# A 1D Eye Tissue Model to Mimic Retinal Blood Perfusion during Retinal Imaging Photoplethysmography (iPPG) Assessment: A Diffusion Approximation – Finite Element Method (FEM) Approach

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# Introduction

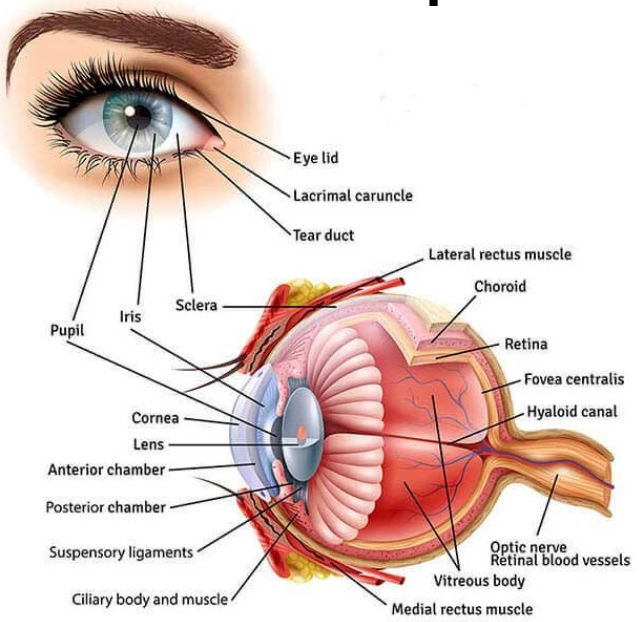
Over the years, the diagnostic and therapeutic application of such spectroscopy, endoscopy, and tomography utilizes photon distribution information to identify abnormalities in tissue, blood perfusion in a blood vessel, oxygen level, tissue degeneration, and tumor (Fass, 2008)(Beyer et al., 2020).

i. The characterization and detection of tissue abnormalities can be achieved by an *in-depth understanding of light propagation in turbid media*.

ii. The *numerical method* probably offers the best approach to solve RTE turbid media with complex boundaries and various interior properties (x,y,z).

iii. The numerical methods can include the *analytical or semi-analytical methods*, Finite Element Methods (FEM), Finite Different Methods (FDM), and Boundary Element Methods (BEM), and Monte Carlo (MC) methods (Handapangoda, 2017).

**Slit lamp**




**Eye Anatomy**

# Problem Statement

The light propagation through turbid media obeys Maxwell's equation that describes electromagnetic fields together with reasonable and simplifying assumptions (Steven L Jacques & Pogue, 2008).

Each of numerical analysis has its own advantages and disadvantages. One of the disadvantages of advanced numerical analysis *is* it requires more computation time and inherit noise during iteration process of particle/electron tracking.

Can we develop a numerical analysis algorithm that (i) quick processing and (ii) no noise - to predict the characteristic of tissue or blood perfusion in the tissue?

# Objectives

Our objectives are:

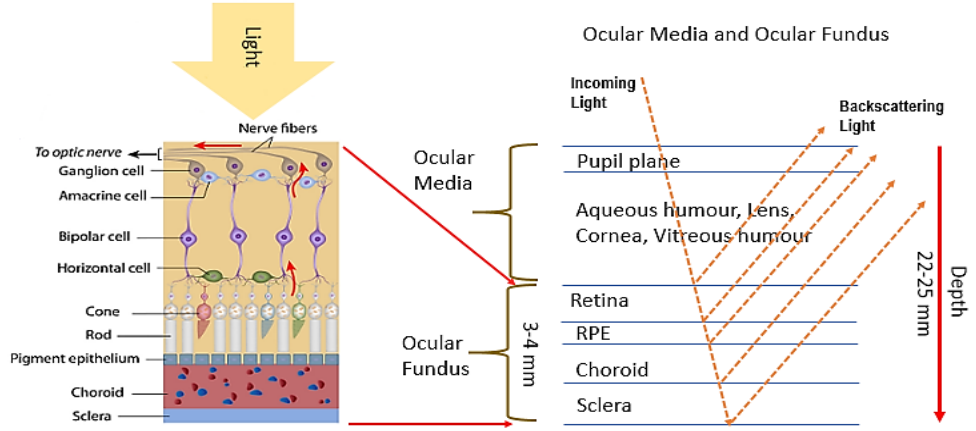
i. To develop numerical analysis model to mimic blood perfusion in the retina and choroid layer – Diffusion Approximation Approach – FEM.

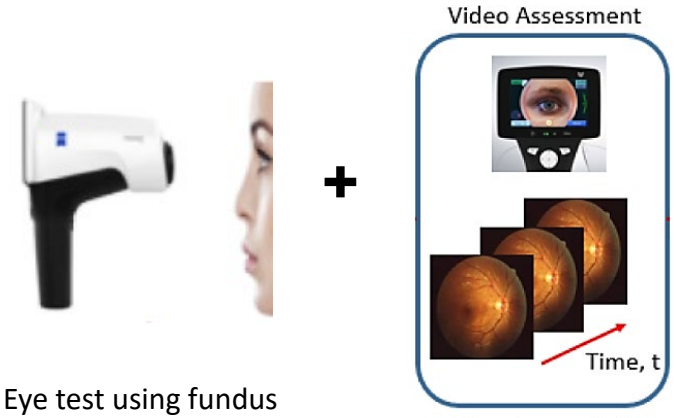
ii. To seek a quick prediction of blood perfusion volume in eye tissue that relates to optical properties of the tissue.

# Literature Review

The light transport theory measures the averages scattering particles with a probability density function, rather than a deterministic function (S L Jacques, 1998).

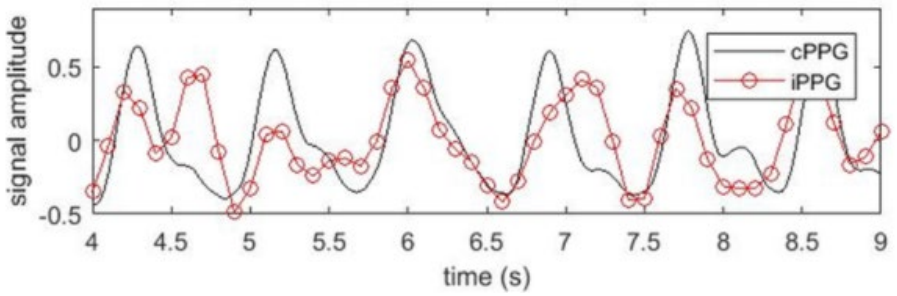
The theory is called Radiative Transfer Theory (RTE) when it is applied to low energy photons with several simplification assumptions, (i) wave effects such as diffraction and interference can be neglected, and (ii) all photons have the same energy where the scattering is elastic.



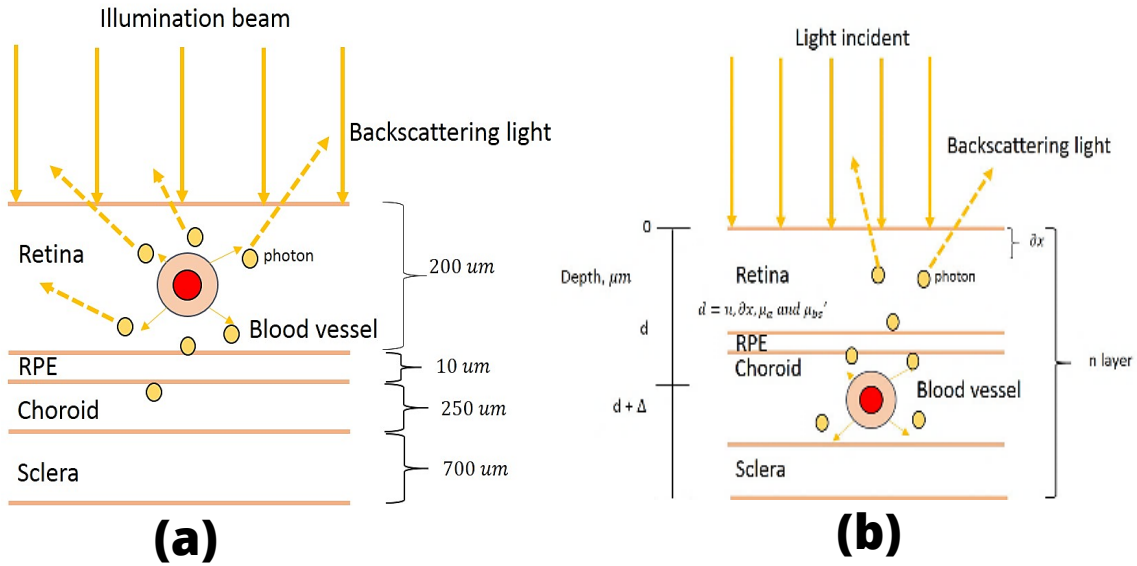

Eye test using fundus camera

Stored recorded video




**Retinal Imaging Photoplethysmography (iPPG)** – *optical measurement to quantify light propagation from the blood volume in the blood vessel that caused by the cardiac activity.*

# Methodology




i. Model – Four tissue layers (retina, RPE, choroid and sclera
ii. Eye – Two blood network (retina and choroid)
iii. Optical properties: scattering coefficient, absorption coefficient, phase function, wavelength (570nm), tissue thickness (D)

| Blood vessel position (embedded) | Retinal Tissue Layers | Thickness of Healthy Tissue (μm) | Healthy Tissue | |
|---|---|---|---|---|
| | | | ($\mu_a$) ($mm^{-1}$) | ($\mu_{s'}$) ($mm^{-1}$) |
| Retina (Case I) | Retina | 70 | 0.147 | 3.10 |
| | Blood | 60 | 23.8 | 70 |
| | RPE | 10 | 63 | 115.8 |
| | Choroid | 250 | 8.383 | 61.53 |
| | Sclera | 700 | 0.4 | 89.8 |
| Choroid (Case II) | Retina | 200 | 0.147 | 3.10 |
| | RPE | 10 | 63 | 115.8 |
| | Choroid | 95 | 8.383 | 61.53 |
| | Blood | 60 | 238 | 70 |
| | Sclera | 700 | 0.4 | 89.8 |

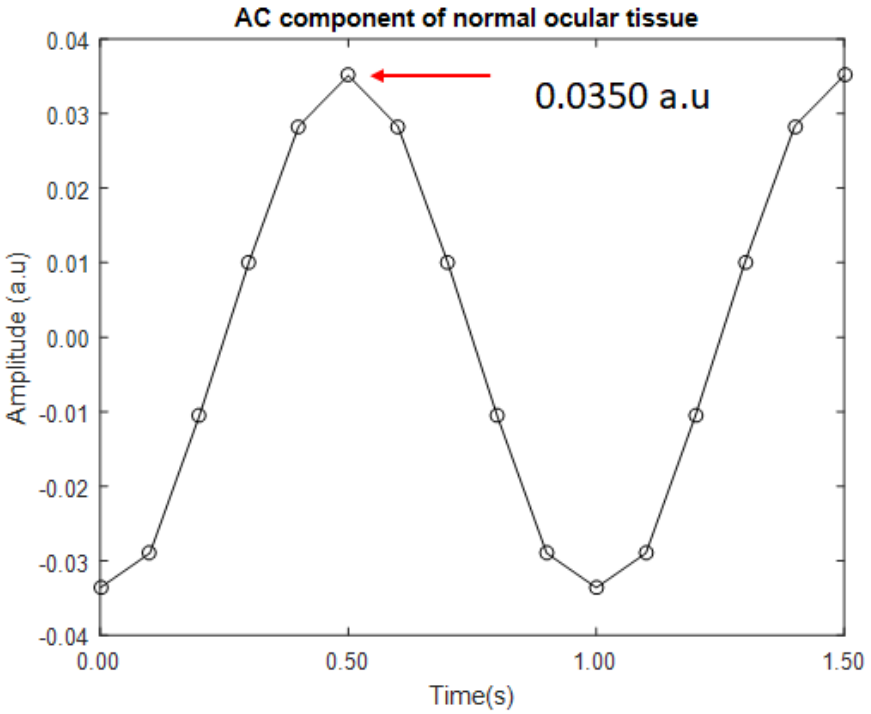
# Methodology

The 1D eye tissue was modeled in the z-direction where a *diffusion approximation-FEM approach* was applied to quantify blood flowing in the blood vessel which is interpreted as the amplitude of AC signal.

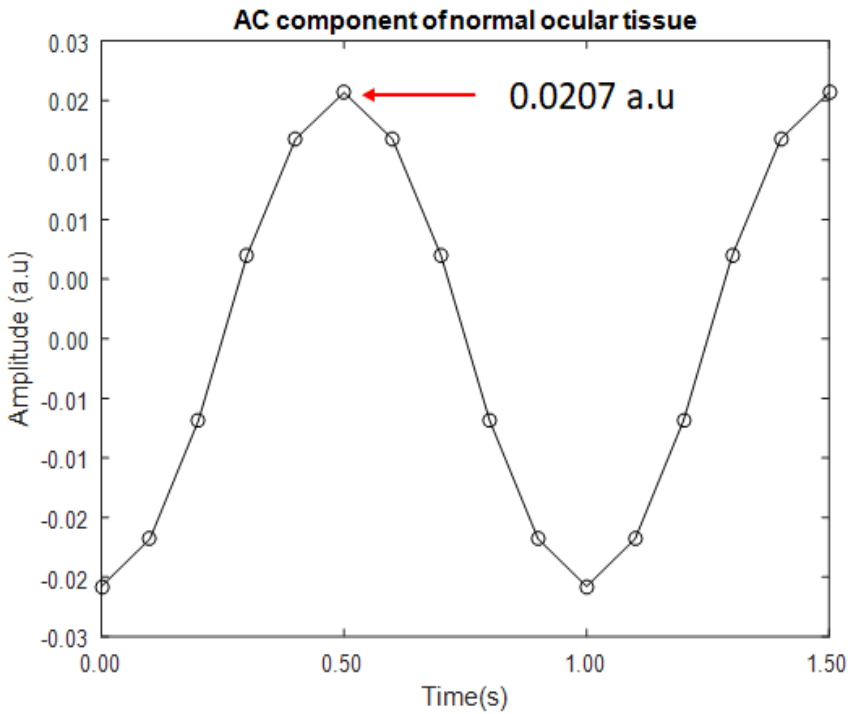
The algorithm of the 1D diffusion approximation – FEM model starts with :

i. the understanding of light interaction in the tissue – eye anatomy and optical properties
ii. the assumption and definition of RTE for blood vessel derivation
iii. solving the RTE with diffusion approximation-FEM approach
iv. solve the boundary condition of $P_1$ approximation
v. transport approximation for a time-varying scattering of AC signal component

# Results & Discussion



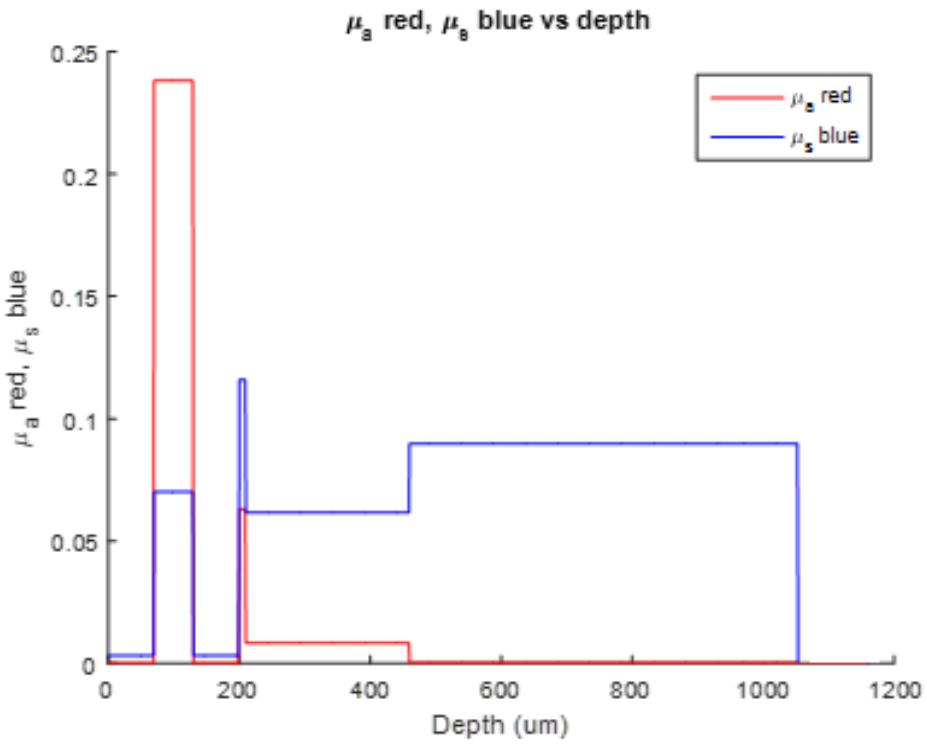

**(a)**



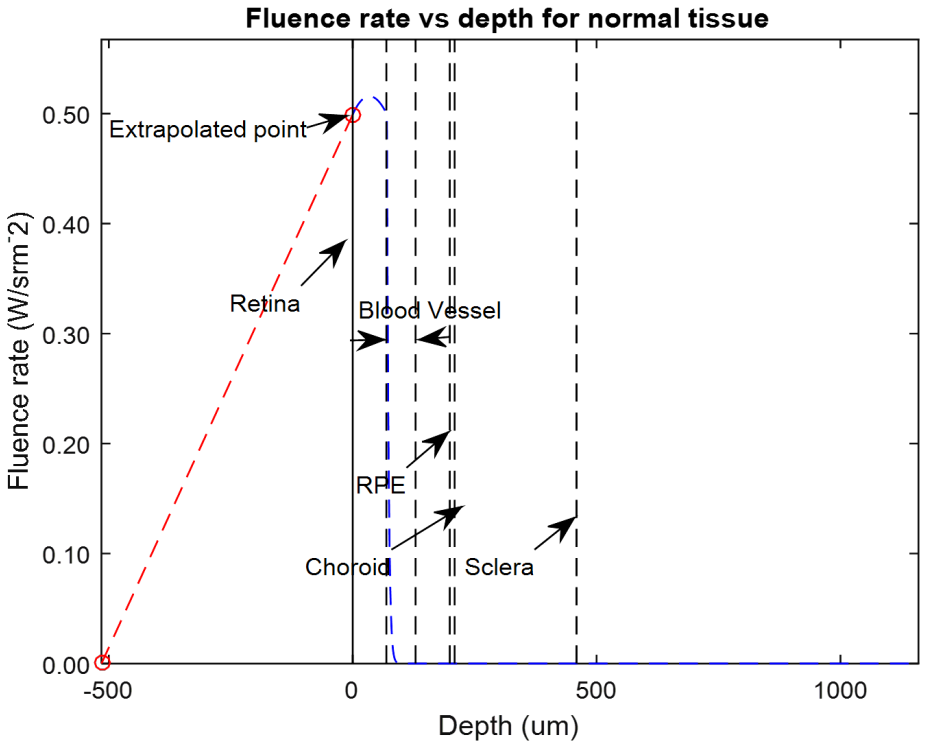

**(b)**

(a) Blood perfusion in retina layer, (b) Blood perfusion in the choroid layer

# Results & Discussion



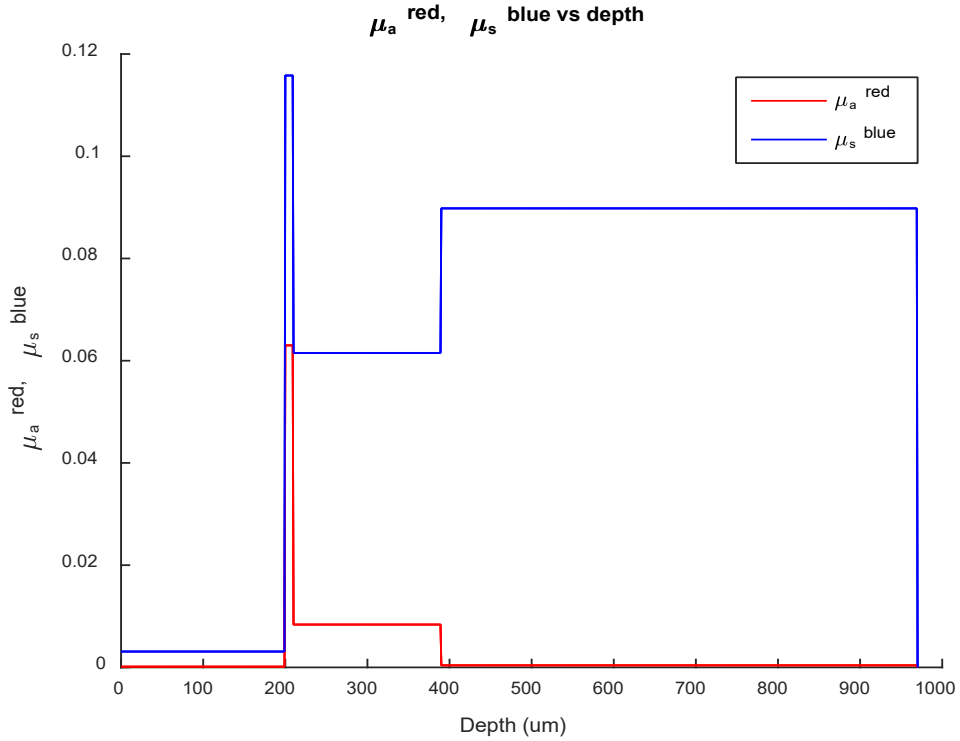

(a)



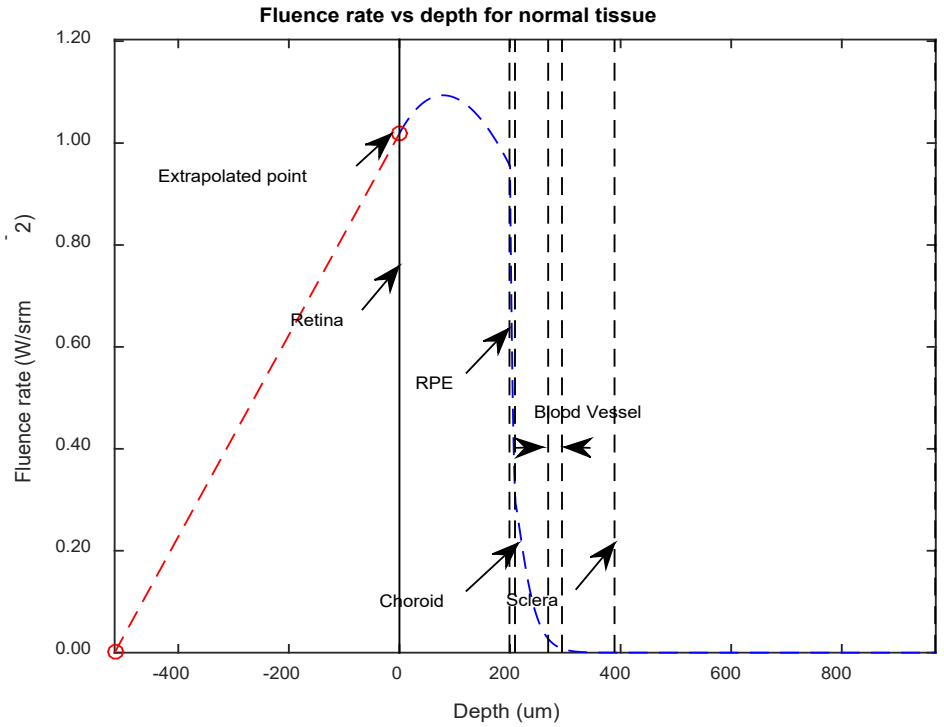

(b)

Case I (a) Absorption and scattering coefficient versus the depth for healthy tissue in *oxy-haemoglobin* condition at 570 nm, (b) Fluence rate for healthy tissue versus the depth for healthy tissue in *oxy-haemoglobin* condition at 570 nm

# Results & Discussion




(a)




(b)

Case II (a) Absorption and scattering coefficient versus the depth for healthy tissue in *oxy-haemoglobin* condition at 570 nm, (b) Fluence rate for healthy tissue versus the depth for healthy tissue in *oxy-haemoglobin* condition at 570 nm.

# Conclusion

The observation of AC has concluded that the amplitude of AC components was not significantly affected by the variation of blood vessel diameter, but the amplitude changes are most likely affected by the blood vessel position and the decrease of scattering coefficient, $\mu_s$.

In Case I the extrapolated point $z = z_B = -2D(0)$, decay rapidly as soon as the photon hits the retina where the absorption coefficient was high when there was the presence of melanin and blood. In Case II, the scattering coefficient, $\mu_s$ was high where the chances of photons reaching the bottom layer were also high. However, the photons were absorbed two times to reach the surface that soon interpreted as backscattering light.

The light distribution described by diffusion theory was less accurate when demonstrated on the eye tissue where the tissue layers were thin and close to sources and boundaries (Jia et al., 2021) Also, the validity of photon distribution theory satisfied $\mu_s << \mu_s'$ for most biological tissue at visible to near-infrared wavelength.

However, the developed 1D diffusion approximation-FEM approach model was capable to demonstrate a fast computation process and can be used as a preliminary prediction of blood perfusion analysis without concerning the stochastic noise produced during the calculations.

The investigation of light quantification and interaction will be extended using 3D Monte Carlo technique for future work.

# THANK YOU

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