Development of line scanner for tomographic blood flow measurements in burn wounds

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Introduction

Partial thickness burn wounds are very painful injuries where rapid diagnosis on whether they will heal on their own or not is highly desirable. Current techniques rely on superficial 2D images of the burn wound, e.g., laser speckle imaging, from which rapid diagnosis can be difficult and may delay needed surgery. Diffuse correlation spectroscopy is another laser speckle technique for microvascular blood flow where varying distances between light source and detector can be used to differentiate different measurement depths. However, this requires time-consuming 2D scanning to form a full image. We are using a hybrid approach to develop a novel depth-resolved speckle contrast Diffuse Correlation Tomography (scDCT) system where laser speckles from different distances from a laser line will be used to determine coagulation depth [1] . This will allow rapid and deeper 3D tomographic imaging and burn wound diagnosis from a simple 1D scan.

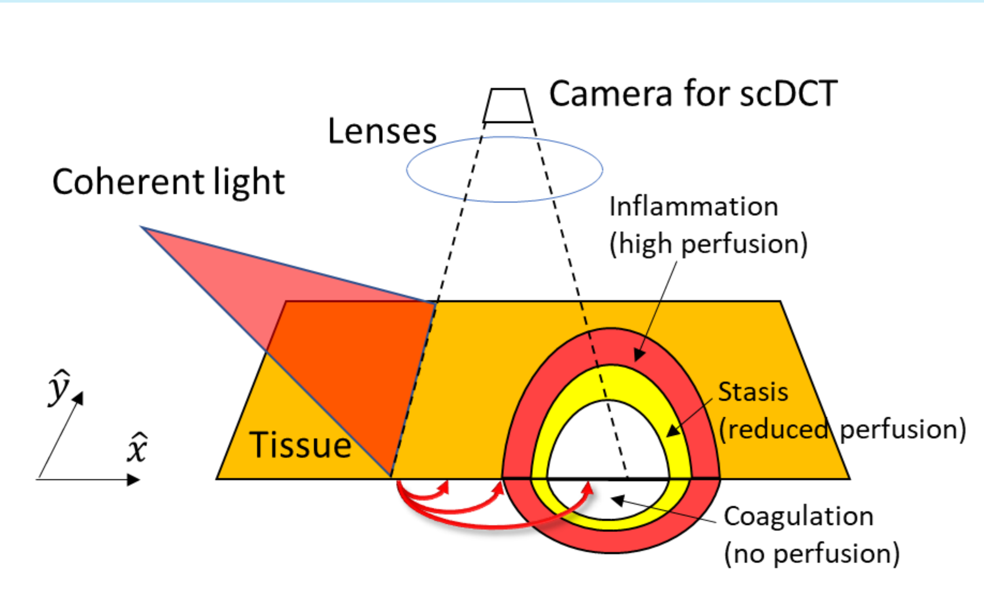

Figure 1. System overview. Laser light is shined through a Powell lens to generate a laser line on the tissue or phantom. Light from larger distances from the line source will have penetrated deeper in the tissue and will be used for tomographic reconstruction of burn wound zones, especially the coagulation zone where blood perfusion is blocked. Response in the inflammation zone may also be of interest to diagnose the healing process.

System

An overview of the system is given in Figure 1. Red laser light is shined through a Powell lens to generate a laser line. Speckles are then measured at different distances from the laser line with light having travelled deeper through the sample with increasing distance from the laser line. Speckle contrast K is calculated from the spatial variance, $\sigma^2_{\text{measured}}$, of the light intensity, I, over 25-pixel lines parallel to the laser line as

$$K^2 = \beta\left(\frac{\sigma^2_{\text{measured}} - \sigma^2_{\text{shot}} - \sigma^2_{\text{dark}}}{\langle I\rangle^2}\right)$$

Where β is the spatial correlation coefficient of the system, σ^2_{shot} the estimated shot noise, and σ^2_{dark} the dark noise. A simple perfusion estimate can then be calculated as $1/K^2$.

References
[1] J. D. Johansson and R. Saager, *Development of a novel line scanner for speckle contrast diffuse correlation tomography of microvascular blood flow*, Photonics West SPIE BiOS San Francisco 27 Jan - 1 Feb 2023
https://doi.org/10.1117/12.2649095

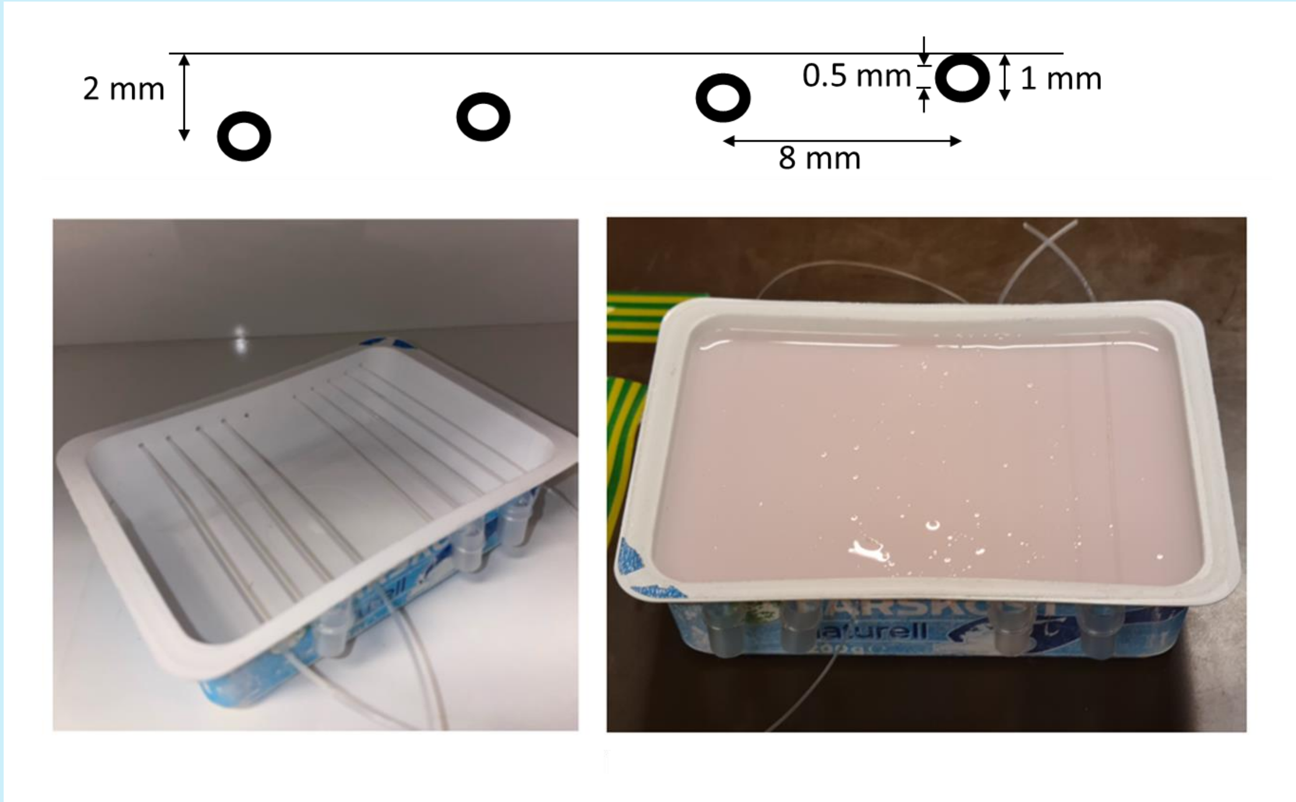

Figure 2. Flow phantom with tubes at depths of 0.5 – 2 mm surrounded by static light scattering silicone to emulate different coagulation depths. (Made by students in Biomedical Engineering project course - TBMT14)

Test flow phantom

The system was tested on a PDMS silicone phantom with tubes at depths of 0.5 – 2 mm perfused with 1 % fat Intralipid dilution at a flow of 1 ml/min (Figure 2). Measurements were compared with Finite Element Method (FEM) simulations (Figure 3). Results of measurements and simulation is given in Figure 4. Deeper tubes emulates a deeper zone of coagulation without blood perfusion above them.

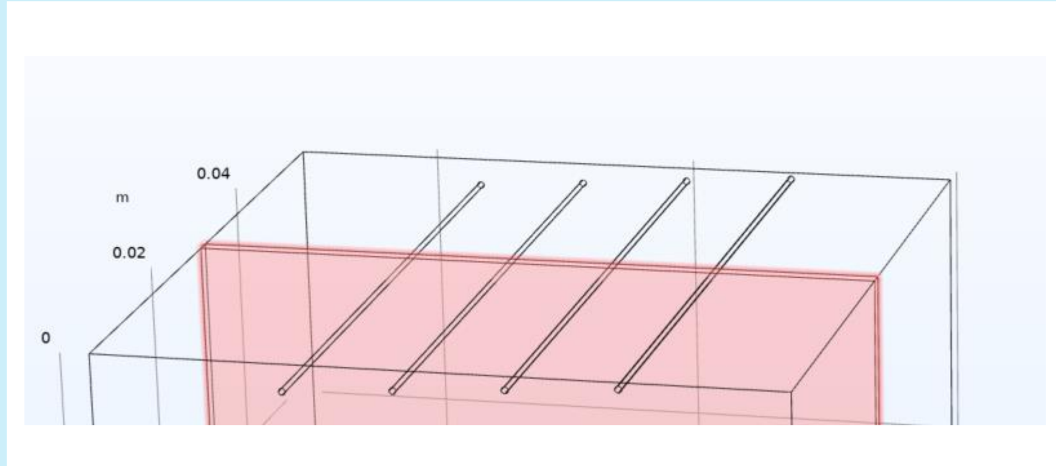

Figure 3. FEM simulation of light transport in the flow phantom. Diffuse light is modelled with a with depth exponentially decaying light source from the laser line.

Future outlook

A rotating mirror will be used to scan the laser line over the tissue. Simulations will be set up to train Machine Learning for real-time tomographic reconstruction of blood flow. Such reconstructions will allow for quantitative determination of coagulation depth, i.e., the depth without blood flow, and better diagnosis of when surgery is needed for the burn wounds.

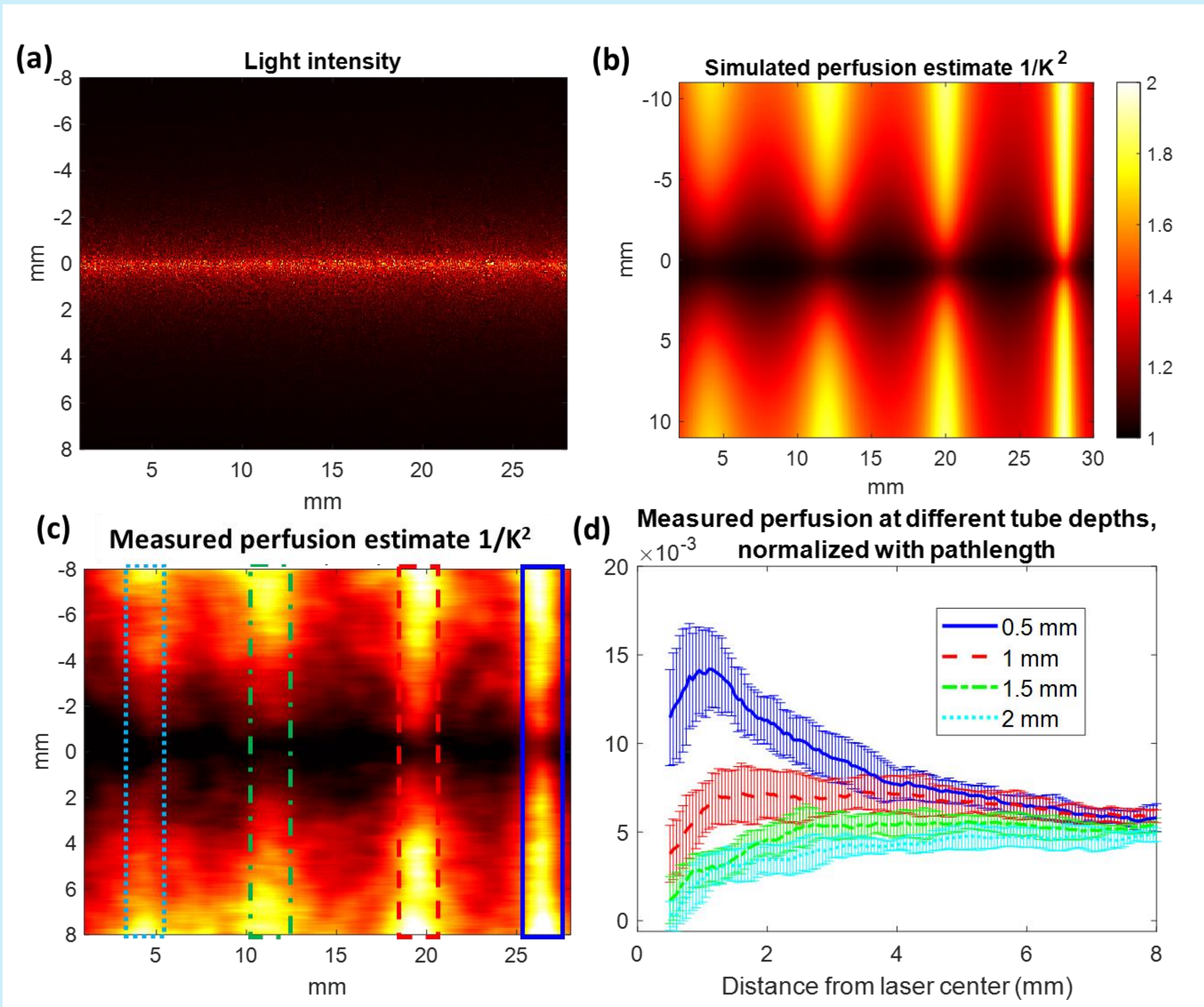

Figure 4. ***(a)*** *Measured light intensity from the laser line.* ***(b)*** *Simulated perfusion estimates.* ***(c)*** *Measured perfusion estimates from the light intensity in (a). Deeper tubes become more visible further away from the laser line as the light has travelled deeper there.* ***(d)*** *Light that has travelled further from the laser line will give higher perfusion estimates as more Doppler shifts occur. Normalizing the perfusion estimate with the optical pathlength to compensate for this separates the tubes at 0.5, 1, and 1.5 mm well, showing promise of the system to differentiate different coagulation depths. (Error bar: Standard deviation over repeated measurements on different positions of the flow phantom.)*

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