Edema detection using absorption spectroscopy for early diagnosis of preeclampsia

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A portable device was developed to detect preeclampsia early by measuring subcutaneous fluid in the finger using optical sensors at 570 nm and 970 nm. Silicone finger phantoms were designed, into which a variable but defined amount of NaCl could be filled. The device is able to detect the amount of NaCl qualitatively and transmit the corresponding sensor values to a smartphone.

1 Introduction

Preeclampsia describes a pregnancy-related multi-system disorder affecting numerous organs [1]. For diagnosis, hypertension (≥ 135/85 mmHg) must be present along with at least one other newly occurring organ manifestation [2]. The main symptoms next to hypertension include proteinuria and edema in the form of subcutaneous fluid retention in the periphery. Preeclampsia occurs in approximately 2 % of all pregnancies and is responsible for 10-15 % of all maternal deaths worldwide [3].

The aim of this work is to develop a portable measuring device for the early detection of preeclampsia through symptom monitoring. The focus is on the non-invasive measurement of subcutaneous fluid retention on the index finger. In addition, wireless data transmission via Bluetooth between the measuring device and a smartphone app has been established.

2 Methods

An optical sensor system based on the principle of diffuse reflection measurement was developed to detect subcutaneous fluid retention on the fingertip. Two pairs of sensors, each consisting of an LED (SMC970 and SMC570, Roithner Laser Technik GmbH, Vienna, AUT) and a photodiode (BPW 34 FS and SFH 2440, ams-OSRAM AG, Premstätten, AUT), are used to take radial measurements at wavelengths of 570 nm and 970 nm in order to detect differences in tissue and fluid content.

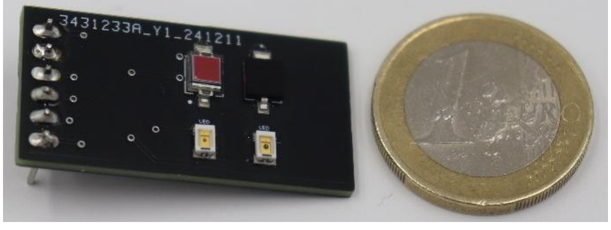

Fig. 1 *Circuit board for edema detection with two sensor pairs consisting of LED and photodiode*

To validate the measurement principle, a tissue phantom made of silicone (SORTA-Clear 18, KauPo Plankenhorn e.K., Spaichingen, DEU) was produced that replicates the absorption properties of human finger tissue at 570 nm. By coloring it with red silicone pigment (RED, KauPo) at a weight ratio of 0,01 %, an absorption coefficient of $\mu_a = 0{,}4\ mm^{-1}$ was achieved.

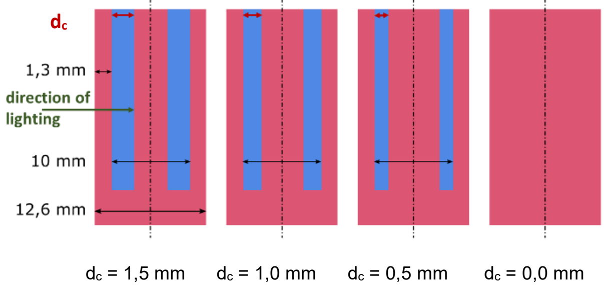

Fig. 2 *Schematic drawing of the four finger phantoms with d_c as cavity width*

Four different silicone finger phantoms were then produced from this mixture ratio with corresponding optical properties. Each of these had an outer diameter of 12,6 mm and a ring-like cavity. These cavities were located at a tissue depth of 1.3 mm and were filled with 0.9 % NaCl solution to simulate edema. This depth corresponds to that of the subcutis in which edema occurs in preeclampsia. Cavity widths of 0, 0.5, 1.0 and 1.5 mm were selected to simulate different degrees of edema (Fig. 2).

Five measurements were taken on these four finger phantoms each, making a total of 20 measurements. The tests were conducted at a room temperature of 23 °C. In order to measure the NaCl-filled finger phantoms in an upright position, the measuring sensors were removed from the casing (**Fig. 3**).

To avoid interference from ambient light, the measurement site was shielded with a light-protection box.

The measured sensor values are displayed on the built-in display (as shown in Fig. 3) and are also transmitted to a smartphone app via a Bluetooth connection (HC-05 Bluetooth wireless RF

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transceiver module, AZ-Delivery Vertriebs GmbH, Deggendorf, DEU).

Fig. 3 *Measuring device with silicone finger model in finger measuring box resting on sensors*

3 Results

Fig. 4 shows that the sensor value at 570 nm is lowest at 0 mm cavity filled with NaCl and highest at 1.5 mm. The values at 0.5 mm and 1.0 mm are correspondingly increasing in between. The sensor values at 970 nm behave in the opposite manner. They show the highest values at the longest light path through the silicone (at 0 mm cavity for NaCl). The trend of the two sensor values depending on the light path through silicone or NaCl is clearly visible.

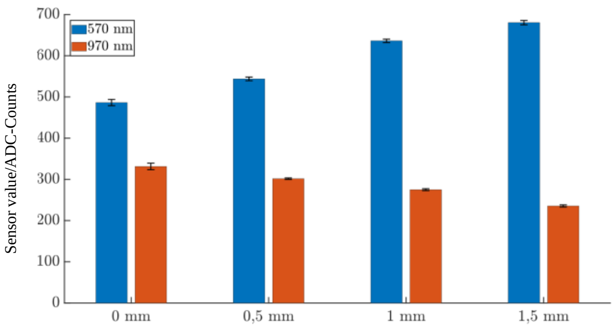

Fig. 4 *Comparison of sensor values on the finger phantom at 570 nm and 970 nm*

4 Discussion

The portable measuring device developed enables the early detection of preeclampsia symptoms by measuring subcutaneous fluid retention in the finger using optical sensors in finger phantoms.

The integration of a Bluetooth interface allows communication with a smartphone app that controls the device, transmits measurement data, and stores it for progress monitoring.

The detection of subcutaneous fluid retention was successfully validated using a silicone-based finger phantom that simulates the absorption properties of finger tissue. Fluid differences of 0,5 mm depth could be detected and distinguished from tissue changes.

The contact pressure of the finger significantly influences the measurement, which is why a standardized fixation (e.g., clamping device) is necessary.

Disturbing factors such as ambient light and the distance between the LED and the photodetector influence the detection depth and signal quality and must be considered.

5 Outlook

Further investigations should improve the resolution limit of the sensor technology in order to be able to detect even small changes in fluid at an early stage.

Interference, especially ambient light, should be reduced by compensation during the measurement process in order to increase measurement accuracy.

The best configuration of the distance between the LED and the photodetector for maximum detection depth and signal strength should be determined in a series of experiments.

The finger phantom can be made more realistic, e.g., by increasing the number of tissue layers, introducing scattering particles to simulate the scattering behavior of the skin, and evenly distributing the fluid in the tissue layer.

The development and integration of a clamping device for uniform fixation of the finger during measurement is planned in order to minimize measurement errors caused by varying contact pressure.

In conclusion, the presented measuring device shows great potential for the early detection of preeclampsia through reliable detection of subcutaneous fluid retention, with future improvements and further studies expected to further improve accuracy, applicability, and user-friendliness.

6 References

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