Towards point-of-care diagnostics and monitoring of hypertensive episodes (A Monte Carlo approach)

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Abstract: We present an assessment of photon transport through healthy and hypertensive tissue models using Monte Carlo methods. The tissue models (including skin layers and blood vessels) are assessed under red wavelength illumination in TracePro.

1. Introduction

High blood pressure, also known as hypertension, is characterised by episodes of sustained blood pressure of 140/90 mm Hg or above (High blood pressure (hypertension), © 2022 NHS 24). If left untreated, multiple and regular hypertensive episodes can lead to strokes, heart attacks, thrombosis and aneurysms. Regular and constant monitoring of blood pressure can potentially lead to individual-specific assessment and diagnosis. A point-of-care diagnostic device capable of recording and analysing blood pressure data would assist in identifying patterns and signs of hypertension.

Prior research shows the viability of longer visible and near-infrared wavelengths and their application to measuring at and beneath biological tissue [1]. Biophotonics applications, from pulse oximetry to cancer imaging, exploit the principles of light transport at different wavelengths through tissue. While beneficial, this has also resulted in a wide range of optical properties reported in literature [2, 3]. Building on this knowledge for optical simulation, we compare healthy and hypertensive tissue models using Monte Carlo methods within TracePro.

2. Methods and Results

A bespoke wrist model was designed in AutoCAD and appropriate optical properties (Table 1, Table 2) are assigned to the tissue layers in TracePro. These properties characterise absorption (μ_a), scattering (μ_s), anisotropy (g), refractive index (η) and thickness (d). The two models are designed with varying blood vessel wall thicknesses (Table 2).

Table 1. The optical properties of the tissue model is adopted from literature [1– 3].

Layer	Epidermis	Dermis	Fat	Homogeneous Muscle	Bone
μ_a (mm^{-1})	5.09	0.03	0.02	0.12	0.06
μ_s (mm^{-1})	29.67	26.82	5	10.45	33.47
g	0.82	0.9	0.75	0.9	0.9
η	1.34	1.4	1.44	1.38	1.56
d (mm)	0.1	1.83	1.14	56 -70 mm	-

Table 2. The blood vessels are incorporated in the model with varying dimensions (healthy model properties presented below) different depths, assuming a degree of randomness.

Layer	Arteriole (wall)	Arteriole (blood)	Venule (wall)	Venule (blood)	Artery (wall)	Artery (blood)	Vein (wall)	Vein (blood)
μ_a (mm^{-1})	0.12	0.29	0.12	2.61	0.12	0.29	0.12	2.61
μ_s (mm^{-1})	16.19	365.87	16.19	335.76	16.19	365.87	16.19	335.76
g	0.87	0.99	0.87	0.99	0.87	0.99	0.87	0.99
η	1.33	1.37	1.33	1.37	1.33	1.37	1.33	1.37
d (μm)	20	10	2	18	1000	3000	500	4500

The tissue model is illuminated with light at 633 nm, simulating a Gaussian beam from a laser diode module. The wavelength and laser power parameters applied to the simulation are within the skin safe range. The optical properties are appropriately chosen at this wavelength from published literature [2, 3].

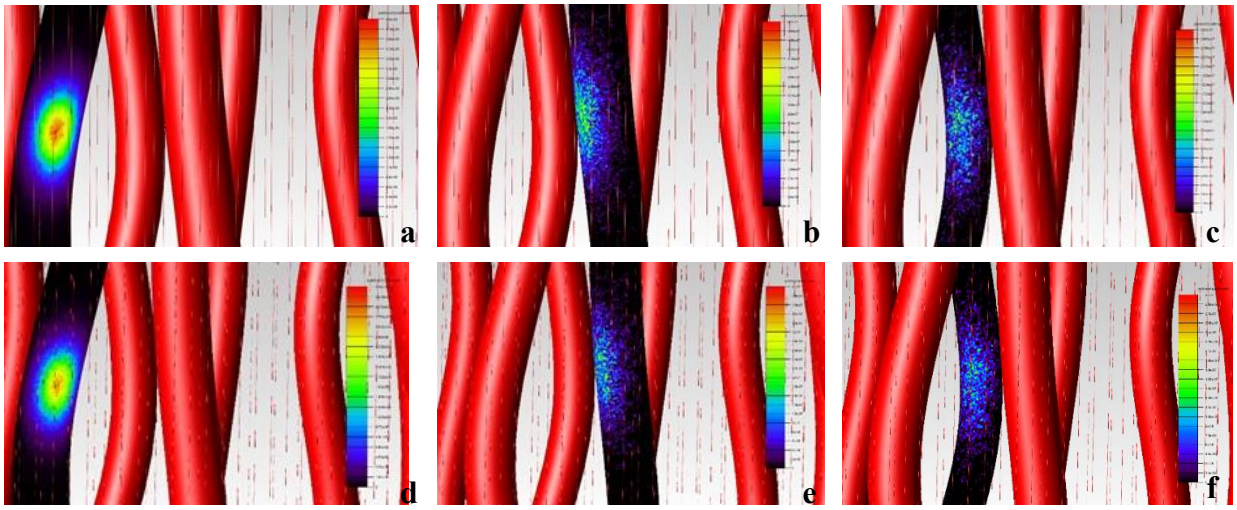

Fig. 1. Blood vessels at different depths shows a greater degree of scattering when comparing healthy (a-c) and hypertensive-prone (d-f) models. In the latter, the blood vessel walls are 50% thicker, restricting blood flow.

3. Discussions and Conclusions

The variance in the results is substantial when comparing the incident flux on the vascular walls across the two tissue models. In the first two vessels (Fig. 1 a, d and b, e), the maximum incidence is greater with the healthy model having a 35% higher maximum value in the first vessel and an 18% increase in the second vessel. These results are in line with our expectations that a larger amount of blood results in a greater amount of forward scattering (healthy model). This allows more photons to interact with the vessels during propagation. In the deepest vessel (Fig. 1 c, f), the opposite is the case, with a higher maximum incidence on the unhealthy model. We reason that this could be due to one of two reasons: (1) limited number of photons penetrate to this depth in the tissue leading to seemingly larger variations due to small numbers of incident events, and/or (2) isotropic scattering dominating photon attenuation at greater depths, thereby producing more incident events beyond the propagation direction. The overall scattering angle is greater in the hypertensive model, with incident photons diverging from the point of incidence to a larger degree.

Within the scope and constraints of this study, we conclude that an increase in vascular wall thickness leads to a wider angle of overall scattering from the incident beam radius. This confirms the hypothesis that a thickening of vascular wall structures causes a variability in scattering. Future questions could explore a more accurate and detailed detection of scattering within the tissue and the backscatter outside the model. Although the differences are not as substantial as expected, it is nonetheless a positive confirmation that these variations could be identified through future experimental work.

4. Acknowledgements

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5. References

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