

Transdermal Monitoring of Volatile Anesthetic Concentration During Surgery

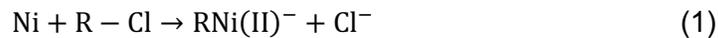
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Background/Introduction:

Monitoring the therapeutic dose of any anesthetic agent is critical for patient safety during surgery. Modern anesthesia machines are equipped with infrared spectroscopy monitors to detect inhaled volatile anesthetic (VA) dose. However, the latter are not readily portable, impractical for use in austere conditions and unaffordable in low resource environments. In this work, a low cost miniaturized, wearable fuel cell sensor was tested in patients undergoing surgery to determine the clinical utility of a totally non-invasive transdermal sensor to reliably monitor Isoflurane dose.

Methods: A wearable device integrated with a micro-fuel cell and built-in miniaturized potentiostat was developed as a practical and portable solution for transdermal VA gas detection during surgery. The device can be modified to detect any VA. The method used in this system is amperometric and its functionality described previously (1). A customized printed circuit board (PCB) was designed to accommodate the potentiostat (LMP91000) with a low power data processing microcontroller (nRF51822) with Bluetooth (RN-42). The device begins operation when it detects a voltage less than -0.05 V across the fuel cell electrodes (reference and anode). The current corresponds to the concentration of the VA, which can be determined through calibration. The current from LMP91000 is converted to a potential and fed to the internal analog-to-digital converter (ADC) of the wireless microcontroller. Data is transmitted wirelessly to the end device (e.g. smartphone). After IRB approval we conducted an observational pilot clinical trial of the device on 11 randomly selected patients to validate its ability to sense the start, steady-state and end of Isoflurane administration during elective surgery. The platform was attached to the wrist of patients in the holding area. Baseline readings for calibration of the device were obtained before the start of Isoflurane inhalation in the OR. The reaction mechanism of the fuel cell involves oxidation at the anode and reduction at the cathode. The anodic reaction is expressed in equations (1– 3), where oxidative addition of Isoflurane occurs instead of direct oxidation reaction.



where, R-Cl is the Isoflurane. As given in equation (2), the byproduct HCl gets oxidized on the anode and the electrons are produced in this process. On the cathode, the oxygen gets reduced as given in equation (4).



During this reaction, the electrons and H⁺ ions flow from anode to cathode generating Faradic current proportional to the concentration of Isoflurane. This current is detected amperometrically. The biasing voltage across working and reference electrodes was -0.3V. The platform includes nRF5 series supported BLE for wireless data transmission and smart phone readout. Electro-chemical signals from the sensor were then recorded and later converted to parts per million (ppm) using equation (5):

$$\text{Concentration (ppm)} = \frac{\{389.29 - (I_{\text{conc}} - I_{\text{baseline}})\}}{0.0152} \quad (5)$$

Results: The raw sensor data plots in the Figure show real-time trends in readings for the onset, steady-state, and intraoperative variations of Isoflurane concentration, and discontinuation of Isoflurane inhalation in patients. Although the duration of anesthesia varied in all cases, the signal was sensitive and specific to changes in concentration within a therapeutic range Isoflurane (0-2.5%).

Conclusions: We developed a wearable platform to measure VA gas vapors transdermally. The device was tested on 11 patients undergoing general anesthesia with Isoflurane. The resultant current was calibrated to parts per million (ppm). Our preliminary results showed that the sensor tracked anesthesia dose with good reliability within a therapeutic range for general anesthesia with Isoflurane. Further testing will require fine tuning of the signal, optimum anatomic placement, influence of external factors and validation in a larger clinical trial.

Reference: Anal. Methods, 2019,11, 2007-2012

