Fiber based frequency-modulated continuous-wave near-infrared spectroscopy for transabdominal fetal pulse oximetry

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Abstract
We propose a novel non-invasive approach to transabdominally measure fetal oxygen saturation via time-domain near-infrared spectroscopy. We employ the frequency-modulated continuous-wave technique to measure the time-resolved reflectance of near-infrared light shining on the maternal abdomen. The time-of-flight reflectance reveals path-lengths of different photons traveling through the tissue, facilitating separation of signal from the shallow maternal layer and the deep fetal layer. Using two optical wavelengths, oxygen saturation of the fetus can be measured. This technique has the potential to improve labor outcomes by providing an important assessment of fetal health intrapartum.

Keywords
Oximetry, Near-infrared spectroscopy, Frequency-modulated continuous-wave, Interferometer, Time-of-flight, Fiber optics

250-word abstract for technical review
Transabdominal fetal oximetry allows fetal health monitoring through the maternal abdomen. It provides an important assessment for physicians, and enables early detection of fetal hypoxia in a non-invasive manner. While continuous-wave pulse oximetry offers a mature technique to measure arterial blood oxygen saturation in patients, it cannot effectively support separation of the weak fetal signal from the mixed detected signal reflected from both maternal and fetal layers.

We propose a new approach to transabdominal fetal oximetry based on time-domain near-infrared spectroscopy. Compared to the continuous-wave approach, this approach enables discriminative detection of weak light signal that carries information from the deep tissue layers. It works through a fiber-based frequency-modulated continuous-wave (FMCW) technique, implemented by an optical interferometer with a wavelength-swept laser source, to measure time-resolved near-infrared light reflecting from the maternal abdomen. Laser light reflected from the maternal abdomen is collected by a single-mode fiber. The collected light interferes with the light from the reference arm, generating a time-domain interference fringe pattern, from which the time-resolved reflectance is extracted. The time-resolved reflectance effectively yields optical path-lengths of light passing through both maternal and fetal tissue layers, facilitating separation of signals from the shallow maternal layer and the deep fetal layer. Utilizing two laser wavelengths and the Modified Beer-Lambert Law, blood oxygen saturation can be measured for both mother and fetus. The FMCW near-infrared spectroscopy provides a promising approach to intrapartum detection of fetal hypoxemia and assessment of fetal well-being.