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Agar-based phantoms for skin diagnostic imaging

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Aim

To validate previously developed smartphone-based RGB imaging devices and algorithm for concentration evaluation of skin chromophores using agar-based phantoms

Tasks

- To produce one-layer and two-layer agar-based phantoms with different chromophore concentrations.
- To evaluate absorption properties of the phantoms using transmittance and diffuse reflectance images.
- To analyze the influence of experimentally determinend photon mean free path values on chromophore concentration maps.
- To compare the results obtained from RGB images captured by two self-developed smartphone-based prototypes

Agar phantoms

Benefits

- easy to produce
- flexible
- variety of shapes- detailed heterogenety possible
- inclusions possible
- biologically compatible
- adjustable absorption and scattering
- index of refraction (n=1.35) close to the tissues

Limitations

- not stable over long periods of time

Agar phantoms

Components

Matrix

- **Agar (Ag) powder** (A7002, Sigma-Aldrich)

Absorption

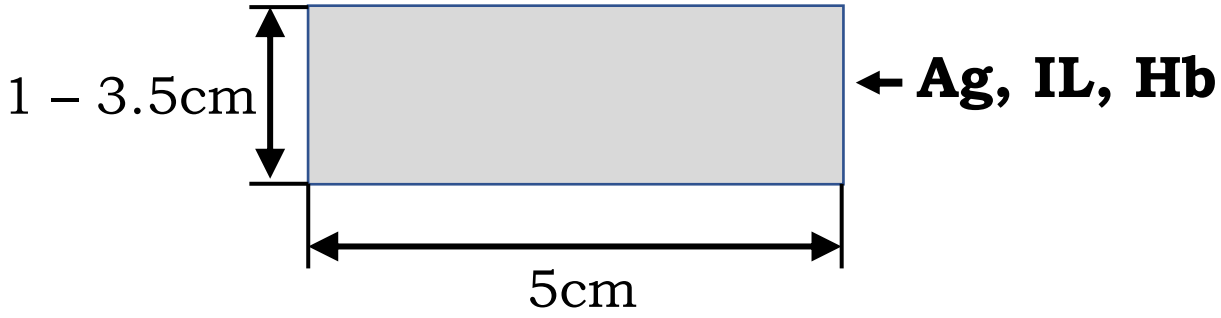
- **Hemoglobin (Hb) water soluble powder** (198285, Sigma-Aldrich)

Scattering

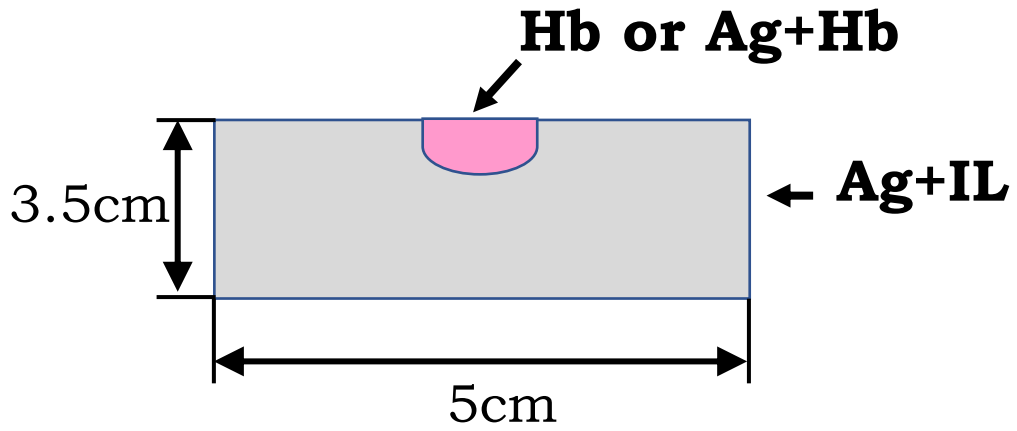
- **Intralipid (IL) emulsion 20%** (I141, Sigma-Aldrich)

Agar phantoms

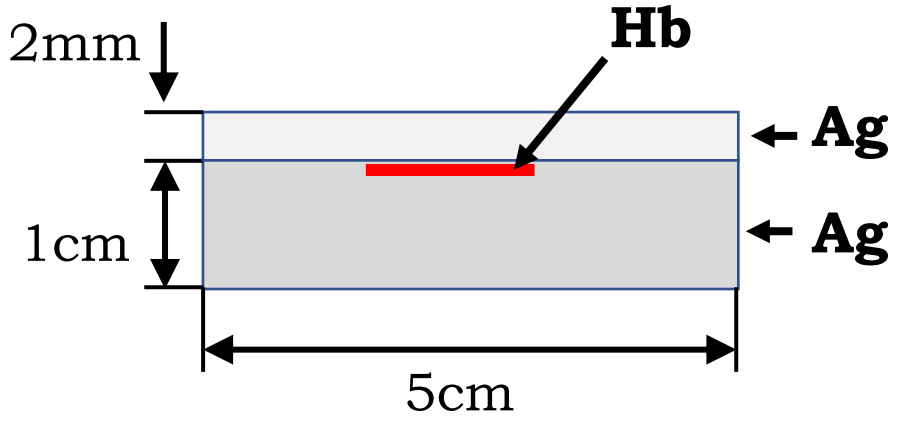
One-layer



One-layer with neoplasm



Two-layers with vascular vessel



Agar phantoms

Agar

h=3.3 cm

Agar+Hb

h=3.3 cm

Agar+Hb

h=1.5 cm

Agar, IL, Hb

h=3.3 cm

Agar, IL, Hb

h_1 = 2 mm

h_2 = 2 cm

Phantom measurements

Point spectral measurements

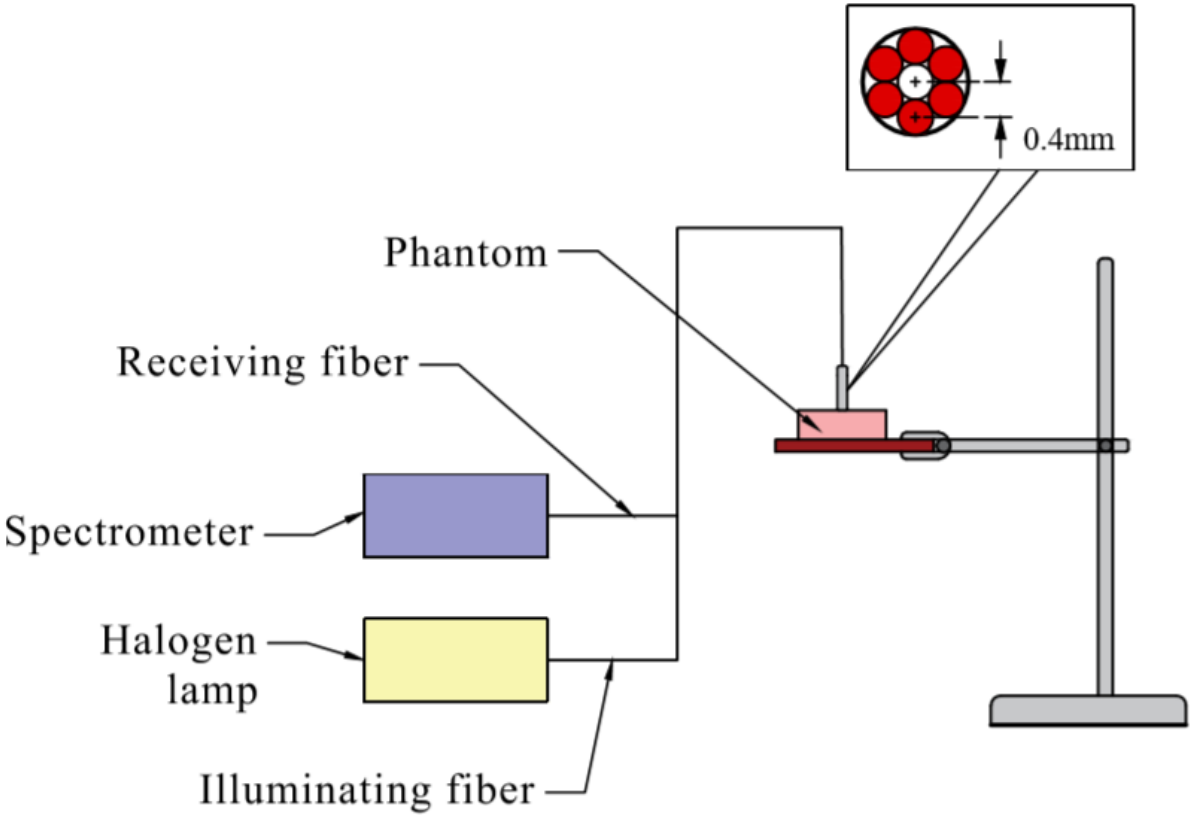
1. Steady state spectra: VIS-NIR
2. Photon time-of-flight signal -> photon mean pathlength

RGB imaging

1. Smartphone + LED illuminator
2. Smartphone + Laser illuminator

Spectral point measurements

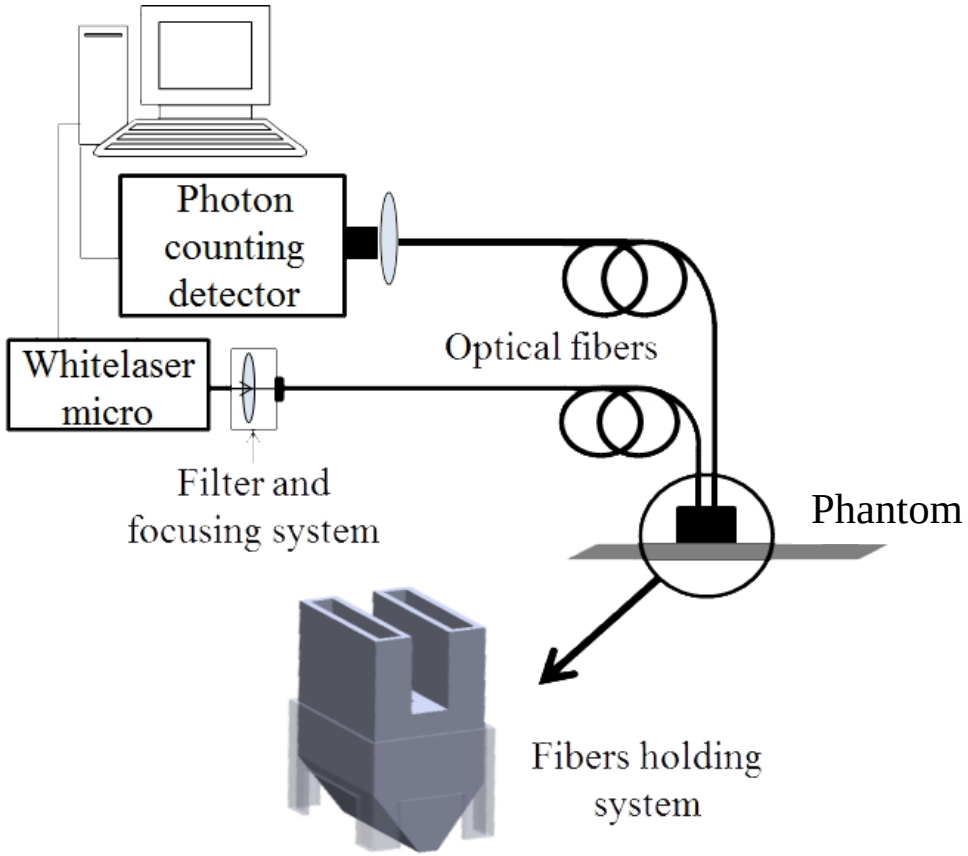
Steady state DR



Halogen lamp – *AvaLight-Hal*
Spectrometer – *AvaSpec-Mini4096CL-UVI10*
λ=300-1100nm
Source-detector distance: d=0.4mm.

Spectral point measurements

Time-resolved DR



Time-correlated single photon counting (TCSPC) system

Fianium White-Laser-Micro (400-1000nm)

Interference filters (FWHM=10nm)

λ_G= **520nm,** λ_R= **680nm**

Source-detector distance: d=1mm.

Photon time-of-flight (**PTOF**) signals

Photon mean path length (**MPL**)*

*Lukinsone et al, Nov. Biophotonics Tech. Appl. V 1107505(July), 4 (2019)
Lukinsone et al, PE2020, Paper 11363-73 'Remitted photon path length in human skin, skin phantoms and cell cultures'

RGB imaging

Nexus 5 smartphone camera

SkinViewer App
(self-developed)

ISO:100

$\mathbf{t_{Exp}}$: 0.2s

LED illuminator:

R: 663nm

G: 535nm

B: 460nm

FWHM= 20nm

AZ camera App

ISO:100

$\mathbf{t_{Exp}}$: 0.25s

Laser illuminator:

R: 659nm

G: 532nm

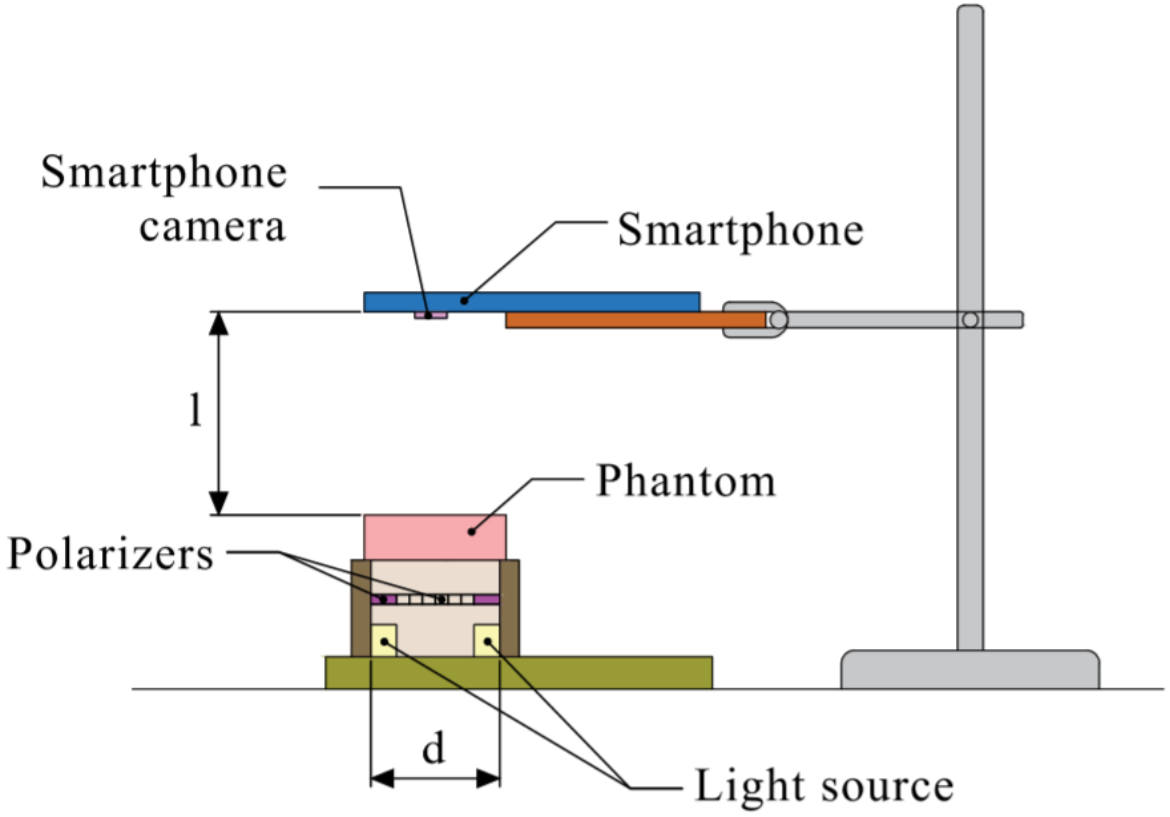
B: 448nm

FWHM= 2nm

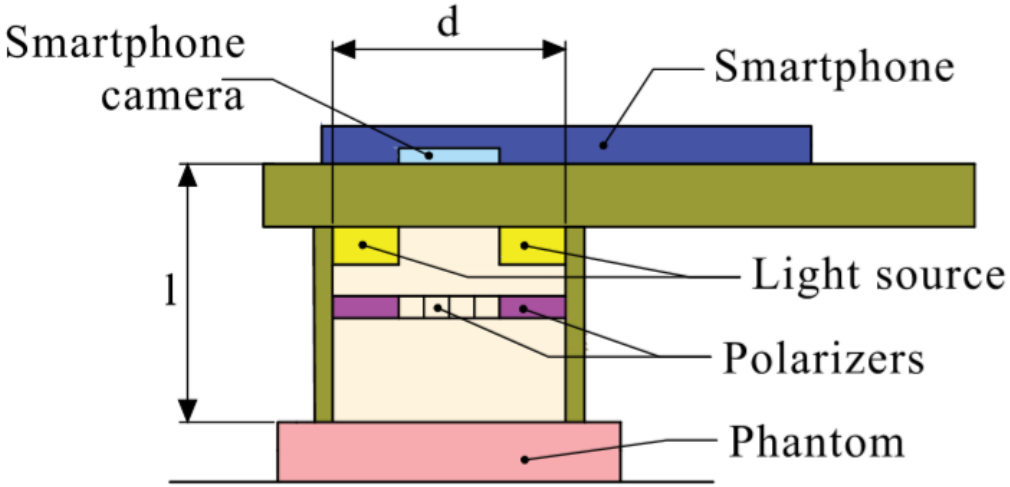
Kuzmina et al, J. Biomed. Opt. 20(9), 090503 (2015)
Spigulis et al, J. Biomed. Opt. 20(5), 050503 (2015)

RGB imaging

Transmittance



Reflectance



Laser: d=4cm. l=8cm
LED: d=4cm, l=7cm

Calculation algorithm

Beer-Lambert law: $I = I_0 \cdot e^{-\mu_a z}$ $\mu_a = 2{,}303 \cdot C \cdot \varepsilon$

$$\varepsilon = \frac{ln\left(\frac{I_0}{I}\right)}{2.303 \cdot C \cdot z}$$

μ_a – absorption coefficient,
ε – extinction coefficient,
I - intensity of transmitted/diffuse reflected light of sample phantom,
$\mathbf{I_0}$ – intensity of transmitted/diffuse reflected light of reference phantom,
***z* –** thickness of the phantom layer/photon mean path length,
C – concentration of a chromophore.

One-layer phantoms

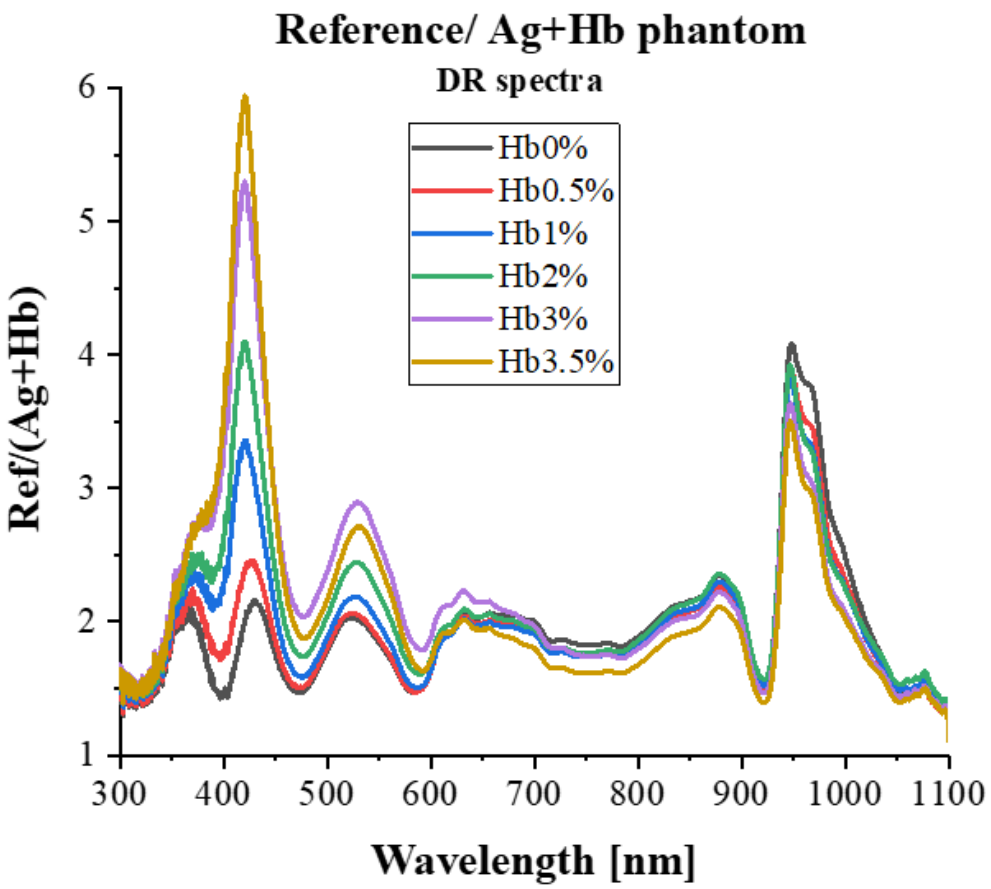
Reference phantom	Sample phantom	c_{Hb}, v/v %	c_{IL}, v/v %	Phantom thickness (mm)	Measurements
Ag	Ag+Hb	0.5-3.5	-	0.9	RGB imaging (T&DR) DR spectra
				1.5	
				3.5	RGB imaging (T&DR) DR spectra PTOF
Ag+IL	Ag+IL+Hb	1-2	1	3.5	RGB imaging (DR) PTOF

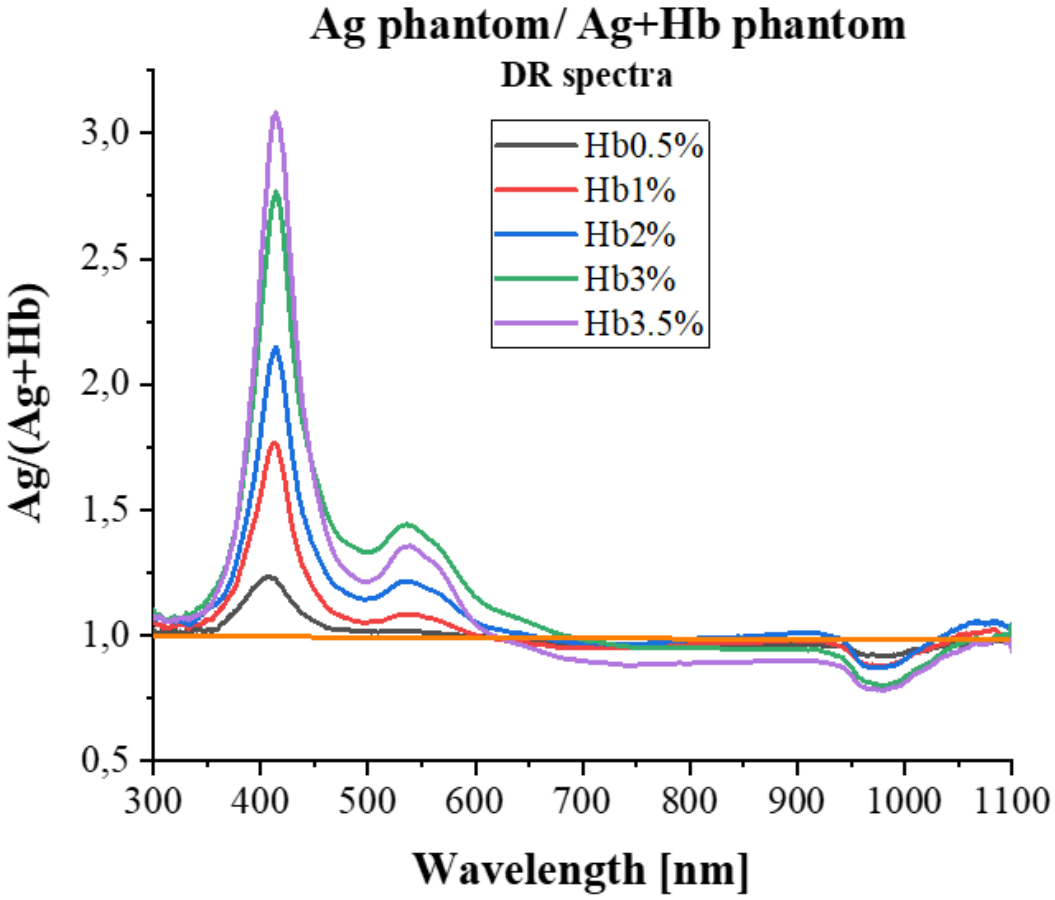
C_{Hb}	v/v %	0.5	1	2	3	3.5
	μM	**1.5**	**3**	**6**	**9**	**10.5**

Mr_{Hb}=65000 g/mol

Results

Phantom spectra



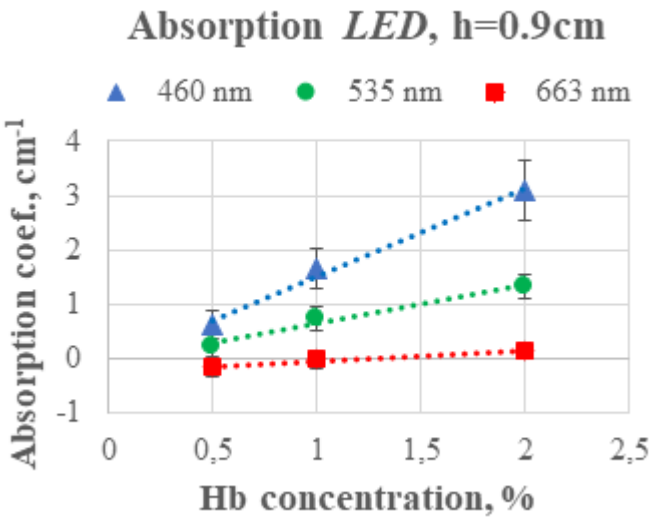


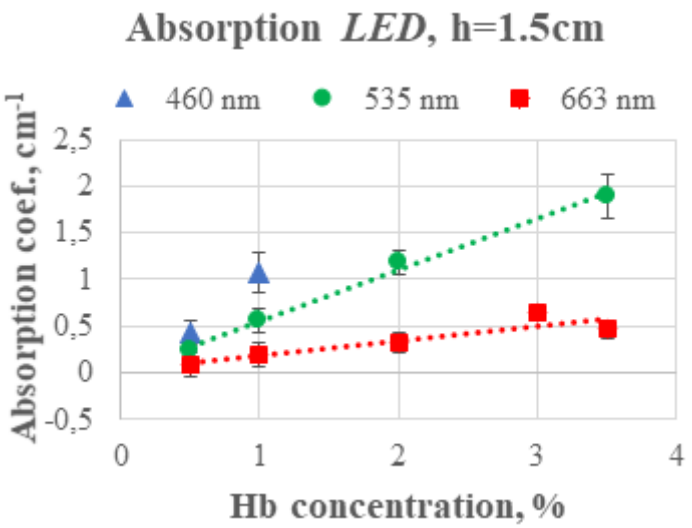
Results

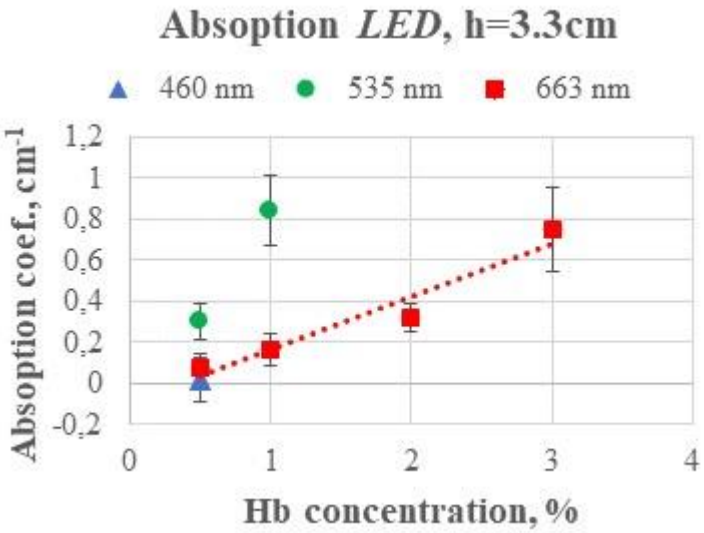
Mean path length

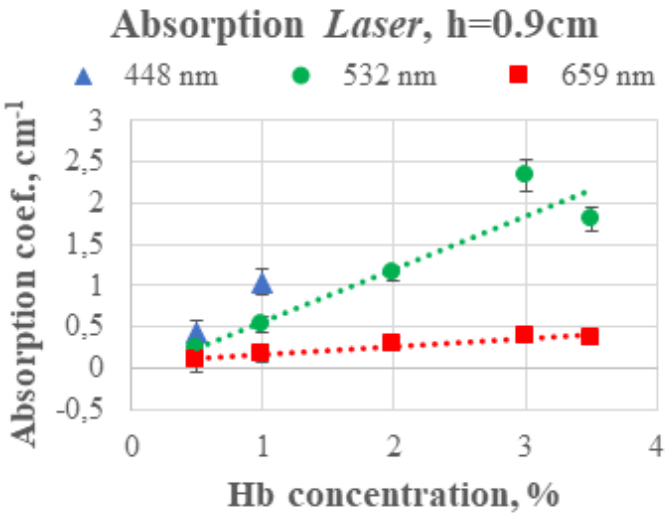
Wavelength, nm	MPL, mm			
	C_{IL}=1%	C_{Hb}=2%	C_{IL}=1% C_{Hb}=1%	C_{IL}=1% C_{Hb}=2%
520	20.7	14.4	14.9	16.1
680	24.5	22.5	18.9	21.1

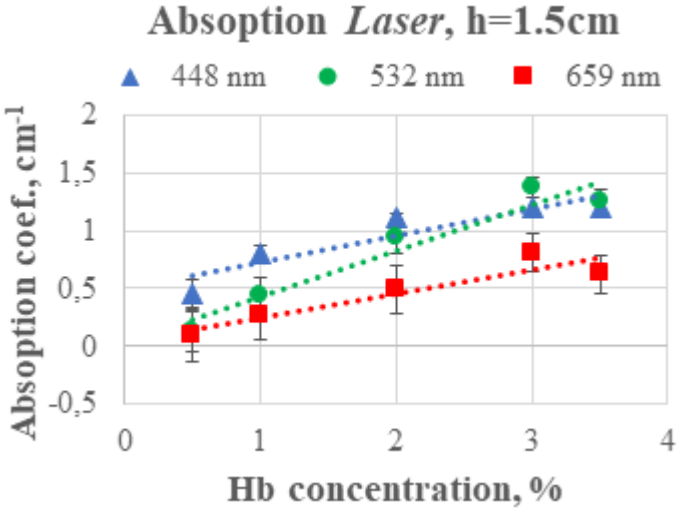
Results - Transmittance

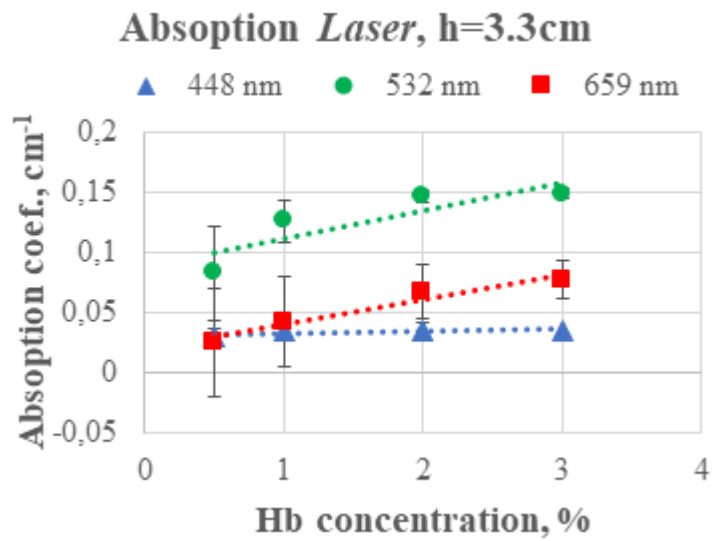




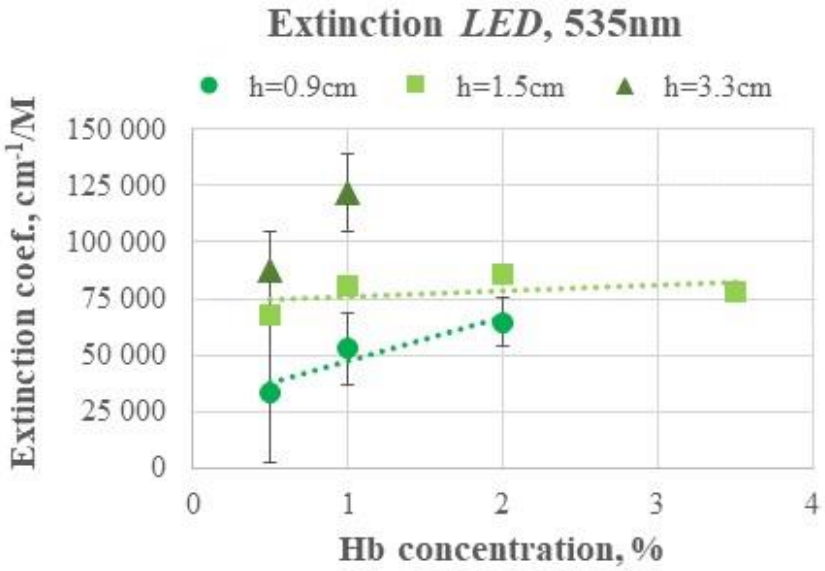


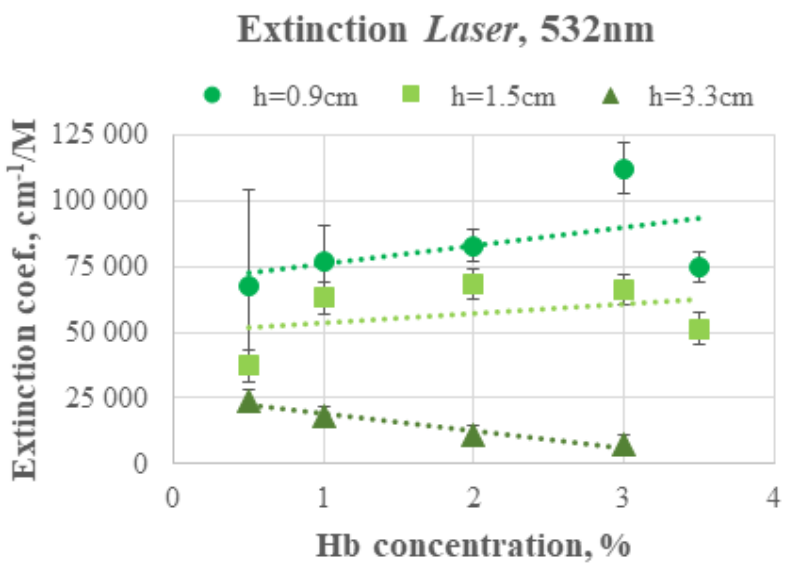


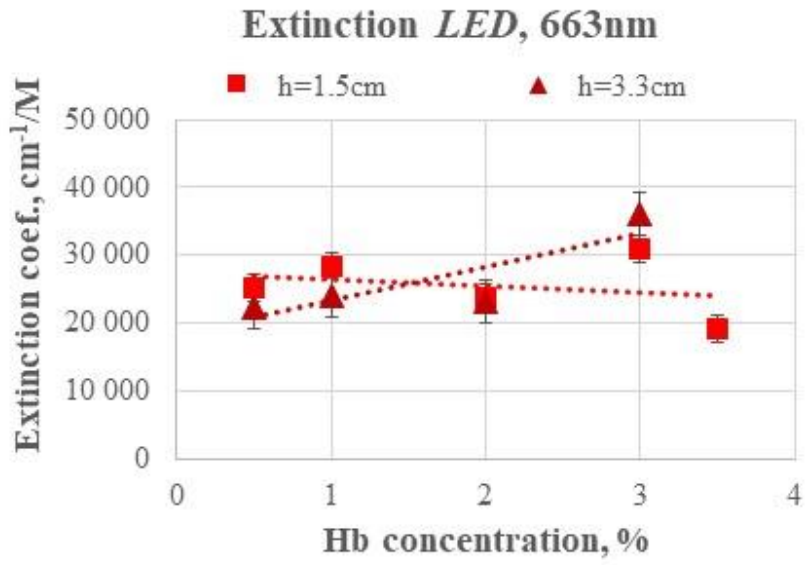


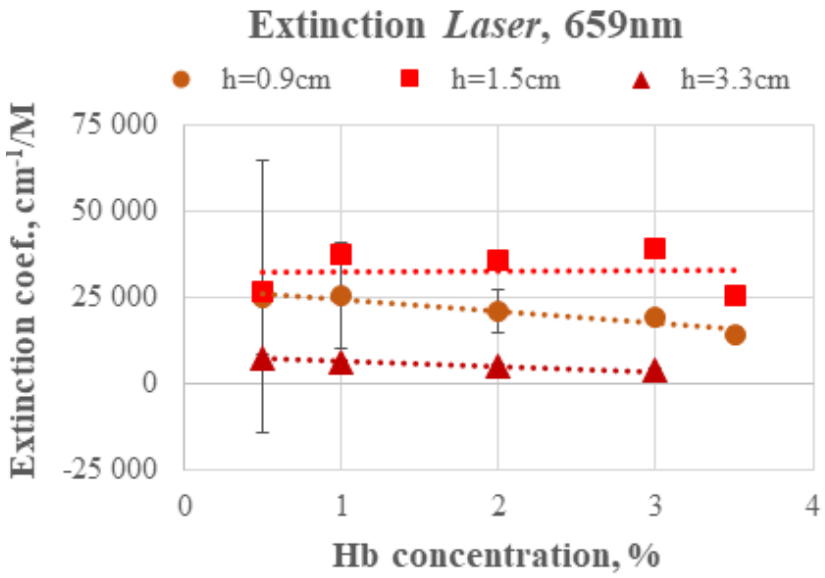


Results - Transmittance



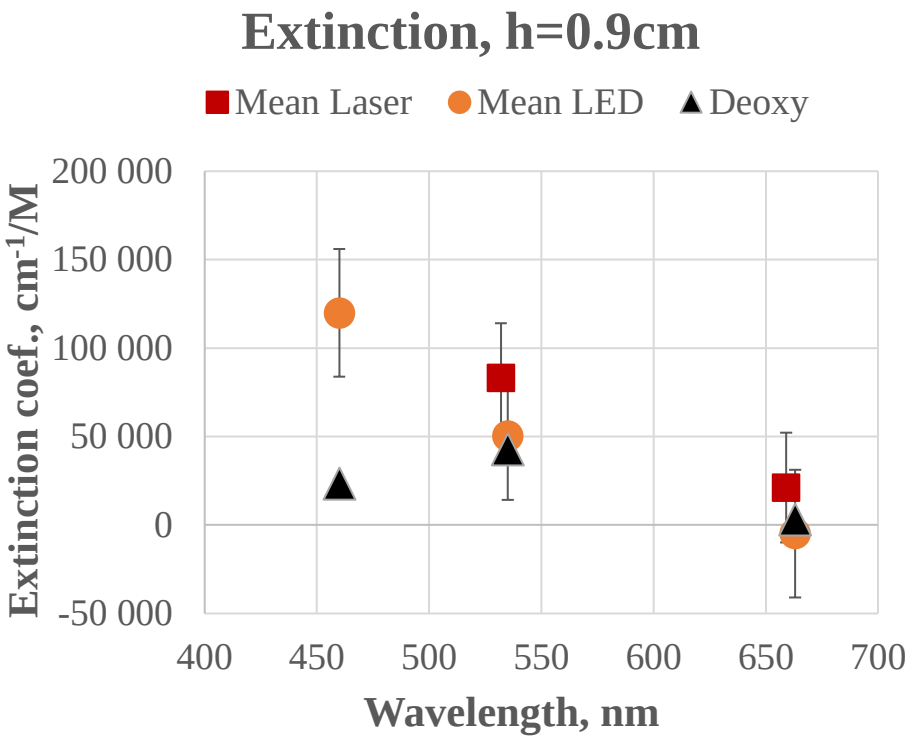


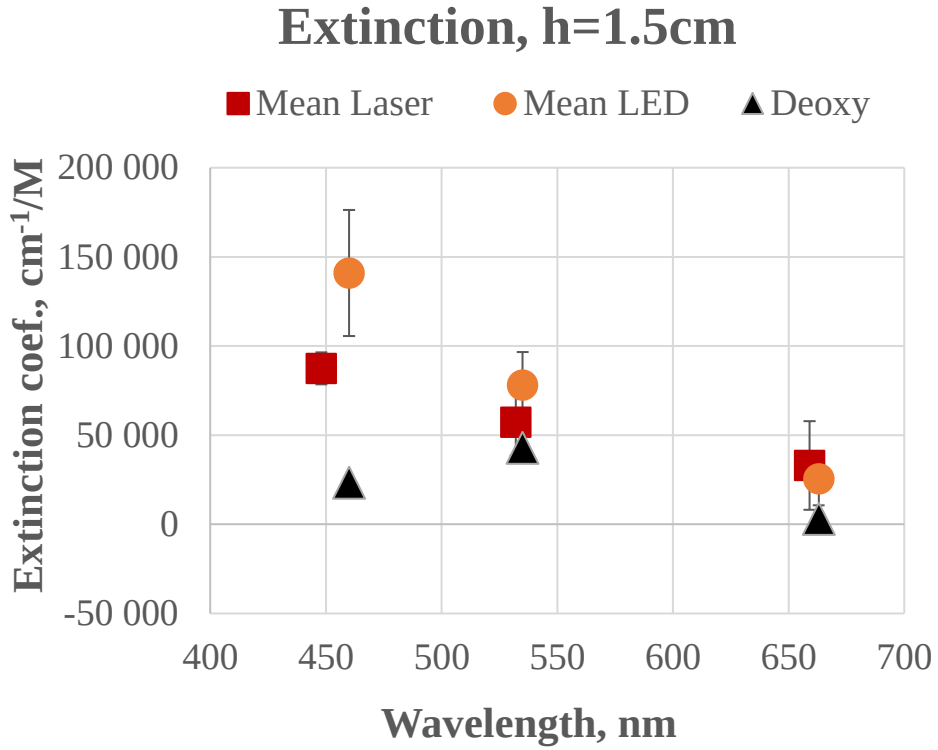




Results

Transmittance

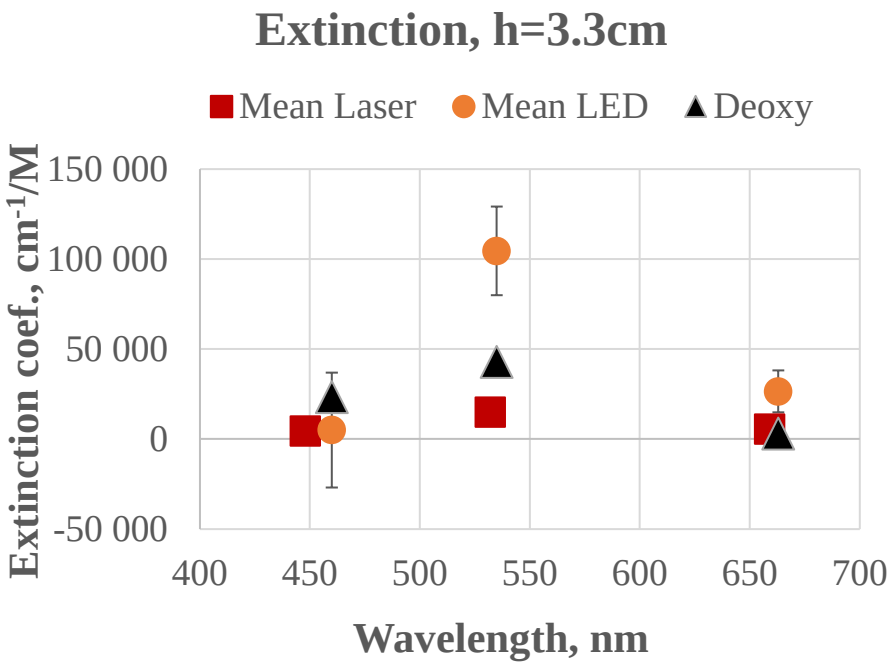




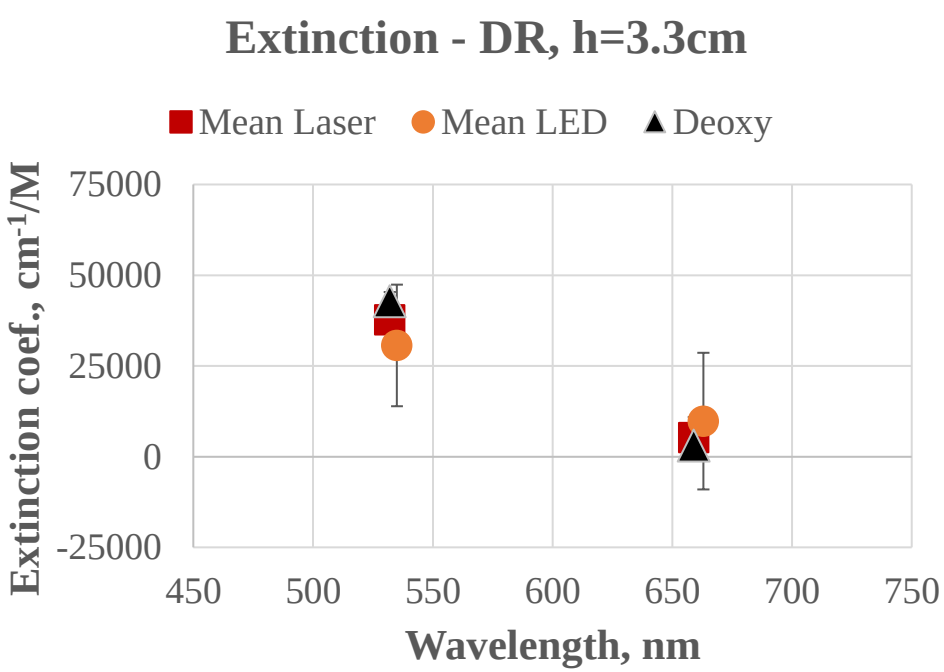
Deoxy – values of the deoxy-hemoglobin from **Prahl, S., "Optical Absorption of Hemoglobin," Oregon Med. Laser Cent., 1999, <https://omlc.org/spectra/hemoglobin/>**

Results

Transmittance



Reflectance



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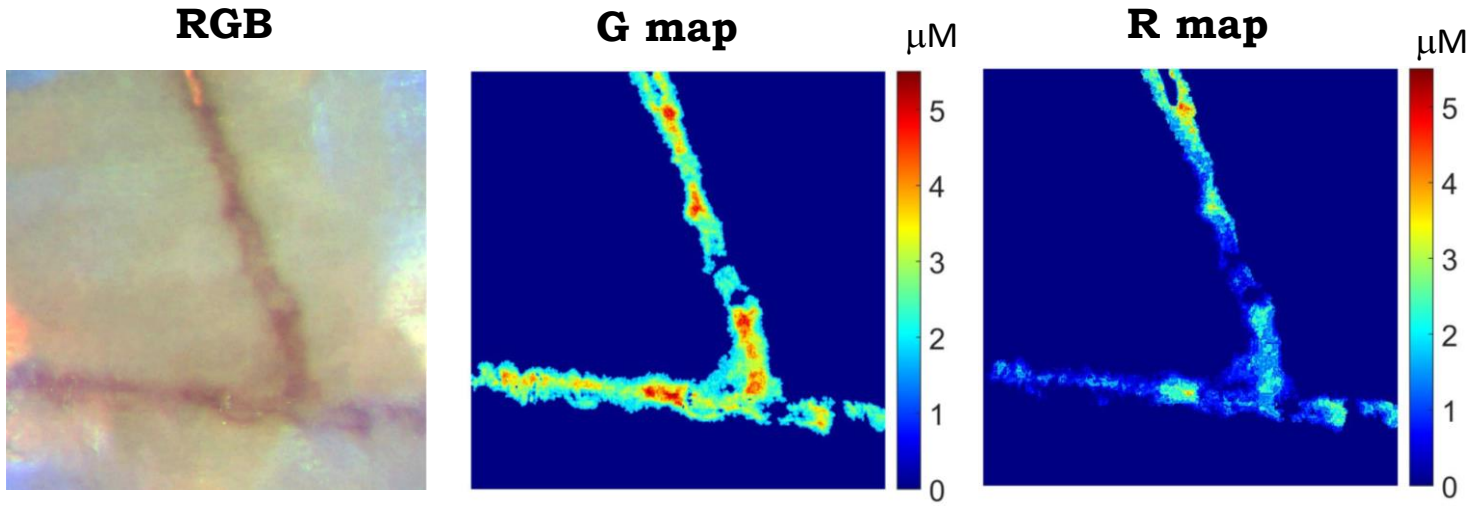
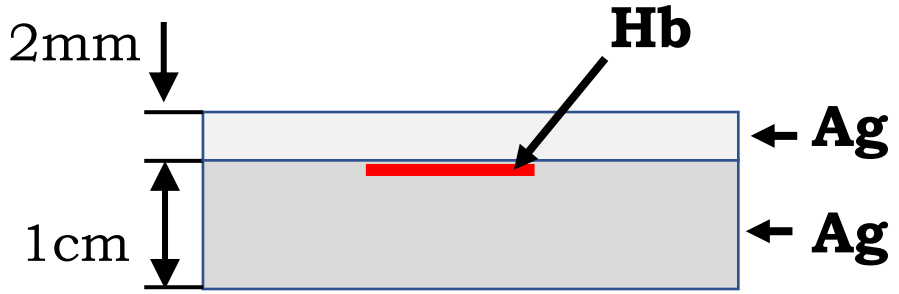
Results

Hemoglobin concentration maps

LED illuminator

Matrix:
Agar
Vessel:
Hb stock solution
C_{Hb}=307μM



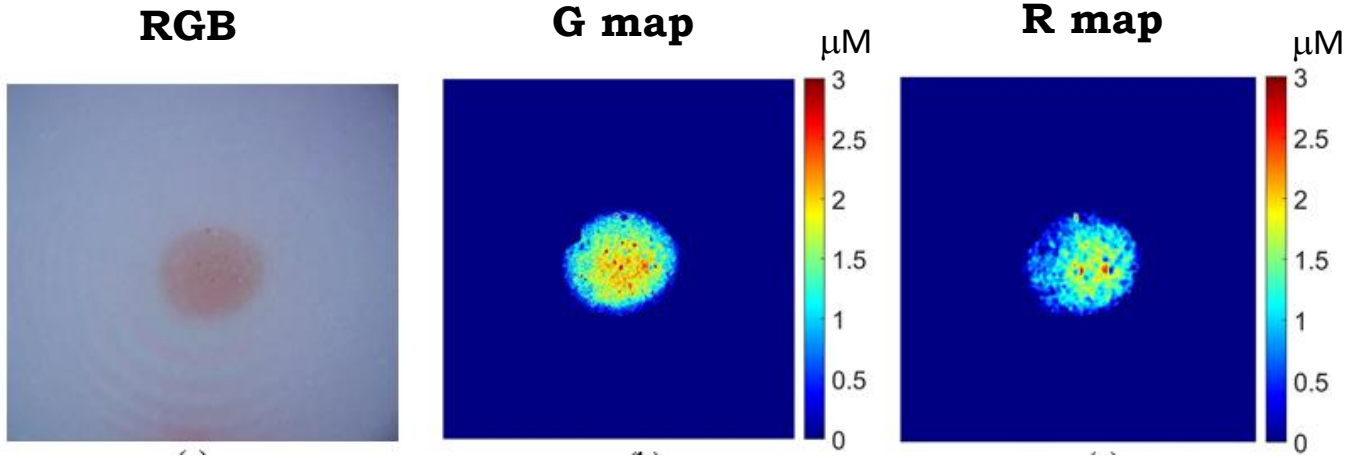


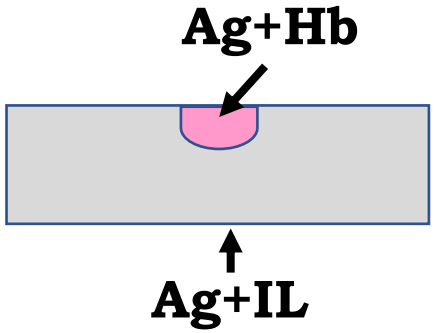
Results

Hemoglobin concentration maps

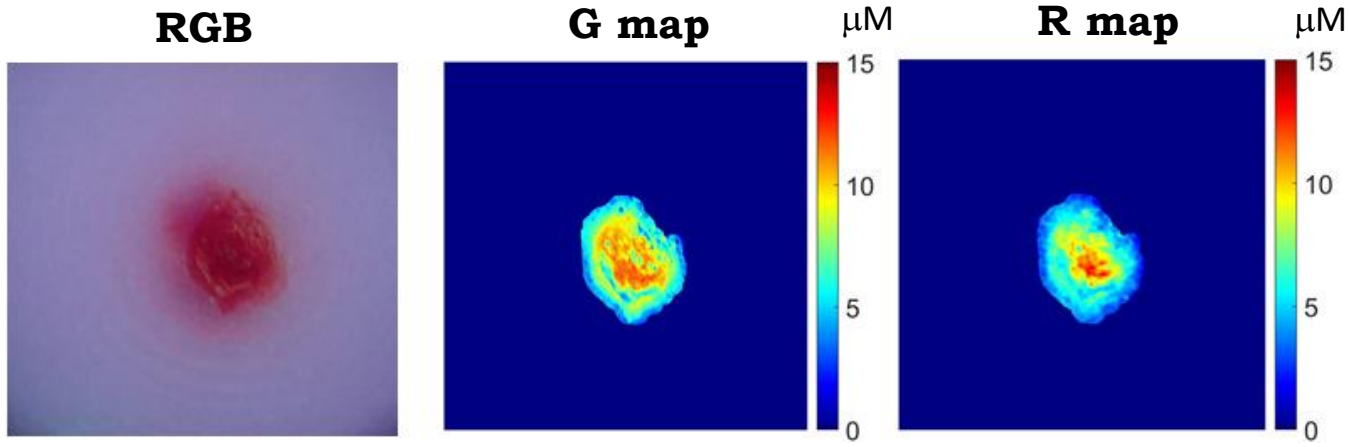
Laser illuminator

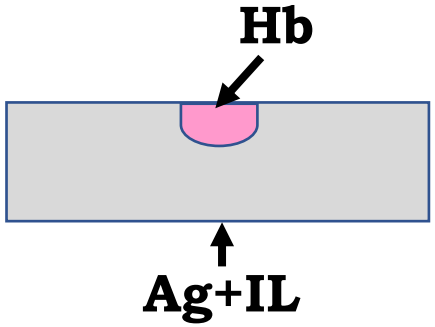
Matrix:
Agar+IL
Inclusion:
Agar+Hb
C_{Hb}=6μM





Matrix:
Agar+IL
Inclusion:
Hb stock solution
C_{Hb}=307μM





Summary

1. **We presented agar-based phantoms for** evaluation and mapping of the hemoglobin concentration by transmittance and diffuse reflectance RGB imaging.
2. We evaluated **hemoglobin concentration maps** of the phantoms from diffuse reflectance images by **using the experimentally measured photon time of flight signals**.
3. **The values of extinction coefficients** from diffuse reflectance images are closer to the values obtained by other authors compared to results from transmission images.
4. The images captured by ***Laser* prototype showed more precise results** compared to the *LED* prototype.

Acknowledgment

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Thank you for attention!

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