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Research paper

Tissue Differentiation by Refractive Index using Fiber Optic Displacement Sensor

Rania Al-Ashwal[1]*, Amirul Ridhwan Sazali[1], Alex Lo Zhen Kai[1], Amir Mustakim Ab Rashid[1], Mohamad Hafiz Mohamad Afandi[1], Muhammad Syafiq Mohd Najib[1], Nurul Afiqah Fadzil[1], Syakirah Mohamed Amin[1]

[1]Departmment pf clinical sciences, School of Biomedical Engineering and Health Sciences, Faculty of Engineering, Universiti Teknologi Malaysia, 81310, Skudai, Johor, Malaysia
**Corresponding author E-mail: rania@utm.my*

Abstract

The optical properties can differentiate biological tissues. Refractive index (RI) is one of the optical parameters that can be used for the said purpose. Many different methods of measuring the refractive index of tissue have been found but involve complicated procedure and setup. The proposed way of measuring the refractive index of fabric using fibre optic displacement sensor does not include difficult steps. The installation has the highest measurement at 4 mm displacement between the fibre probe and the tissue sample. Sensitivity achieved when tested with three different solutions was 82.74 nW/RIU at the maximum movement. The installation can determine the refractive index of skin, muscle and fat tissue of porcine sample with a difference of 4.3%, 7.4% and 3.9% respectively using the standard RI of each tissue. The proposed method shows promising results and possible application of simple non-contact refractive index measurement of biological tissue.

Keywords: *displacement; fiber optic; refractive index; sensor; tissue differentiation*.

1. Introduction

Optical properties of tissues play an essential role in the application of light for diagnostic and therapeutic purposes. The light ray can penetrate, refracted, reflected or absorbed by the membrane depending on its optical properties [1]. Previous research has shown that different type of fabric exhibits a different value of optical properties, making it possible to differentiate each tissue by its optical properties [2]-[4]. Refractive index (RI) is one of the critical parameters for characterizing optical properties of biological tissues. Refractive index specifies the amount of light reflected and transmitted when passing the interface between two media. Many biomedical applications benefited from knowing the refractive index of the tissues. For example, a drug delivery system can be conceived to deliver the drug to a specific membrane with a specific refractive index [5].

Multiple attempts in determining the refractive index of biological tissues have been performed previously. Bolin et al. [6] replace the cladding of fibre with the different type of tissues. Tsenova and Stoykova [7] proposed the use of laser refractometer. They measured the refractive index of dehydrated tissue samples initially and then multiply the value with the estimation of water content to obtain the refractive index of fresh tissue.

In this paper, we propose the use of a fibre optic displacement sensor for measuring the refractive index of biological tissues. Fibre optic displacement sensor is typically utilised to measure the displacement between the fibre optic probe and a specified point. It consists of transmitting fibre and receiving fibre which light is transmitted from the transmitting fibre to a plane. Light reflected by the plane is collected by the receiving fibre and calculated as a function of time to obtain the displacement. Previously, fibre optic displacement sensor has been used in measuring the refractive index of the liquid solution [8]. In principle, the light is directed towards the tissue sample, and it will reflect the light back to the fibre probe. The amount of reflected light is dictated by the refractive index of the specified tissue. By determining the refractive index of each tissue, we can differentiate each tissue type.

2. Methodology

The setup consisted of the light source, fibre optic probe and optical power meter as shown in Figure 1. A 5 mW 650 nm laser diode used in the setup. The laser diode coupled to one transmitting end of the fibre optic bundle and the receiving end coupled to the optical power meter. The probe was placed vertically at a set distance to the sample where the light coming out from transmitting fibre will be reflected into the receiving fibre. The intensity of the reflected light is dependent on the distance between the probe and the sample. The optical power of the reflected light was measured by the optical power meter which was then analysed to determine the optimum distance between the probe and tested solution and tissue sample and RI of the skin, muscle and fat tissue sample of porcine. The overall methodology is summarised and presented in Figure 2.

2.1. Calibration of the Experimental Setup

Three samples with a known refractive index which is distilled water, 100% concentrated ethanol, and polyethene glycol 400 with a refractive index of 1.33, 1.36 and 1.47 respectively were used in the experiment to test and calibrate the setup. First, light from the laser diode directed towards the solution via the transmitting fibre and the displacement between the probe and sample was set at zero and increased by 1 mm at each subsequent reading. Reflected light was measured at each interval to obtain the power-displacement relation, which in turn will be compared to the refractive index of the samples to determine the sensitivity of the setup. The experiments were done in a dark room to ensure no external light to enter the receiving fibre.

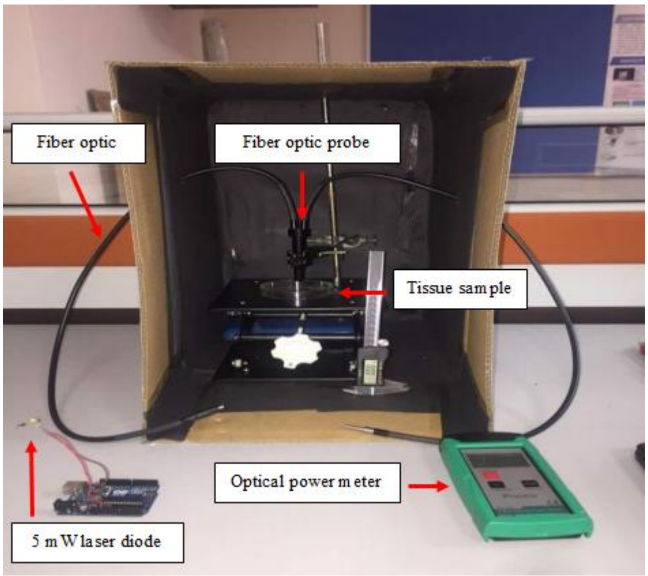

Fig. 1: Fiber optic displacement sensor setup

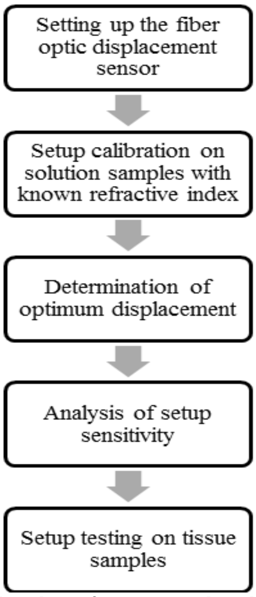

Fig. 2: Flowchart of experimental methodology

2.2. Tissue Sample Testing

The setup was then tested with the fat, skin and muscle tissue of porcine to differentiate each type of tissue by its refractive index. The tissue samples prepared before the test. Porcine tissue samples used were within 4 to 5 hours from slaughter to maintain the water content and freshness. The surface of the tissue was flattened to minimise the scattering of light. The same procedure for calibration repeated in experiments with the tissue. Peak power is measured to obtain the refractive index of the tissue sample.

3. Results and Discussion

3.1. Results of Calibration

The initial experiment was testing the setup with three different solutions to measure the optical power reflected at different displacement. The measured optical power for all three solutions increased until it reaches maximum peak power output at 4 mm and gradually drop after the peak as it is visualised in Figure 3. It was deduced for this specific setup, 4 mm displacement between the fibre probe and surface of the sample is the optimum displacement to measure the highest amount of reflected light. The curve of optical power-displacement formed due to the way the light reflected from the sample surface. A small displacement reflected cone of light from the transmitting fibre to the sample surface is too small, causing the only little amount of light reflected the receiving fibre. The cone size was enlarged with the increasing displacement, allowing more light to be collected by the receiving fibre until the peak distance. However, the intensity of reflected light beyond 4 mm dis-placement diminished. It was suspected that larger cone size of light at this displacement to cause the amount of light scattered to the surrounding increase.

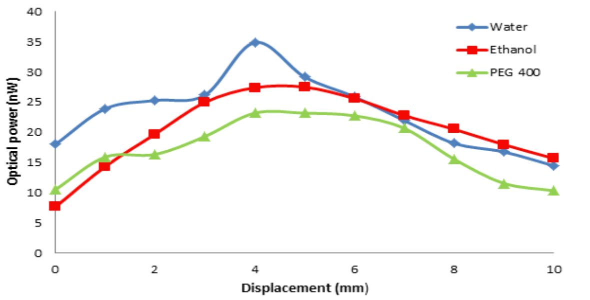

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Fig. 3: Reflected optical power measured at different displacement

From the measured data on the solutions, analysis of frontal slope, back slope and peak power of the optimum displacement graph was performed to determine the sensitivity of the setup. From the optimum displacement graph, the gradient of each solution in the frontal slope is calculated, and the chart is plotted as shown in Figure 3. The front slope, back slope and peak power from the three solutions were plotted individually to determine the sensitivity of the setup. The sensitivity obtained from the gradient of the plot, which indicates how much power change at each refractive index unit. From the front slope shown in Figure 4 determines that the sensitivity of the setup is 18.17 (nW/mm)/RIU with increasing linearity of 96.38%. The sensitivity of the setup on the back slope was calculated as 14.57 (nW/mm)/RIU with decreasing linearity of 94.51% as shown in Figure 5. At the peak power shown in Figure 6, the sensitivity is 82.74 nW/RIU with the linearity of 85.11%. Due to the constant emission of light within the fixed displacement, the front slope, back slope and peak power appears to be in a continuous linear range. From the analysis, peak power was concluded as exhibiting the highest sensitivity compared to the front and back slope. That proved the setup works optimally by measuring the peak power and has the advantage of the consistent displacement of 4mm. However, the front and back slope have higher repeatability as evidenced by the linearity of the graph.

Table 1: Refractive index calculated from fiber optic displacement sensor analysis

Sample	Standard RI	Peak power			Front slope			Back slope		
		Power (nW)	RI	Diff (%)	Slope (nW/mm)	RI	Diff (%)	Slope (nW/mm)	RI	Diff (%)
Skin	1.364	9.19	1.62	4.3	0.92	1.29	5.19	0.64	1.50	10.08
Muscle	1.35	4.83	1.67	7.4	0.31	1.26	6.68	0.28	1.53	13.04
Fat	1.4463	8.73	1.62	3.9	0.82	1.29	10.96	0.38	1.52	5.06

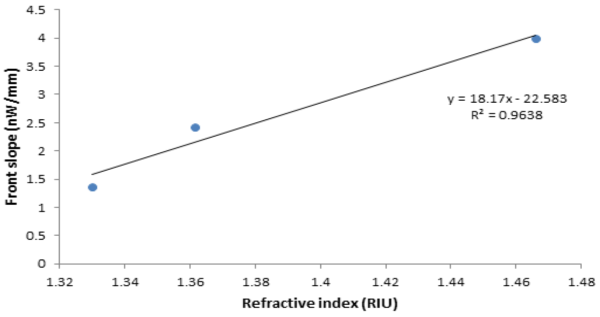

Fig. 4: Front slope against refractive index

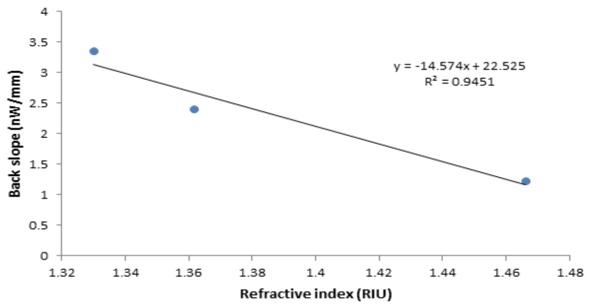

Fig. 5: Back slope against refractive index

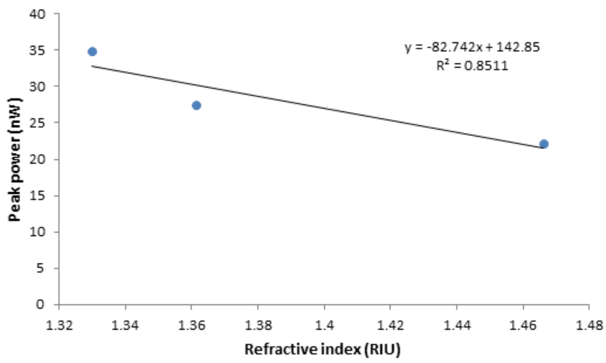

Fig. 6: Peak power against refractive index.

3.2. Experimental Results from Tissue Samples Testing

The next step of the experiment is testing the setup with the different layer of porcine tissue. Figure 7 shows the measured reflected power from the skin, muscle and fat mass of porcine at different displacement. The same analysis of the first slope, back slope and peak power of the reflected light is repeated to determine the refractive index of each tissue.

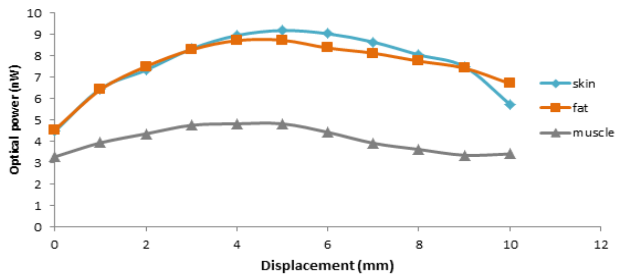

Fig. 7: Reflected optical power measured from tissue samples.

Table 1 summarises the performance of fibre optic displacement sensor in measuring the refractive index of skin, muscle and fat porcine tissues. By measuring the peak power obtained from the three tissue samples, the percentage of the difference between the standard refractive index and experimental refractive index for the skin layer of porcine is 4.3% while the muscle and fat are 7.4% and 3.9% respectively. For the preliminary refractive index obtained from the back slope of the graph, the percentage difference of the standard refractive index for the skin of the porcine is 10% while the muscle and fat are 13% and 5% respectively. For the difference in percentage obtained from the front slope, the percentage difference for the skin of the porcine is 5.2% while the muscle and fat layers are 6.7% and 11% respectively. Across all three peak power, front slope and back slope measurements, measurement at peak power resulted in highest sensitivity and the lowest difference between standard RI and experimental RI. Conforming the previous analyses to solutions sample in section 3.1 where the peak power measurements give the best reading. In contrast, following slope measurements have the least sensitivity and highest difference variation between standard RI and experimental RI. From the analysis, we concluded that the fibre optic displacement sensor is capable in determining the RI of skin, muscle and fat porcine tissues with different to standard RI of 3.9% to 7.4% at the optimum distance.

4. Conclusion

Tissue differentiation via refractive index measurement by fibre optic displacement sensor is proposed in this paper. The setup can differentiate the refractive index of skin, muscle and fat porcine tissue with the difference to standard RI of 4.3%, 7.4% and 3.9% respectively when measured at peak power. Peak power gives the highest measurement due to the highest amount of light reflection at maximum displacement. The sensitivity of the setup is 82.74 nW/RIU with 85.11% linearity at peak power. Fibre optic displacement sensor provides a non-contact method of differentiating tissue by refractive index measurement.

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