Droplet-based Simulation of Photoplethysmogram Waveforms and Oxygen Saturation

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Background: Pulse oximetry is an important monitor in anesthesia, as it provides an early indicator of hypoxemia. Pulse oximetry is also being increasing used in other monitoring and screening applications. Many new devices are coming to market, and the challenges of calibration and testing are a significant barrier to implementation. Regulatory approval of new pulse oximeters requires expensive and invasive tests to be performed on human subjects. It is possible that physical simulations can ease the testing requirements, but such simulators have so far been too complicated [1] to be of general availability and use. Commercially available simulators are electronic rather than physical, and require a priori manufacturer specific calibration that makes them of limited use for testing new devices.

Objective: To realize a simple physical simulation of the pulsatile light absorption as captured by a pulse oximeter using repetitive droplet formation of a non-toxic water-based dye solution.

Methods: A pulse oximeter clip is mounted on a transparent test tube, in which a vertically mounted tapered tip is set to form droplets (Figure 1a & b). The infusion rate relates to the measured heart rate through the rate of droplet formation (Figure 1c). Water is inherently absorbent in the infrared range, and changes in oxygen saturation can be simulated simply by changing the concentration of green or blue food dye with a dual syringe pump mixer.

Results: The droplet-forming tip made acceptable artificial PPG waveforms, as the gradual formation of the drop gives rise to a broad peak in the pulse oximeter sensor signal. The simulated heart rate can be varied over the clinical range (30-235 bpm) by changing the pump infusion rate, and oxygen saturation can by changed by varying the concentration of dye in the liquid, ranging from 100% to below 30%. The pump infusion rate (ml/h) has very little effect on the PPG waveform and SpO_2. However, the setup is sensitive to the alignment of the sensor and the site of drop formation, as well as to the size of the drop itself.

Conclusions: The use of infusion pumps and a water-soluble dye represents a novel and practical way to physically simulate arterial peripheral pulsation, and can be used advantageously in situations where the calibration curve of the oximeter under test is unknown. Work is underway to relate dye concentration to SpO_2 value and minimize ambient light interference, to realize an accurate and robust instrument based on this technology.

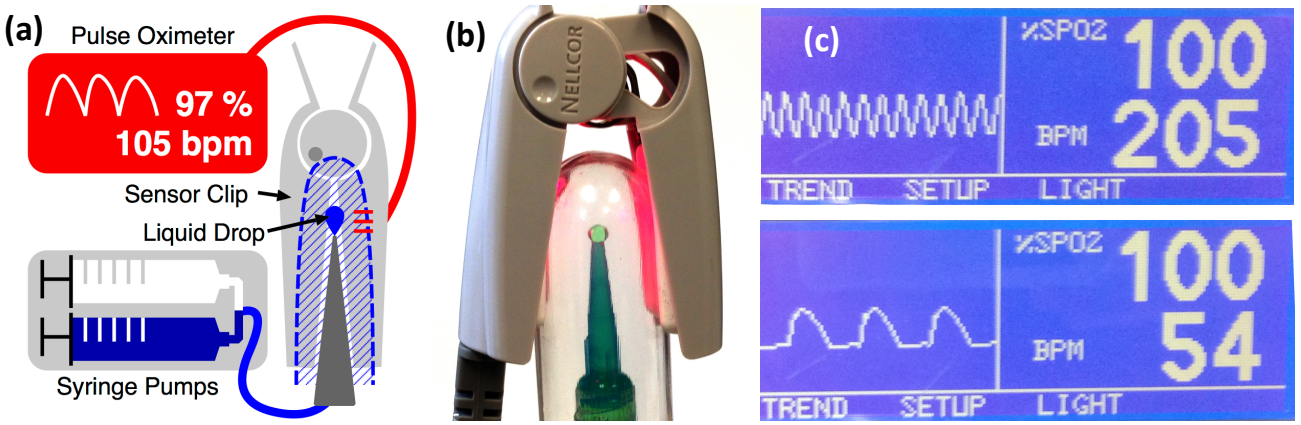

Figure 1:Drop based pulse oximeter simulator: Setup (a), drop chamber (b), and example waveforms (c).

[1] Oura M, Kobayashi N, Yamamori S, Takeda S, Iwasaki K, Umezu M. Calibration System for Pulse Spectrophotometry using a Double-Layer Pulsation Flow-Cell.ConfProc IEEE Eng Med Biol Soc. p. 8962009.