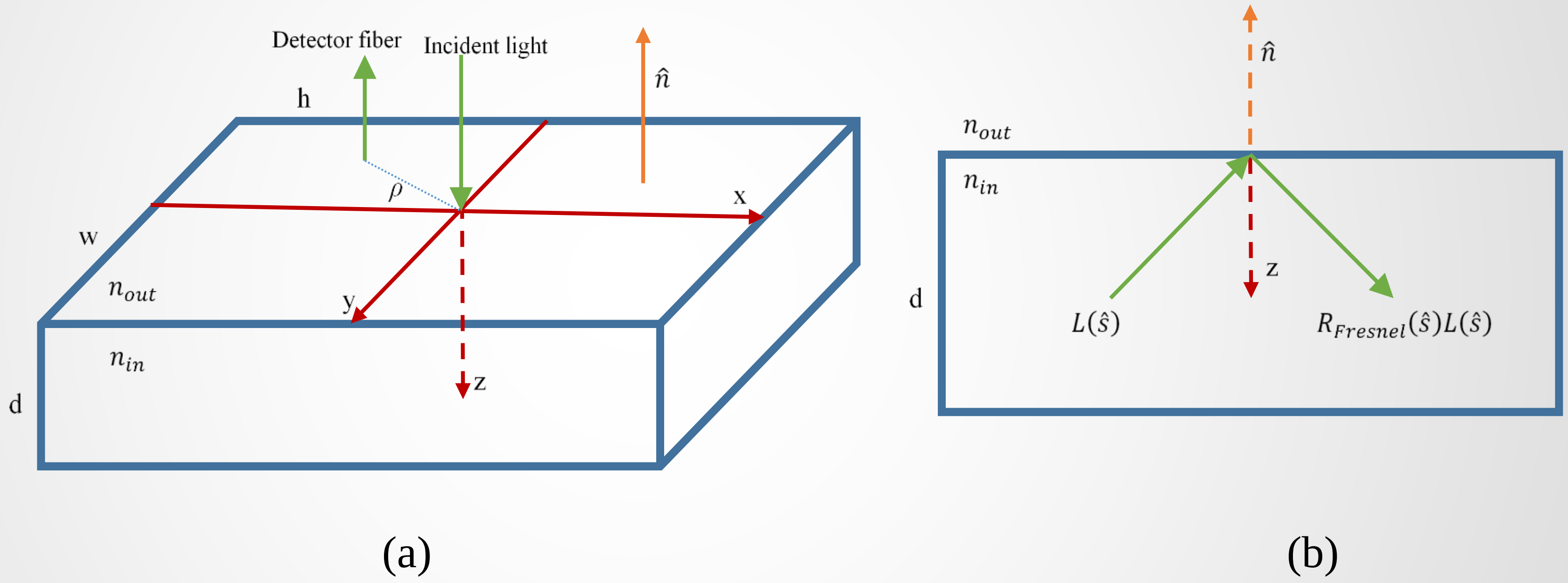

Figure 1. (a) Geometrical model of the tissue (b) Tissue cross-section.

DPDW phase against source – detector separation

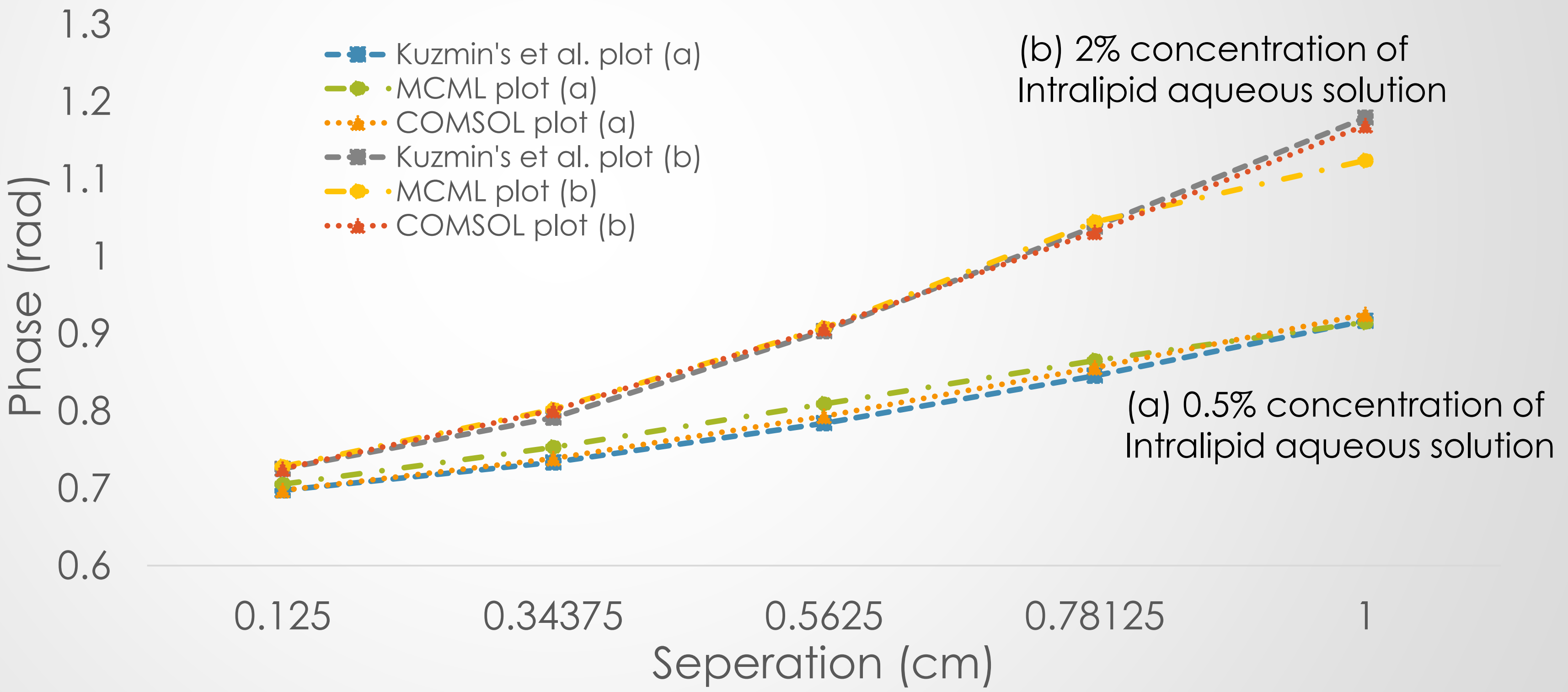

Figure 2. DPDW phase against source – detector separations for two different concentrations of aqueous intralipid solution

DPDW intensity attenuation against source – detector separation

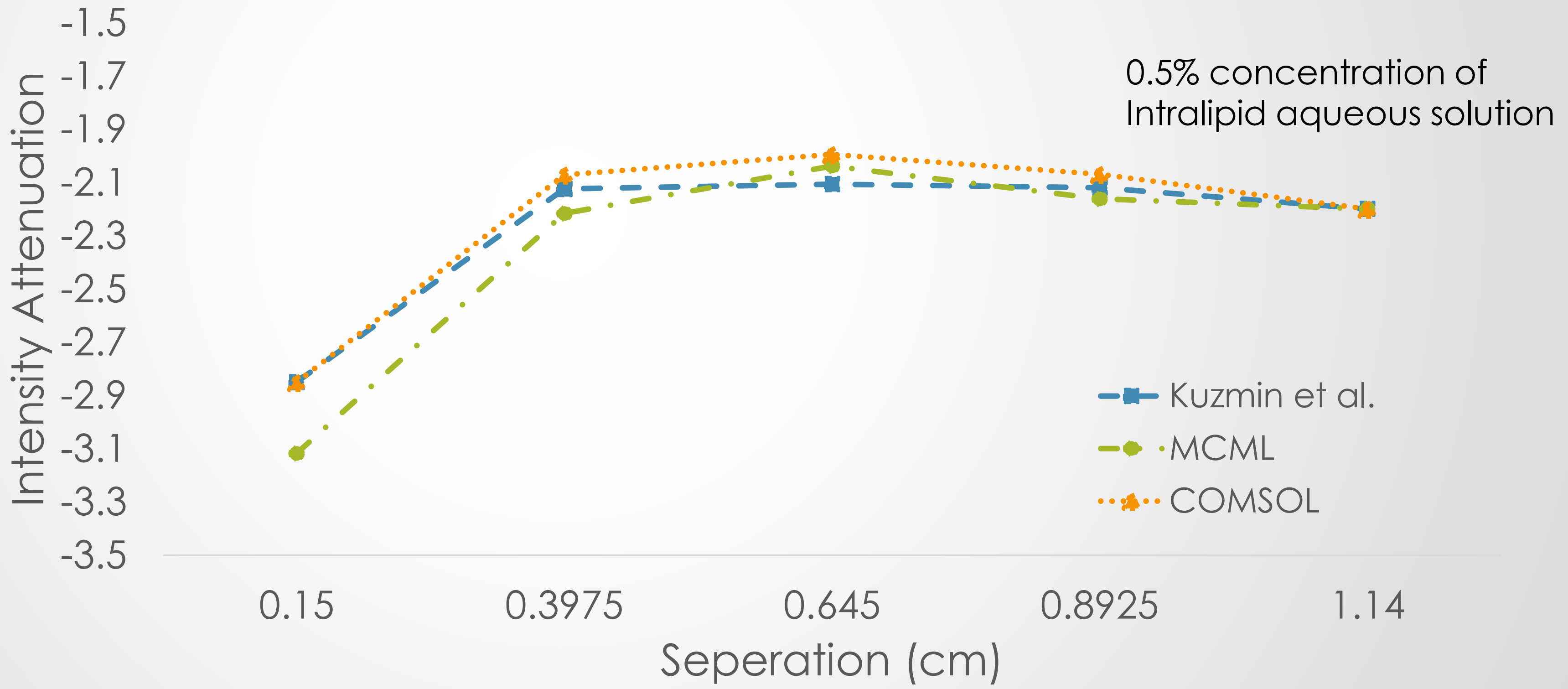

Figure 3. DPDW intensity attenuation against source – detector separation

Thank You

- Questions?

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