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Determination of the optode array representation using optical properties at systole and diastole

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The necessity to develop an optode array in order to probe the fetus oxygenation noninvasively regardless of the fetus position has been highlighted in previous literature. In this paper, a series of optical simulations are carried out to determine the best representation of optode array by using optical properties at systolic and diastolic states. The selection is based on the highest flux values accumulated at respective detectors. To accomplish the objective, a homogenous three-layer semi-infinite tissue model is implemented to represent the pregnant woman model. The geometry of the model as well as Monte Carlo simulation are carried out using commercial software, whereas the optical properties related to systolic and diastolic states are defined for all wavelengths. A statistical noise analysis is also introduced in order to find a sufficient number of rays to be launched into the optical tissue system.

Keywords: optical simulation, optical properties, optode array, semi-infinite tissue layer, statistical analysis.

1. Introduction

Fetal surveillance monitoring is crucial as it helps to avoid fetal hypoxia or intrapartum asphyxia that can bring damage to the vital organs such as heart and brain and this can be done by detecting a decrease in oxygen supply in fetus. In conjunction with the use of cardiotocography (CTG), a fetal scalp blood sampling (FBS) technique has been used to determine hypoxia in fetus with an abnormal heart rate pattern by measuring the pH or lactate. Intervention will be recommended if the pH reading shows less than 7.24 or when abnormal lactate points at 4.20 or higher [1].

Although this method can assist medical practitioners or midwifes to handle fetal distress during labor or near labor, it has several limitations. First of all, the FBS method is an invasive procedure, non-continuous, technically uneasy and difficult to obtain an adequate blood sample [2, 3]. Secondly, it shows high failure in sampling and analysis of pH blood at the range of 10.4 to 25% and consumes time in collecting or analysing the data; thus increasing the delay in clinical management [4–6].

The fetal oximetry system is initially developed purposely for intrapartum monitoring [7, 8]. It is reported that continued monitoring of fetal oxygen saturation combined with fetal heart rate monitoring may improve accuracy in the evaluation of fetal well-being [9]. Moreover, it is also recommended to monitor the fetal status using intrapartum fetal pulse oximetry in cases of non-reassuring or pathological cardiotocography to avoid imminent fetal hypoxia [10]. However, commercial optical sensors for fetal oximetry have several downsides. Firstly, the technique is invasive to mothers. In real clinical situation, the reflectance optical sensors are attached on the fetus scalp or cheek by inserting it through the birth canal [11]. Besides that, it is reported that the sensors may leave marks on the skin of the fetus [12] and also contribute to the increased number of caesarean sections for dystocia due to the presence of the sensors itself [13].

To overcome those limitations, a transabdominal measuring of fetus oxygen saturation has been presented by [8, 14–20]. The feasibility of transabdominal oximetry was studied from various aspects, starting from the modelling of photon migration through the fetal head until the development of clinical and experimental models by using continuous wave near infrared spectroscopy [8, 14, 15]. Despite the tremendous works mentioned above, only VINTZILEOS *et al.* [20] claimed to be the first who successfully measured the fetal oxygen saturation values on maternal abdomen with the reported value of fetus oxygen saturation between 54 and 74%.

The idea of using a low-cost near-infrared (NIR) light emitting diode (LED) and a silicon photodetector to detect the fetal heart rate (FHR) transabdominally has been proposed by [21]. To obtain the clinical trial results of FHR, the fetal position needs to be determined first by using the CTG and the results revealed that the fetal position affects the accuracy of the FHR with the best results attained when the probe is close to fetal tissues. The promising results have led to another possibility of exploring the noninvasive fetus oxygen saturation measurement by using a low-cost light source instead of using spectroscopy. In addition to that, all previous works mentioned before have not yet explored the optode arrays in order to probe the fetal signals independently of fetal position.

The gaps shown here motivate the authors to conduct a study to determine the best configuration of a reflectance optode array by measuring the flux values at respective detectors. Since the oxygen saturation is much dependent on pulsatility of an arterial and nonpulsatility of bloodless tissues, it is worth to investigate how the systolic and diastolic conditions may affect the optode configuration.

2. Optical properties

Optical properties of tissues are usually characterized by three parameters which are the scattering coefficient μ_s, absorption coefficient μ_a and scattering anisotropy fac-