Microelectrochemical Smart Needle for Real Time Minimally Invasive Oximetry

Daniela Vieira MSc; Francis M McEachern MSc; Romina Filippelli BS; Edward J Harvey MD; ***Géraldine Merle PhD***
McGill University, Montreal, QC, Canada

Purpose: Compartment syndrome (CS) represents elevated pressure within muscle compartment after trauma. This results in a decrease in capillary perfusion (less blood flow) and therefore tissue death. Diagnosis of CS is extremely difficult leading to missed or delayed treatment. This can result in the loss of motor and sensory function, long-term nerve damage, amputation, and even death. Measuring intracompartmental pressure (ICP) is a well-accepted method in evaluating CS. Repeated ICP measurements over a short time frame with instruments have proven to be unreliable or dangerous. To improve the efficacy of the diagnostic device other parameters directly affected by CS can be assessed. As CS is paralleled by a reduction of the blood circulation, intramuscular partial oxygen tension (pO2) is reduced and can be used as a qualitative marker. We hypothesized that a continuous monitoring of pO2 could drastically improve the accuracy and even identify earlier CS and subsequently reduce its morbidity. In this work we developed a minimally invasive needle-sensor with a high surface area to monitoring O2 levels in brain using acupuncture needles. The approach was to directly etch the iron from stainless steel acupuncture needles via a controlled pitting corrosion process, obtaining a high microporous surface area.

Methods: Stainless steel acupuncture needles were used as "working electrodes." Galvanic pitting corrosion was conducted using 176 g/L NaNO3 to increase porosity of the needles. Then carbon nanoparticle, biocatalyst, and biocompatible conductive polymer were deposited at the surface of needle to enhance sensitivity and selectivity of the O2 sensor. Physicochemical characterization (morphology, roughness, mechanical testing, tissue insertion, etc) of the needles was performed as well as electrochemical analysis for oxygen detection.

Results: The microelectrode displayed excellent electrochemical reduction behavior to O2 and showed a current density of 50 microA/cm2 while control needle showed no obvious current response. It is worth noting that not only did the needle show great reduction capability but also excellent repeatability. Moreover, we confirmed the selectivity of the needle towards some common interfering molecules found in tissues such as gamma-aminobutyric acid (GABA) and catechol.

Conclusion: We have designed a functional needle for real time and in vivo monitoring of O2 with remarkable performances for potential deep-tissue application. The needle exhibited efficient electrocatalysis and high selectivity toward O2, allowing the real-time monitoring of O2 in complex environments. Using a minimally invasive functional acupuncture needle as a simple electrode for in vivo electrochemical measurement is relevant because there is a need for a small diagnostic tool to monitor pO2 with accuracy and free from complications, for a wide spectrum of injuries.